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Master in

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BIM A+ European Master in Building Information Modelling

HBIM for sustainable reuse

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To the BIM A + Master students, my colleagues and friends.

To my family, for the unconditional support.

STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of ethics and conduct of Politecnico di Milano.

Jelena Žurić

SOMMARIO

Titolo: HBIM per il riutilizzo sostenibile

Aumentare la sostenibilità ambientale di un edificio storico con limitate possibilità di modificarne l'aspetto e senza comprometterne il valore culturale, è normalmente visto come un processo irrealizzabile. Si occupa attivamente di questo tema un'organizzazione no profit nel settore della sostenibilità ambientale, Green Building Council (GBC) Italia, pubblicando il protocollo per l'ottenimento della certificazione per la riqualificazione del patrimonio sostenibile (GBC Historic Building Certification). Il complesso processo per ottenere questa Certificazione implica mezzi ben definiti e organizzati. Building Information Modeling (BIM) offre un approccio olistico per organizzare e gestire una grande quantità di dati. Recentemente trova applicazione anche nella gestione dei beni storici, come il cosiddetto Historical Building Information Modeling (HBIM). Pertanto, la fattibilità di implementare l'HBIM nel restauro di edifici storici ecosostenibili viene ricercata all'interno di questa tesi. In primo luogo, vengono riviste le tendenze attuali dell'utilizzo del BIM nella ristrutturazione del patrimonio, nonché nella progettazione di edifici sostenibili. Quindi, le regole di certificazione degli edifici storici GBC e le richieste di informazioni sono state valutate nel contesto dell'applicazione BIM. La valutazione ha portato a un flusso di lavoro BIM olistico per il processo di certificazione degli edifici storici GBC. Ha consentito un'ulteriore focalizzazione della sua integrazione nell'area tematica di nuova introduzione della certificazione della bioedilizia: il valore storico. L'area tematica Valore storico è la base per lo sviluppo del progetto di certificazione. Comprende l'identificazione del valore culturale degli edifici e le possibilità generali di intervento, raccogliendo le informazioni rilevanti e prendendo le decisioni sulla base dei risultati dell'analisi investigativa. Di conseguenza è stato proposto un flusso di lavoro BIM per l'adempimento delle sue richieste procedurali. È stata effettuata un'elaborazione dettagliata per il primo prerequisito di questa area tematica - Prerequisito 1: analisi preliminare. Il deliverable specifico richiesto per il suo raggiungimento, la "Carta d'identità di edificio storico", è stato esplorato in dettaglio, classificando i tipi di informazioni richieste e mappandoli al contenuto BIM. Il risultato finale è una proposta di un framework BIM per la creazione della documentazione consegnabile. Comprende la procedura di gestione delle informazioni per la creazione della documentazione per il deliverable richiesto - "Carta d'identità dell'Edificio Storico", con particolare attenzione all'interoperabilità e alla conservazione dei dati. Il risultato della sua implementazione è un file di strumento di authoring BIM popolato con le informazioni iniziali all'avvio del progetto. Le informazioni sono strutturate utilizzando lo standard per lo scambio di dati aperti (IFC). Il framework è concepito come un principio di base che può essere seguito per l'ulteriore estensione sul progetto di certificazione completo. La dimostrazione del quadro è stata eseguita su un caso di studio: un modello della sezione di Paço dos Duques a Guimaraes, in Portogallo.

Parole chiave: Certificazione di edifici storici GBC, Esperienza utente, Gestione dei dati, Modellazione delle informazioni sugli edifici storici (HBIM), Restauro sostenibile.

ABSTRACT

Increasing the environmental sustainability of a historic building with limited possibilities of changing its appearance and without endangering its cultural value, is normally seen as an infeasible process. A non - profit organization in the environmental sustainability sector, Green Building Council (GBC) Italia, is actively dealing with this subject, publishing the protocol for obtaining the certification for the sustainable heritage renovation (GBC Historic Building Certification). The complex process of obtaining this Certification implies well defined and organized means. Building Information Modelling (BIM) offers a holistic approach for organizing and managing the large amount of data. It is recently being applied in the management of the historic assets as well, as the so – called Historical Building Information Modelling (HBIM). Thus, the feasibility of implementing HBIM in environmentally sustainable historic building restoration is researched within this dissertation. First, the current trends of using BIM in heritage renovation, as well as sustainable building design are reviewed. Then, the GBC Historic Building Certification rules and information requests were assessed in the context of BIM application. The assessment resulted in a holistic BIM workflow for the process of GBC Historic building Certification. It enabled further focus of its integration in the newly introduced thematic area of the green building certification – the Historic Value. Historic Value thematic area is the basis for the certification project development. It includes the identification of the buildings' cultural value and the general intervention possibilities, by collecting the relevant information and making the decisions based on the investigative analysis results. A BIM workflow for accomplishing its procedural requests has been proposed as a result. Detailed elaboration was made for the first prerequisite of this thematic area – Prerequisite 1: Preliminary analysis. The specific deliverable requested for its achievement, the "Historic Building Identity card" was explored in detail, by categorizing the requested information types and mapping them to BIM content. The final result is a proposal of a BIM framework for creating the deliverable documentation. It involves information management procedure for creating the documentation for the requested deliverable – "Historic Building identity card", with focus on interoperability and data preservation. The outcome of its implementation is a BIM authoring tool file populated with the initial information on starting the project. Information is structured using the standard for open - data exchange (IFC). The framework is designed as a basic principle that can be followed for the further extension on the complete certification project. Framework demonstration was performed on a case study – a model of the section of Paço dos Duques in Guimaraes, Portugal.

Keywords: Data management, GBC Historic Building Certification, Historic Building Information Modelling (HBIM), Sustainable restoration, User experience.

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1. INTRODUCTION

Scope and motivation

The concept of heritage redevelopment is rarely connected with environmental sustainability. The large number of parameters to consider in designing an environmentally sustainable new construction makes the process complex by itself. Therefore, implementing the same while redeveloping an asset with a cultural value has barely been addressed, due to additional and unpredicting challenges in its realisation. Building Information Modelling (BIM) is progressively being used in managing the complex processes within architecture, engineering and construction (AEC) industry. Its application for heritage management is called Historic Building Information Modelling, or HBIM (Luggo et al., 2020). Its integration in environmental design projects is proven to help design teams to make informed decisions from the early design stages and during the whole building life – cycle (Wu, 2010). This dissertation explores the potentials and challenges of BIM application in environmentally sustainable heritage reuse. For that purpose, two aspects are to be explored: applying BIM for heritage management, and applying BIM in environmentally sustainable building projects.

Relationship between the asset and its environment is defined by a great number of factors, which accumulate due to long life of a built heritage. In order to reduce the negative impacts of the construction industry on the environment, the concept of sustainable renovation is introduced. As stated by Wu (2010): *In order to efficiently guide the design and construction of green buildings, it is beneficial to have consistent metrics for the quantitative and qualitative evaluation of building performance. These systematic portfolios of metrics are usually known as the green building rating system. With governmental endorsement, the green building market has been rejuvenated, making pursuit of certified green buildings become a huge momentum in the market transformation"* (Wu, 2010). LEED is one of the internationally recognized green building certification systems, which provides verification that a project was designed and built using strategies for improving performance across the defined metrics (U.S. Green Building Council, 2020). Green Building Council Italia (GBC Italia) is a part of the worlds' largest international organization in the sustainable construction market. It is involved in establishing design and construction criteria of environmentally sustainable buildings. They additionally introduced the official criteria on sustainable heritage refurbishment, called GBC Historic Building Certification, which is based on the LEED certification system. The criteria are sorted by thematic areas, called "Credit categories", which represent the general topics to evaluate for the Certification project. GBC Historic Building Certification introduced a new category, called "Historic Value". It is aiming to preserve the cultural value of the built asset favoring the enchantment of its environmental sustainability. Each credit category is evaluated by certain amount of points, represented by credits and prerequisites to obtain. The instructions of obtaining the points for the Certification are presented in GBC Historic Building Manual, structured by the credit categories and the belonging credits (Green Building Council Italy, 2020). This dissertation will focus on the newly introduced, "Historic Value" credit category. The thorough focus will be given to the Prerequisite 1 of Historic Value: Preliminary analysis, its requested deliverable called "Historic building identity card".

The complex process of obtaining the green building certification implies well defined and organized means. The AEC industry aims to increase quality of the process and the buildings with the better information control. It is aiming for the digital objects to be main information carriers (Turk, 2019), and organizing them in digital form, to be used by a great number of diverse teams in a functional way is the challenge for their management. As proprietary tool is often used from the beginning of the project, it implies great importance during all project stages. Companies in the AEC industry are investing time perfecting the guidlines for pre – setting their authoring tools for that reason. Furthermore, computational design tools extend the power of authoring and enabline automatisation of iterative tasks, by influencing the interrelation of internal and external building parameters (Autodesk, 2020). Additionally, following the statement that complete computer integrated construction will never be achieved (Turk, 2019), interoperability of multiple tools and technologies impose a dominant factor in the process as well. Open – data exchange format can be used across the construction industry, regardless of the BIM software, which implies maximizing the data transparency and traceability in the project phases (buildingSMART International, Ltd, 2020).

The interest for adoption of BIM for managing heritage is not on a great level. HBIM usage has demonstrated benefits in managing heritage projects, but the need for further research, and standards of cultural documentation is displayed in the published literature on this subject: *It has been found that existing processes to develop our built environment are confusing, poorly co-ordinated, with design information difficult to find and with many repeated activities, thus raised costs* (Brookes, 2017). Moreover, it has been noticed that the environmental sustainability certification processes are difficult to follow , because the required documentation is not structured in a clear way, resulting in great loss of time due to lack of the clear workflows, and unclear parameters to deliver (Mazzola et al., 2017). Thus, both the process for heritage management and sustainability certification achievement lack of a standardized framework and a clear system to use. The question of applying a BIM framework for optimization of the sustainable restoration process can be drawn from that observation, which will be explored for this dissertation. It is aimed to help the project team from the project starting point by generating the environment for collecting and managing information in a pre – defined organized system. In particular, this research has been made to explore and demonstrate the ways the design team may use BIM as a helpful tool for pursuit of GBC Historic Building Certification.

Objectives and Methodology

Objective of this dissertation is developing a BIM framework for information management procedure of creating Historic Value Prerequisite 1 deliverable documentation, “Historic building identity card”. Framework development includes analyzing the deliverable information needs, based on which the proposal, implementation, and demonstration are to be performed. Framework is planned to optimize the Certification application process by functioning as a set of guidance tools for the users (the project design team), focusing on information management, user experience, interoperability, and data preservation. The guidance tools are to be populated with the information, based on the open - data exchange (IFC) standard, and definining a system to be followed for the documentation creation. The system is to be optimized by using BIM authoring tool in combination with the computational design tool. It is intended that the framework can be used as a basic principle that can be followed for the further extension on the complete certification project.

Dissertation is developed following the methodology:

i. Identify the current practice and needs of BIM application in sustainable heritage renovation
ii. Identify the information needs of GBC HB Certification
iii. Develop holistic BIM procedure for GBC HB Certification
iv. Analyse the information needs for Historic Value category
v. Develop BIM workflows for Historic Value category credits
vi. Identify the “Historic building identity card” documentation data requests
vii. Develop a BIM framework for generating the documentation
viii. Demonstrate results and gather conclusions for the future development

Figure 1 demonstrates the research methodology within its scope, going from the broad to the detailed analysis of the research (from left to right side). It is first outlined by the Heritage Building Information Modelling (HBIM) application for the sustainability certification project – GBC Historic Building Certification, and the design phase of the project. The GBC Historic Building Certification rules and information requests were first assessed in the context of HBIM application. Based on them, the holistic BIM procedure for GBC HB Certification was developed. Then, each category was examined in the context of potential BIM use for their achievement. The requested information types were categorized and mapped to BIM content. Considering the time and amount limitations for the dissertation, focus was then given to Historic Value credit category, for which the BIM workflow for accomplishing its procedural requests was developed. Detailed elaboration was then made for the Prerequisite 1: Preliminary analysis and “Historic value identity card” documentation. The BIM framework was proposed based on data requests, and implemented using BIM proprietary tool, Autodesk Revit, in combination with computational design tool, Dynamo, and Excel spreadsheets, designed to implement the file set – up, properties management, exporting set – up and visual representation template. The framework implementation is finally demonstrated on a case study.

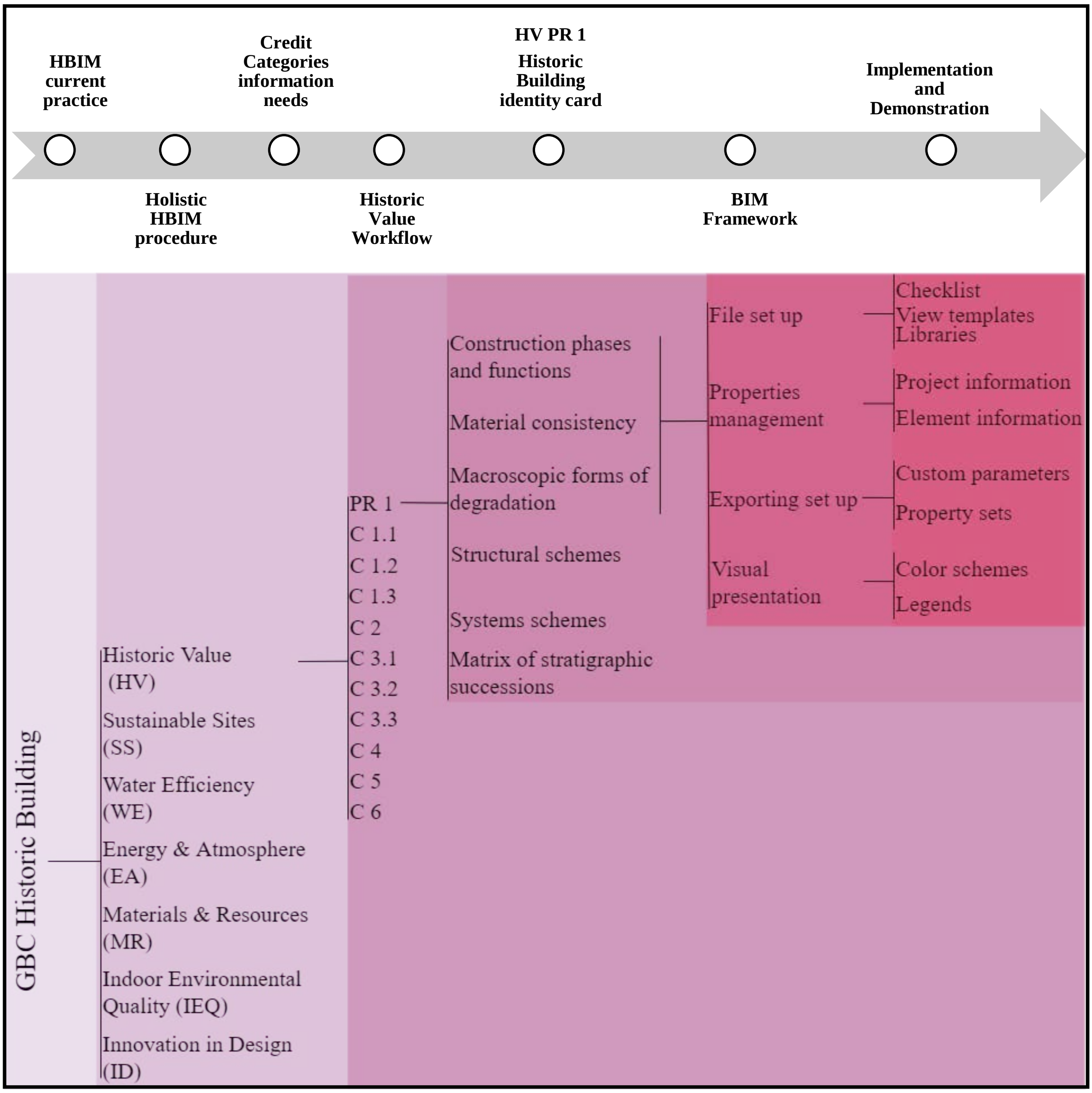

Figure 1: Research methodology.

Chapter outline

Following the Introduction chapter and defined methodology, the chapter outline is presented in Figure 2. Chapter 2 contains the literature review of the current practice and needs of BIM for heritage restoration projects, as well as for the sustainable design projects. The general overview on the sustainable buildings design is focusing on the LEED Certification. GBC Historic Building Certification (GBC HB Certification) is introduced, and the general information needs for its acheivment are identified.

Chapter 3 contains the developed holistic BIM procedure for GBC HB Certification process, based on the identification of the information needs in the previous chapter. It is followed by systematic analysis of the Certification data requests in the context of BIM implementation. BIM workflow proposal for the Historic Value category is the result of this systematic analysis. The chapter concludes with the explanation of the information requests for obtaining the Prerequisite 1 of Historic Value. These requests are the basis for developing a BIM framework proposal.

Chapter 4 contains BIM framework proposal and implementation for generating documentation for obtaining the Prerequisite 1 of Historic Value, and its implementation in the BIM software.

Chapter 5 demonstrates the implemented framework on the case study. Elements of the proposed framework that were in focus are: properties management, exporting set – up and visual representation.

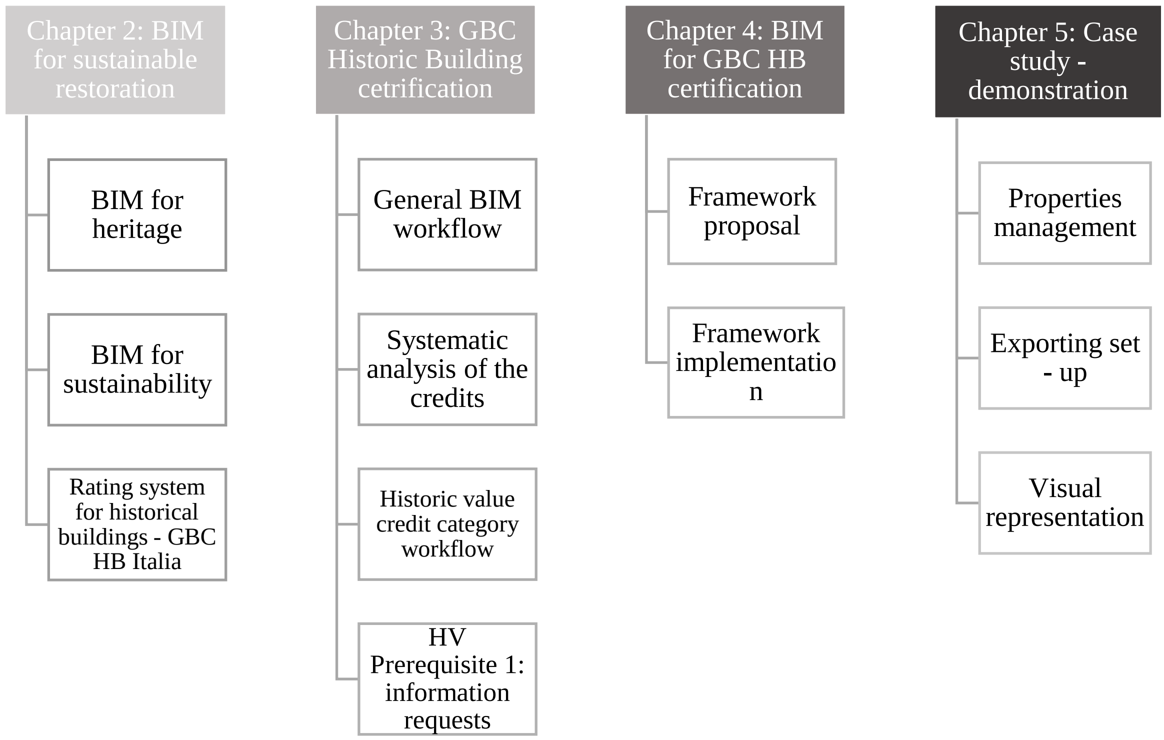

Figure 2: Chapter outline.

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2. SUSTAINABILITY IN HERITAGE

This chapter reviews the concept of BIM in two fields: heritage management and sustainable design. The first part is reflecting on the methodological aspects of BIM for heritage - Historic Building Information Modelling (HBIM), and giving examples of the current practice. The second part briefly describes environmentally sustainable building design principles through sustainable certifications and rating systems. It reviews the present practice of BIM implementation for LEED Certification, and then focuses on the area of sustainable preservation of buildings. The chapter finishes with conclusions about BIM for improving the process of heritage restoration and achieving LEED certification.

2.1. HBIM for heritage management

2.1.1. HBIM definitions

There is no single official definition of Historic Building Information Modelling (further referred to as HBIM). Most broadly, it can be seen as application of BIM in heritage intervention projects. That conclusion is derived from the following citations:

- *Historic Building Information Modelling is a system for modelling historic structures from laser scan and photogrammetric data using Building Information Modelling (BIM) software* (Dore and Murphy, 2015).
- *HBIM is 3D modelling information system for cultural heritage and historical building. It uses the BIM (Building Information Modelling) process.* (Casu and Pisu, 2016).
- *HBIM is an acronym that indicates the activation of a BIM process for a building included in the architectural heritage* (Luggo et al., 2020).
- *A prototype library of parametric objects, based on historic architectural data and a system of cross platform programmes for mapping parametric objects to point cloud and image survey data* (Murphy et al., 2013.).
- *HBIM is a prototype library of parametric objects pertaining to 18th century architectural heritage, which allows the creation of 3D models that are able to represent not only the surface characteristics, but also what is behind the object's surface, its methods of construction, and its material make-up. The language used to facilitate data exchange is Geometric Descriptive Language (GDL)* (Fiorani and Acierno, 2017).
- *HBIM is proposed as the virtual model which will hold heritage data and will articulate processes* (Jordan-Palomar et al., 2018)
- *HBIM is a possible solution for three-dimensional parametric representation, which enables the user to draw models and manage data on historic architectural elements, within a common software environment (IFC, Industry Foundation Classes and gbXML, green Building XML.* (Oreni et al., 2014)

In that sense, the general goals of the HBIM process have been listed in Table 1. It should be formed as an informative database about the heritage elements, and accessible for multiple stakeholders to gather, read and transfer. Naturally, the 3D model serves as a digital representation of the existing state of the building. When the asset is being monitored, the information on its health condition and changes is collected and used in HBIM. Lastly, the proposed intervention on the heritage is simulated and assessed using HBIM processes. From here, the general uses of BIM for historic buildings can be drawn, and are listed in

Table 2. By using the software for designing multiple intervention options, heritage interpretation and design simulation can be performed in order to decide on the best fit solution. Important helpful BIM features in the process include clash detection, 4D modelling, which can be applied in HBIM for evaluating the intervention, simulating the delicate construction process, managing the asset components and plan the health and safety aspects of the reconstructed building. The software are designed to integrate multiple information sources and are striving to be interoperable in as many ways possible. They can integrate the live data from the installed sensors and monitor various conditions of the asset. Finally, the archiving feature of BIM functions as information repository for the uses in further stages of the buildings' life – cycle.

Table 1: HBIM general goals. Adapted from: Historic England (2017).

HBIM - general goals
Informative database about heritage elements, for multiple stakeholders
Digital representation of the existing building
Recurring checking of the health condition
Evaluation of the effects of different typology of intervention

Table 2: Uses of BIM for Heritage conservation project. Adapted from: Historic England, 2017.

BIM software features for historic buildings	Applications of BIM for historic buildings
Multiple design options	Heritage interpretation, design simulation
4D modelling	Construction simulation
Clash detection	Asset management
Integration of multiple sources of information	Security, health and safety (H&S) planning
Interoperability	Condition monitoring
Archiving	Information repository

HBIM process particularities can be identified as major areas to consider when analysing and planning the restoration project using HBIM. They are listed in Table 3. First one is collecting the existing documentation and structuring it according to the given rules. Similarly, collecting the results from the on – site analysis needs to be strucured respectively. The historic building contains the information about its history, which needs to be modelled and represented by its construction phases. Particular materials and degradation states should be appropriately modelled as well. The irregular shapes modelling, such as complex geometries or degraded elements is likewise included in the matter.

Table 3: Particularities for HBIM. Adapted from: Historic England (2017).

Particularities of HBIM
Collecting the existing documentation
Collecting on – site analysis results
Phases, materials and decay modelling
Irregular shape defining

2.1.2. Methodological aspects of HBIM

According to Historic England (2017), the diagram in Figure 3 can be drafted as a summary, in the form of input – process – output (IPO) diagram. From the diagram, it can be seen that the inputs for the modelling include various types of sources. Direct sources from the on – site survey, indirect sources from the existing documentation, location data (GIS) and real – time data collected from the buildings' behaviour monitoring provide the information about the building that needs to be structured in the model. The strucuring process is controlled by the defined standards and regulations, as well as by the modelling template. By setting and following the rules, the consistency is kept throught the project phases. Tools that are used for modelling the digital twin are often the authoring software combined with the integrated tools, such as plug – ins, web – based platforms, non – BIM software (e.g. MC Neel Rhinoceros for modelling irregular shapes), or any software designed to aid in the modelling process. When the modelling process of the existing building is finished, the result is called a "Digital twin", which is furthermore the input for the next process – the simulation of the intervention options. The controls for this process remain the same as for the previous step, standards and regulations combined with the modelling template. Tools to use for this process expand to simulation and analysis software that estimate potential solutions, and are the basis for the decision – making. After finishing the simulation and analysis of the various intervention aspects, such as energy, water, light, costs, appearance and any other steps that are defined by the future intervention, the decision can be made to form the oputput, the design project.

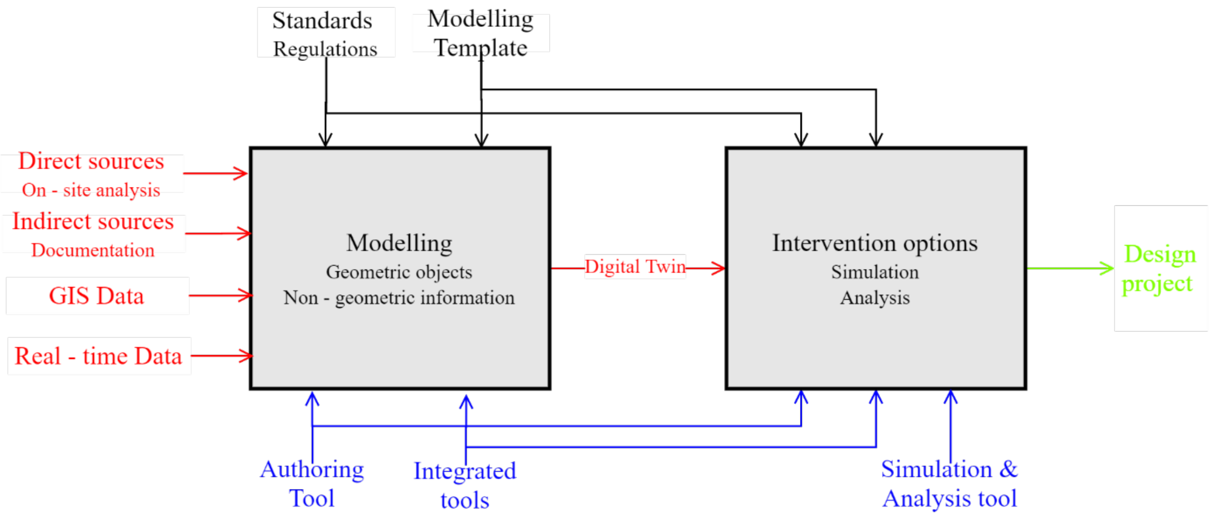

Figure 3: IPO for the initial stage of HBIM.
Source: conclusion from Historic England (2017).

Thorough and clear guidance for heritage management in BIM environment has been published by Historic England in 2017, and is briefly presented in the following paragraphs. The process consists of three main steps, which are graphically represented in Figure 4: collection of the data about the asset – "Survey", digital representation of the assets' elements – "Modelling" and data manipulation through the project phases – "Data management".

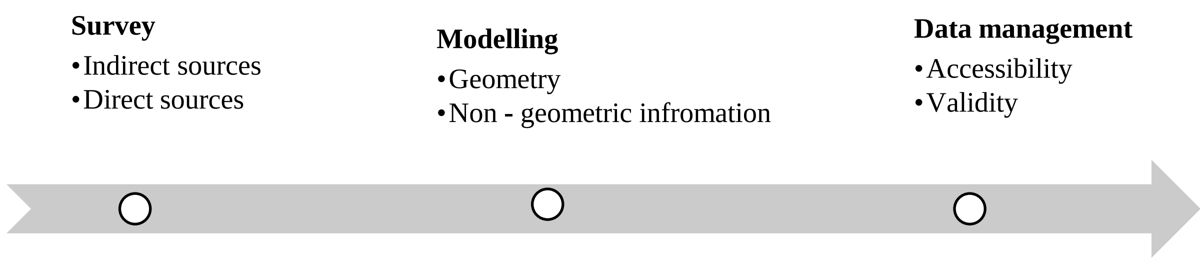

Figure 4: Main steps of HBIM. Adapted from: Historic England (2017).

Step 1: Survey

Collecting the data about the built asset of cultural value is a step specific for HBIM process, and the basis for the subsequent steps as well. Information to be collected comes from two types of sources:

- Indirect sources: archive material (documents), bibliographic material, historic maps (land registers, maps), iconography (depictions, historical photos), important local events.

- Direct sources**:** on - site analysis, degradation form analysis, mechanical tests, archaeologic analysis; inscriptions, construction and surface stratigraphy, dendrochronology, mensiochronology, archaeological essays (GBC Italia, 2016).

Table 4 shows geometric data acquisition techniques and the factors to consider prior to the survey. Three - dimensional survey techniques have been widely used to document historic buildings and sites. They include laser scanning, photogrammetry, closer range scanning, mobile mapping, lidar scanning and, most commonly, the combination of two or more of the methods. The result of obtaining the 3D data, the point clouds, is usually a reference for HBIM modelling, and is supported by the most of BIM software. Other simpler methods can be used without the 3D survey, for intelligible assets, and include 2D drawings, orthophotographs and measured building surveys. Information about the heritage can be furthermore collected from the existing (usually paper based) documentation (indirect sources), which is additional data type that needs to be structured as a part of HBIM process. Before starting the data acquisition, the aspects to consider include point density related to the required modelling level of detail, metadata and data formats, information about the color, and control and coordinate systems. Features of the built assets, time constraints, accessibility of information, team skillsets and finances are some of the conditions determining the survey techniques to be used. Historic England has published technical advice documentation on surveying and recording heritage (Historic England, 2017).

Table 4: Geometric data acquisition techniques. Adapted from: Historic England, 2017.

Data collection techniques			**Aspects to consider prior to survey**
3D digital survey		Other methods	Point density relating to the required level of detail
Laser scanning	Photogrammetry	Measured building survey	Metadata and data formats
Closer range scanning	Mobile mapping	2D drawings	Color information
Combination of methods	Lidar scanning	Orthophotographs	Control and coordinate systems

The use of information in a HBIM process is mainly determined by two conditions: accessibility and validity of data. Accessibility is determined by where the information is stored, in what format, and by constraints on its usage (e.g. ownership, security). Collecting information and translating it into a format suitable for BIM is the core of the technical part of the process. Considering that the existing data can be incomplete or inaccurate, legacy information is to be validated before it is used in the modelling process. It is therefore necessary to establish a process of quality control and validation for the data. These steps ensure that formation of the HBIM model is aligned with the state of the physical object in any phase of its development. The survey result is a record of the existing state of the building elements geometry, position and appearance (Historic England, 2017).

Step 2: Modelling

After collecting and sorting information, a 3D model representing geometry of the existing asset is created. Non – geometric information can then be added to the model in a structured way, associated with the correct BIM elements - components or spaces. Table 5 shows common HBIM modelling process, challenges and proposed solutions. One step of the modelling process is creating the geometry itself. The undefined or deformed shapes present the challenge in the geometry creation, for which the principal solution is adopting a certain tolerance level for geometry representation. When it comes to object creation, similar problem is found - irregular geometry of the object. The standard solution is to define the level of modelling detail needed for specific purpose, or project stage. When it comes to metadata in general, one of the major issues is importing too much information that results in large files. The solution is seen as simplifying the model by marking the assumptions and / or modelling only what is necessary, and representing with simpler elements (e.g. point clouds) the rest of the asset. That process is called hybrid modelling.

Table 5: HBIM process, challenges and solutions. Adapted from: Historic England, 2017.

Process	Challenges	Proposed solutions
Geometry modeling from survey	Undefined deformed shapes	Modelling tolerance
Modeling objects	Irregular geometry	Level of detail
Inserting metadata	Large files	Marking assumptions; hybrid modelling

Table 6 shows the list of general modelling approaches of HBIM. Usually, the design team uses combinations of the approaches. Scan-to-BIM refers to creating BIM elements by using the 3D geospatial datasets as a direct reference of the geometry. Alternative approaches, such as modelling from the 2D drawings can be used when the building geometry is simple enough to derive the shape, or when the level of detail requested is not very high. Modelling tolerance is usually defined before the modelling starts, and specifies the maximum possible discrepancies of the model from the exact geometry of the asset. In that sense, level of detail (LOD) defines how much of geometric detail is included in the created elements, since not every component needs to be fully represented. In that way, time – consuming process is shortened and unnecessary data is not being created. Next approach is defining custom contents. Since the historic buildings consist of particular elements that are mostly not included in standard BIM element libraries, custom ones need to be created. In some cases, the elements can be repeated, and the BIM solution can be creation of the custom element libraries, which can be used on multiple occasions. Hybrid BIM model is a term used for using the point clouds as a representation of the existing elements while modelling only interventions as BIM components. Lastly, the incomplete / unavailable information is often a part of the historic asset. Since the model should be created by using the validated data, the assumed elements should be clearly represented as such, in order to separate the known from the missing data (Historic England, 2017).

Table 6: Modelling approaches. Adapted from: Historic England, 2017.

Modelling approaches		
Scan-to-BIM	Modelling tolerance and LOD	Hybrid BIM
Alternative approaches	Custom content requirements	Incomplete / unavailable information

Step 3: Data management

A digital ecology of interconnected BIM software is usually used for comprising the whole process, since one software does not perform every needed action. Software choice is influenced by multiple constraints such as price, software capabilities and interoperability requirements. Additional tools functioning as plug - ins or cloud - based services cover wide range of actions. They can be open – source or paid – for. Common data environment (CDE) reinforces interdisciplinary collaboration in BIM as a single source of information for the project. The CDE may be a shared network location, project extranet or an electronic document management system. Protocols for the steps of the process need to be followed by team members to ensure information consistency. Pre – agreed procedures to be followed in order for the process to be productive are listed in Table 7. They include naming conventions for any cerated component, modelling standards which include creating by defined levels of geometric and non geometric information, adopting certain software to use and file transfer approach, templates for creating the model in the software and definition of parameters to use (Historic England, 2017).

Table 7: Adapted from: Historic England, 2017.

Pre – agreed procedures to be followed	
Naming conventions	Software usage and file transfer
Modelling standards	Object standard (non - specific content)
Templates	Parameter definition

The whole process is clearly represented as HBIM life – cycle diagram, as shown in Figure 5. The starting point of the HBIM process is the survey of the asset. Practically, knowledge and understanding of the historic assets' existing state translates into initial input of information into the HBIM. After the options and detailed surveys are performed, the intervention type is decided so it can be physically performed. When the work is done, the handover and operation phases can be realized, after which the information is stored for the future intervention strategies (Historic England, 2017). After giving an overview of the general process, detailed focus in the next chapters will be given to the information management first step of the HBIM modelling life cycle – Preliminary survey.

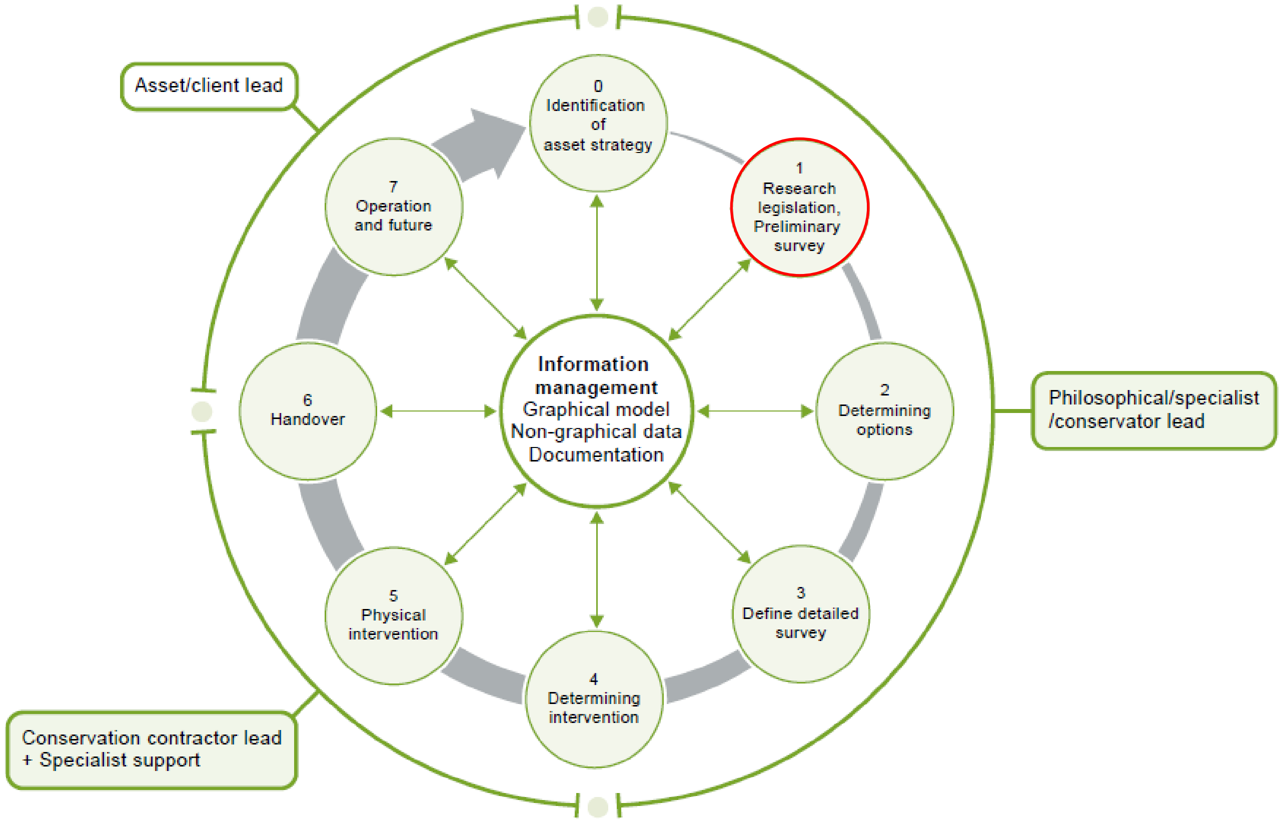

Figure 5: Historic Building Information Modelling life cycle. Source: Historic England, 2017.

2.1.3. HBIM uses in practise

Aspects of a successful HBIM are knowledge, modelling, and validity of data (Attenni, 2019). Attenni (2019), has distinctly framed three key fragments of the HBIM process:

1. Adopting proprietary BIM platforms and creating libraries
2. Integrating tools (plug-ins, open source software or commercial data storage and management)
3. Expanding to web - based applications.

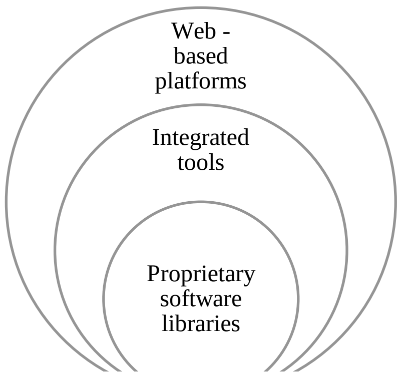

Figure 6: HBM extents. Adapted from: Attenni, 2019.

1. Adopting proprietary BIM platforms and creating libraries

HBIM models are devloped using proprietary software, with creation of historic objects libraries. Modelling integrates geometries provided by the platform with the documentation related to the history of the asset (Attenni, 2019). Once the parametric objects are modelled using the architectural, historical documentation and laser scanning data, libraries of the modelled elements are generated. HBIM libraries are used in design, rehabilitation, reconstruction, management, and maintenance processes (Murphy et al., 2009, cited in Lopez et al, 2018). The modelling process itself is been seen as complex and there are different approaches to model historic elements creation. Non - Uniform Rational Basis - Splines (NURBS) - based parametric generative modelling process (and scan to NURBS) had been used by Brumanna et all (2019) for Bacilica of Collemaggio in L'Aquila, to make the model and make it more accesible to the stakeholders. HBIM was used for different purposes: comparison, simulation; conservation plan, material and surface decay analysis and representation; structural analysis for damaged elements; WBS of restoration activities; CoSiM, scaffoldings simulation; Virtual Reality management, and touristic purposes (Brumana et al., 2019). Bacci et al. (2019) explored the possibility of organizing the BIM model into temporal phases, integrating documentation in a structured way. Oreni et al. (2016, 2017) and Barazzetti et al. (2015) suggest implementation of HBIM element libraries for structural analysis (Oreni et al., 2013). Quattrini et al. (2015) modeled components directly on the raw data of numerical model, for quality and precision in modeling geometries, and created the complex geometries through B-Rep operations (Quattrini et al., 2017). One major particularity of HBIM is documenting degradation state. Hamdan et al. (2019) have developed DOT (Damage Topology Ontology), a web ontology which contains terminology to represent construction related damages, their topology, and relations of the affected elemets and their location, which is presented in Figure 7. Geometrical damage representations are separated from the topology, so that it is possible to record damages during the inspection without any geometrical properties and link it later with a corresponding representation using terminology from geometry-related ontologies. DOT can be applied as a stand-alone web ontology to represent damages in a machine-interpretable format and replace conventional record approaches. Therefore, a generic terminology is used that enables the inclusion of various types of damage, which can be extended with domain-specific information. (Hamdan et al., 2019)

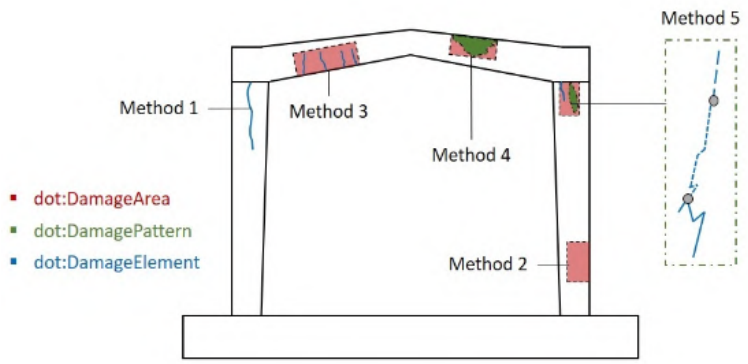

Figure 7: Damages presentation methods. Source: Hamdan et al (2019).

Chiabrando et al. (2017) proposed a workflow for mapping the decay using adaptive components (Figure 8) which can be associated to any modelled surface. Graphical representation was defined using the official standards, pairing the decay types with the legend icons. As needed, parameters can be inserted, including the external information links (Chiabrando et al., 2017). The adaptive components can be therefore a part of a decay element library, which can be easily reused for similar projects.

Figure 8: Decay typology representation. Source: Chiabrado et al. (2017).

2. Integrating tools

Integration of additional tools such as plug - ins, open source software or commercial data storage and management has been mentioned in the literature numerous times. Dore et al. (2015) used the GDL 3D ruled plug – in for digital modeling of the four courts in Dublin on historical documentation, the analysis of the current state, and the reading of specific aspects, to compose a library of parametric objects. Quattrini et al. (2015) used an open - source plug - in, (Protégé), to integrate parametric data with each modelled element. Fregonese et al. (2015) and Rechichi et al. (2016) used open source software, 3Dreshaper and BIM3DGS, which are used for the processing of survey data and for the construction of parametric models, and the integration with GIS applications (Atteni, 2019). Banfi (2019) developed add - in made for transferring generative modeling and GOGs within the BIM software authorig tool – Revit (Banfi, 2019).

3. Expanding to web - based applications

Collaborative process implies interaction with the data from the model, in a user - friendly way, by stakeholders who do not have to be involved in the modelling itself. Therefore, tools such as applications based on AR and VR are frequently used, enabling sharing and communicating through the model without modelling skills required. In this way, instant and precise feedback can be given, locating the errors on – site and immediately transferring the notions on the model. The parametric properties of the model stay and the model can be reloaded on the online platform, being updated when needed. Osello et al. (2018) have analysed the interoperability of authoring software and AR and VR tools and reported successful interaction.

Quattrini et al. (2017) proposed semantically structured representation of metadata and on IFC that can be easilly querried through the user – friendly semantic web (Figure 9). User can browse the data and access model, its elements, digital worksheets, and multimedia content (e.g. pdf, video, images, or web links). The methodology demonstrates that it is possible to switch from the parametric representation of the HBIM to the management of the 3D web objects. This operation allows for better understanding of the elements through thematic information on the asset, connecting them with thematic databases (Quattrini et al., 2017).

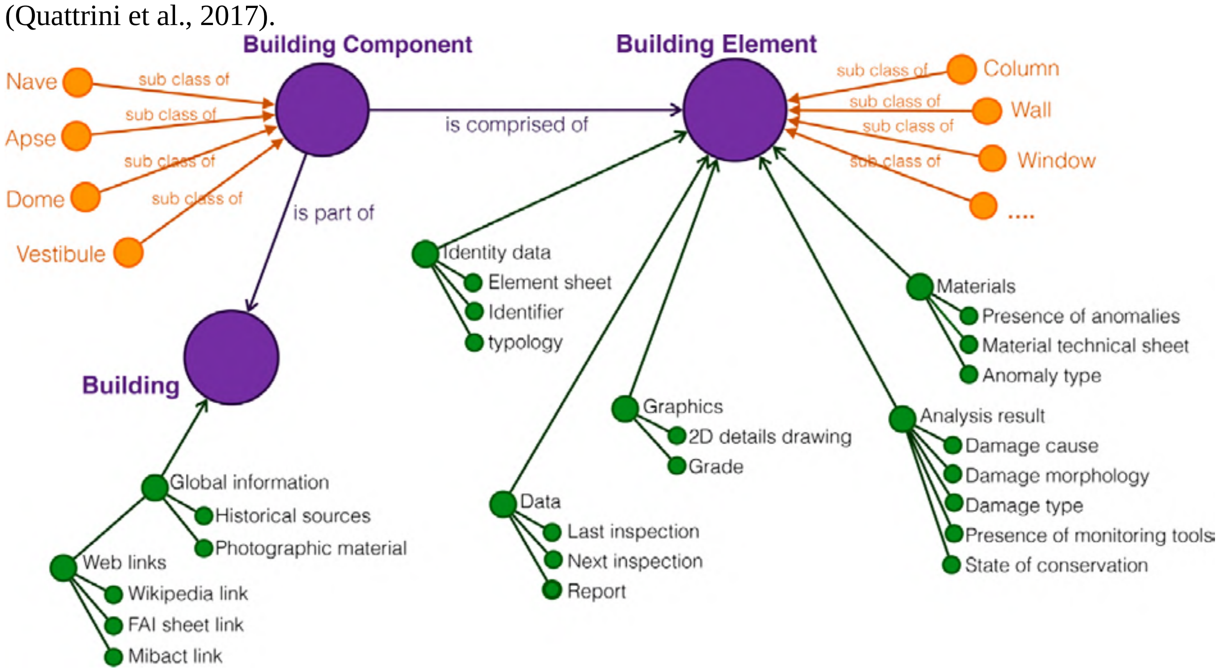

Figure 9: Example of the OWL ontology for semantic data representation. Nodes represent classes, sub-classes, metadata. Source: Quattrini et al. (2017).

They have presented the advantages in using HBIM in this way. Data enrichment enabling cross - model queries in a single environment. Formatting data in a semantic way means it can be queried according to their meaning and not the structure. It also implies exchanging information in a human readable format with a minimum of human intervention and fit the large amount of collected data in the standard format.

Brumana et al. (2019) suggested connection between HBIM and online environment, by using semantic – based hub platform, and GeoPan Atl@s, including real - time sensor data acquisition and integration of HBIM and GIS. Such data will progressively include the growing availability of real-time Open Data, temperature, raining parameters and sea level rises. The platform was made for vaulted systems, which HBIM models would be coonnected to the Hub and updatable by various stakeholders. (Brumana et al., 2019). Jordan (2019) developed an online platform, ‘BIMlegacy’, and the protocol to manage historical context, which allowed the synchronisation of the information in real time, accelerating the response time of the involved stakeholders. Lack of technical skills needed for the modelling process, was overcome by discussing the project evolution through viewing platform, without the need of every stakeolder to have modelling skills (Jordan-Palomar, 2019). Similar had been done with the INCEPTION project, created for 3D digital reconstruction and preservation of European cultural heritage. As well as DURAARK (Durable Architectural knowledge) project, it is created for developing methods and tools for the preservation of architectural knowledge, by semantically enriching building models and preserving them in single web – based database (DURAARK, 2020, Inception, 2019).

Information life – cycle represented in Figure 10, by Jordan-Palomar (2019) can be compared to HBIM Life – cycle (Figure 5). It can be noticed that a step has been added after the handover step, which is integration of the contents in a unique online communication environment that is later the information basis for the asset usage.

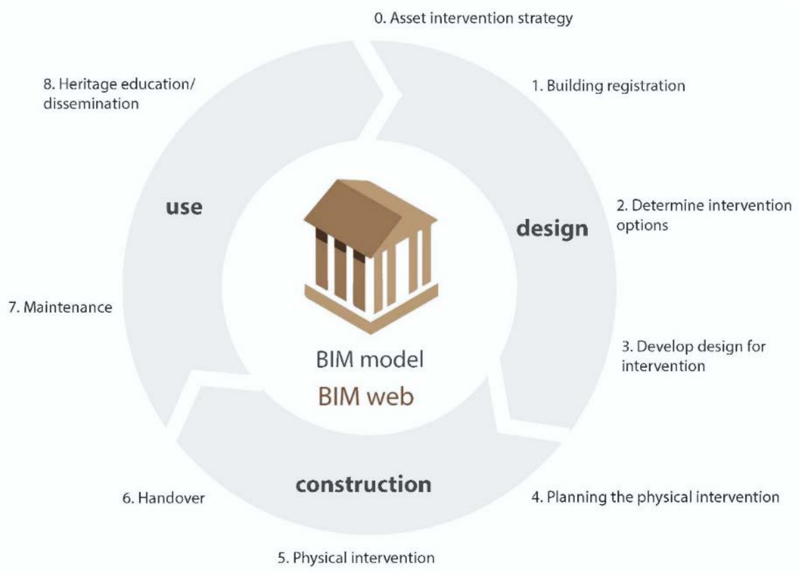

Figure 10: Web - based HBIM, "BIM legacy platform" information life cycle. Source: Jordan-Palomar, 2019.

HBIM uses – challenges and reccomendations

When it comes to the milestones in HBIM process found in the reviewed literature, shape complexity had been seen as an ongoing challenge in the modelling process, making the geometry modelling a time and cost consuming process (Brumana et al, 2019, Atteni, 2019, Quattrini et al, 2017, Lopez et al, 2018, Pocobelli et al, 2018, Malinverni et al, 2019, Khodeir et al., 2016). Non – BIM software (such as McNeel Rhinoceros) are still greatly used in modelling the historic building objects (for example in the case of Brumana et all, 2019). The complexity of modelling is further hindered by the lack of standardized HBIM libraries (Lopez et al., 2018). Solutions exist in creating or using external tools, but the use of additional software (such as internal office plug – ins, specific platforms) are usually dependant on the company's technological skills, or costly, therefore not widely available yet. Additionally, using external software can result in loss of information when exporting data (Atteni, 2019). Regarding the technical part of non – geomeric data management, the process of inserting the semantics and structuring it in the model has beeen seen as difficult for the professionals outside the IT field (Bacci et al, 2019). The process requires particular technical skills a great number of stakeholders are not equipped with. Furthermore, as Quattrini et al (2017) noticed, there is a lack of vocabulary and standard definitions in data enrichment, as well as the lack of linking between the ontology modelling and the data enrichment phase. Similar problem was mentioned by Brumana et al. (2019). Furthrermore, there are no pre - existing defined properties for heritage assets found in IFC standard. NBS has an extensive library of BIM objects, which is directed towards the new constructions. IT results in having to make custom libraries and insert custom properties for heritage descriptions. As stated previously, official standards are crucial for the control of the process, which implies that IFC should be developed in this direction in order for HBIM to become fully functional.

Scripting tools are surely powerful, connecting the features of programming into the AEC context. Process such as data analysis, data depiction, simulations are some of many functions made accessible and faster in the recent past, by those tools. Regarding the complex geometry, Lopez et al. (2018) suggest creating shape recognition algorithms to automate the parametric reconstruction of entire buildings, directly from the point clouds. Another related suggestion for the future of HBIM is to create a universal and open - access HBIM library containing the information useful for AEC stakeholders (Lopez et al, 2018). Publications frequently mention development of plug - ins for creating different kinds of operations. To do this, either the corresponding tools should be used to program the BIM API, that can expand the digital environment where experts in the AEC field can interact, not relying on their physical location or devices used (Lopez et al, 2018). One particular example of these statements was demonstrated by Pocobelli et al (2018) for depicting moisture variation in walls, using the data that are stored in Revit through spreadsheets linked to smart masses. They suggest that visual scripting tools can be used to develop a weathering forecasting model and link it into the proprietary software model. Geometric parameters and building material properties would be derived directly from the model, while the weather parameters would either be user - inputted or taken from the damage functions. Forecasts will be produced through the solution of damage functions and moisture ingress theories. The output is designed to be a surface distribution of degradation. (Pocobelli et al., 2018). Similar topic was described by Hamdan et al (2019) for damage representation. They suggested versioning of damages and how they evolve over time. Since damage representations from earlier inspections are not to be removed in order to follow damage progression, an ontology for version control of damages should be implemented (Hamdan et al., 2019). When it comes to the collaboration, the future result is expected to be a specific HBIM platform which unifies in real time heritage information and serves a workspace for the interdisciplinary stakeholders (Dore and Murphy, 2017). Articulated computerized management as a response to demanding data acquisition and processing over time, implies collaboration between industrial and research sector to systemize the automation processes based on ontologies and semantic recognition of information (Chiabrando et al., 2017).

2.1.4. Remarks on HBIM

From what has been presented in the literature, a few notions can be derived. The general concerns are that there is no official standardization when it comes to the environment where the process can be performed, workflow, or the historic elements and material libraries. The data is still defined individually, having no clear or well - defined guidelines. What is more, the interoperability between proprietary software and additional tools is needed for the process to be complete and functional. In order to make the collaborative process fluent, open file formats, such as industry foundation class (IFC) are used. However, the use of open file formats is likewise developing, as there are no clear conventions in the context of heritage. No official standard exists for historic element properties or libraries. In addition, it is frequently needed to integrate tools into proprietary software, which implies having additional software skills related to the IT sector, making the implementation more complex. Further on, web – based HBIM managing platforms are shown to have high potentials too. Additional IT skills are also required for connecting the model with the online repositories. In general, in order for the descibed solutions to be succesful, a clear and accessible framework needs to be developed and implemented, with the information structured following the rules of open formats, enabling interoperability, so the data can be used in multiple platforms by multiple stakeholders.

2.2. Building sustainability management

Report of the World Commission on Environment and Development (WECD): 'Our Common Future' (1987) defined: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Principles of sustainable design promote regulation of building activities to mitigate impacts on climate change - energy consumption, resource depletion, water conservation, land degradation, biodiversity, indoor quality, and occupants' health and comfort. Final products are to be "green buildings" (GBC Italia, 2017).

2.2.1. Standards and certifications - outline

One of the ways of achieving environmentally sustainable development is obtaining certification for the buildings according to standardised rating systems. Some of the widely known are LEED, WELL, BREEAM, Energy start, Green Globes and DGNB. Following those standards, the goals of reducing the consumption of energy, carbon, water, and the production of waste are ensured. (Romano and Riediger, 2019). Rating systems systematically asses the level of environmental quality achieved through checklists. They assign certain scores according to the quality level and reward the project, the construction site management and the asset management. World Green Business Councils are independent, non-profit organisations working in the building and construction industry that provide third party credentials and verifications for various sustainability classification systems. They formed a global action network consisting of around 70 Green Building Councils around the globe (World Green Building Council, 2016 - 2020).

LEED ® Certification system

LEED ® - Leadership in Energy and Environmental Design is a building certification system that provides third - party verification of green buildings and is applied in over 150 countries. The LEED standard was originally created in the United States by US Green Building Council (US GBC), a non – profit organisation that oversees sustainability assessment practice according to the LEED standards. LEED is made applicable for different building types (Figure 11): commercial, homes, neighbourhoods, retail, healthcare, and schools, and their development stages (from design to management). The assessment is structured accordingly and divided into thematic areas, by key aspects of the buildings. Each thematic area represents a credit category which contains certain number of specific topics, called credits. Credit categories with maximum amount of points to obtain are represented in Figure 13. In the version LEED 2009, and LEED Italia, there are seven credit categories: Energy and atmosphere, Water efficiency, Sustainable site, Materials and resources, Indoor environmental quality, Regional priority and Innovative design. Newest version, LEED v4, contains additional two categories: Location and transportation and Integrative process. In order to obtain each credit, there are defined rules to comply with. The credit achievement results in certain amount of points (U.S. Green Building Council, 2020). LEED® certification is awarded when the project obtains all the prerequisites a minimum number of credit points by adopting the requested sustainable strategies. Based on the final score, the project can earn one of four LEED certification levels: certified, silver, gold and platinum (Figure 12) (U.S. Green Building Council, 2020).

The credit score system is based on the following criteria:

- All credits are worth at least 1 point; prerequisites are mandatory and do not score;
- All credits have a positive integer value; there are no negative values;
- There is maximum of 110 points to obtain.

LEED online is a platform for the project submittal. US GBC has made available fillable PDF forms and Excel calculators for most of the submission and calculations to deliver.

Figure 11: LEED Rating systems. Source: US GBC (2020).

Figure 12: LEED Certification levels. Source US GBC (2020).

Figure 13: LEED 2009 & LEED Italia with LEED v4 credit categories and points. Source: Ongreening 2013.

2.2.2. BIM uses in sustainable design practise

Succesful LEED certification project requires a holistic approach, integrated planning and coordination. The process is arranged as a continuous cycle of programming, revision, analysis and correction. Extraction and retrieval of the required data implies a lot of iterative work and coordination of diverse and often incompatible sources. BIM is the tool used for holistic approach on project management and for repetitive data collection, design, simulation and verification processes, and in that sense seen as a tool to use in optimization of this process. Some examples of using BIM for optimizing the process of certification will be portrayed in the following paragraphs.

While applying for “LEED v4 for Building Operations and Maintenance” Certification, Mazzola et al (2017), noticed that it is difficult to follow the process of certification, due to the complexity of internal parameters and the documentation required, which can deter surveyors and technicians from obtaining certification. They formed a methodology for obtaining the minimum requested points and optimize technical resources and documents, through examination, deconstruction and reformulation of the internal difficulties. For that, they proposed a mathematical approach to select a list of useful credits and to organize the requested documentation for achieving the certification. They have given major attention to the credits that have the most points and require the least work in terms of documentation (Mazzola et al., 2017).

One of the frequently mentioned BIM features in the context of complex certification projects is a flexibility of the proprietary software. It allows to develop scripts that extend the existing capabilities of the original software. There are examples in the literature creating plug – ins and successfully implementing them in the process, and in the case for LEED Certification through BIM tools, they have proven to be very efficient process optimizing tools. There has been a plug – in called “Revit Credit Manager for LEED” created by Autodesk specifically for the purpose of documenting the LEED Certification project, enabling faster workflow through connection with the authoring tool and the documentation request format themselves. It is currently not available, although it is presented as a functional solution for the complex documentaiton rules. Nevertheless, there are a few examples of individual teams developing their own plug – ins for the similar purposes. Jalaei et al. (2019) proposed a methodology for from the conceptual project stage. They have developed a plug – in for BIM authoring tool (Autodesk Revit) to calculate and predict the LEED credits to obtain. It is linked with energy analysis and lighting simulation tool, Google Map and their associate libraries. The plug - in estimates the credits that are not obtained too, providing the whole frame of evaluation. According to them, the plug - in gives a consolidated look on the projects, controls information handling throughout multiple platforms. Moreover, it minimizes repetitive tasks and assists in the calculations. Since the proposal has not been used in a great number of projects, they plan to develop the model as they gain more experience in using it. (Jalaei et al., 2020). Figure 14 shows schematic representation of steps for their framework proposal. First step is data collection, when the Revit – based model is made, materials and LEED certification studied, and the areas to intervene on are selected. For the second step, they developed an automated LEED calculation system which is inserted in Revit. The created plug – in is connected to Google Maps, Autodesk Revit API and their online libraries. During the third step, the plug – in is used to perform the analysis. Data exchange was done using the programming tools. Final, fourth step is the estimation of LEED potential for the proposed project. Calculation is performed for each section and point numbers estimated. Then, the documents and proofs are adjusted accordingly, so the project is ready to apply for the certification.

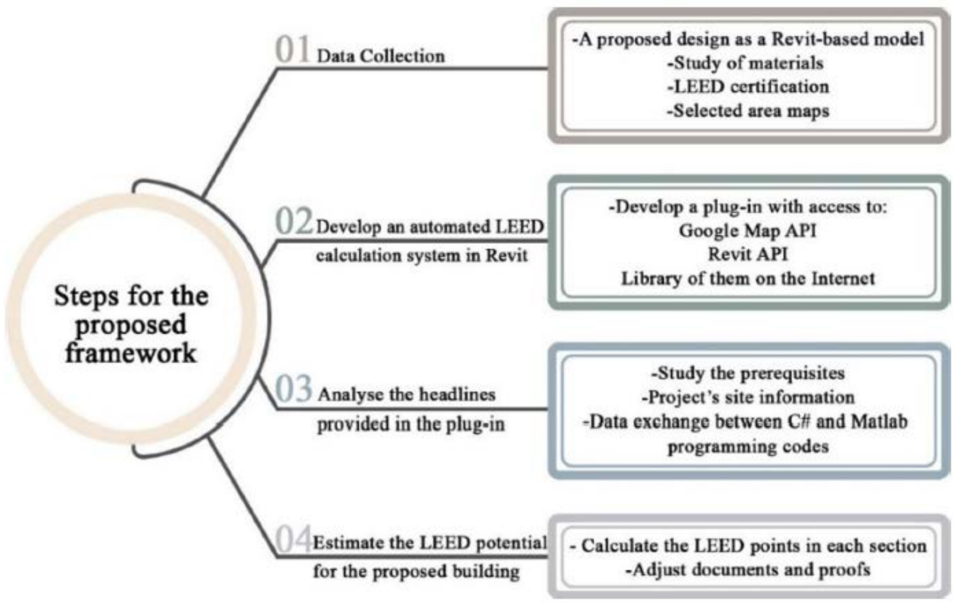

Figure 14: Steps for the proposed BIM – LEED framework. Source: Jalaei et al. (2019).

Figure 15 shows the workflow diagram for the LEED certification by Jalaei eet al. (2019). According to it, there are five main phases. In the first one, the BIM design is made, for architecture, structure and mechanical field, and is connected with the material database of the project. Second phase consists of developing the plug – in for LEED calculation, interoperable with Revit and performing the point estimation. If the estimation gives positive results, the process can continue to the third phase, which is the detailed project. The third phase consists of three main aspects: location, material, and energy and water information. For the first aspect, the plug – in interprets the Google Map information and uses it to calculate the requested distances, map and evaluate parking potentials. Second aspect deals with material quantity take – off information from Revit through IFC format. It transfers the information to online server where LEED relevant information is linked to the materials in authoring tool, as well as manufacturer information. Third aspect collects energy and water analysis results and makes a link to energy analysis software to prepare the energy model. Then, the water and energy simulations are made. Each of the aspects are then evaluated by calculating the potential LEED points, using the plug – in. After that, the fourth phase, when all the points are collected, evaluated and exported happens. Final phase is representing the final result and potential for obtaining certified, silver, gold or platinum certification.

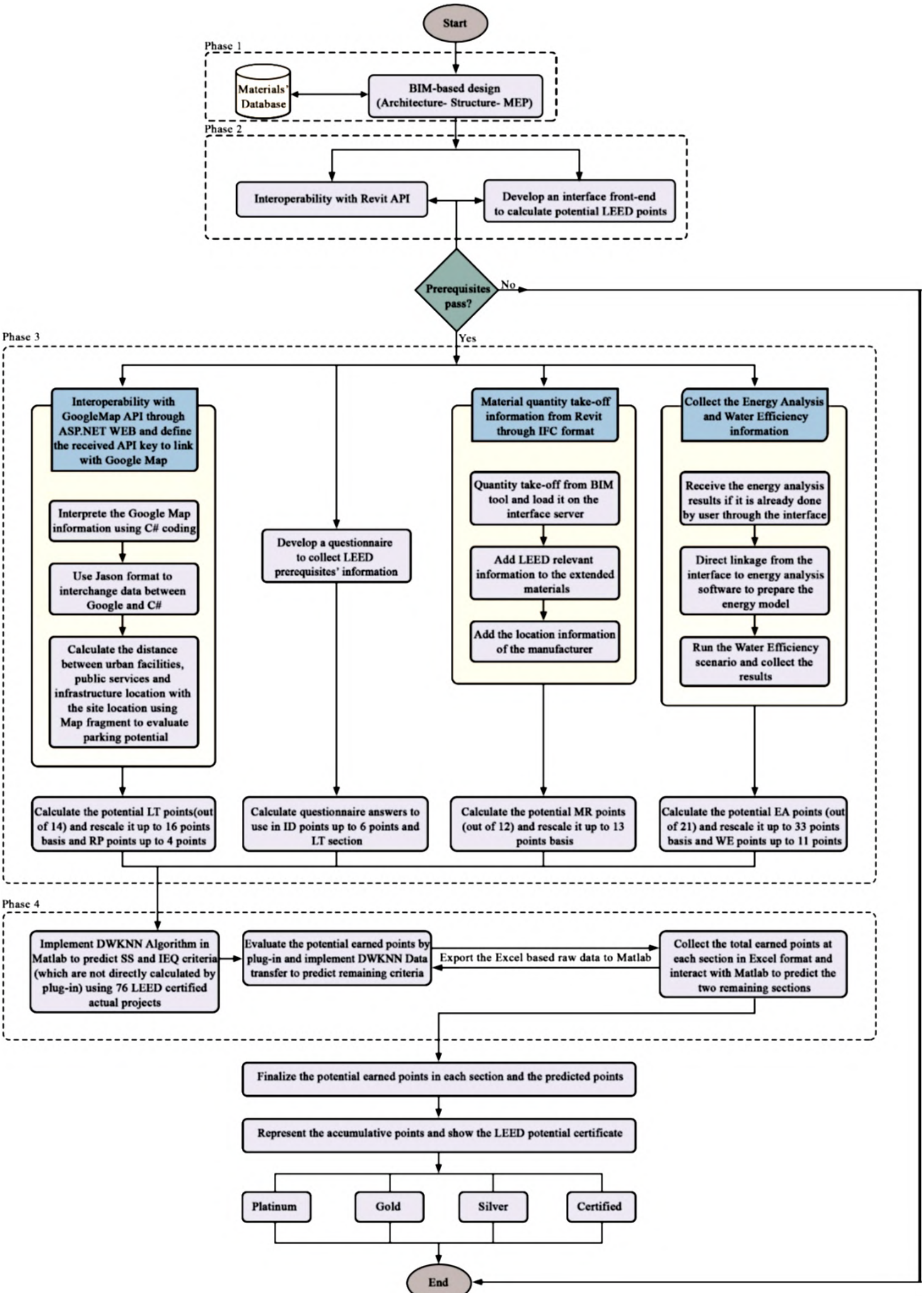

Figure 15: BIM - LEED integration workflow proposal. Source: Jalaei et al. (2019).

The plug – in appearance in Autodesk Revit environment is shown in Figure 16. This is the example of material properties manipulation. Elements are listed by categories (doors, windows, walls, floors and columns), with the associated materials which are linked to their specifications. The specification includes details about the material.

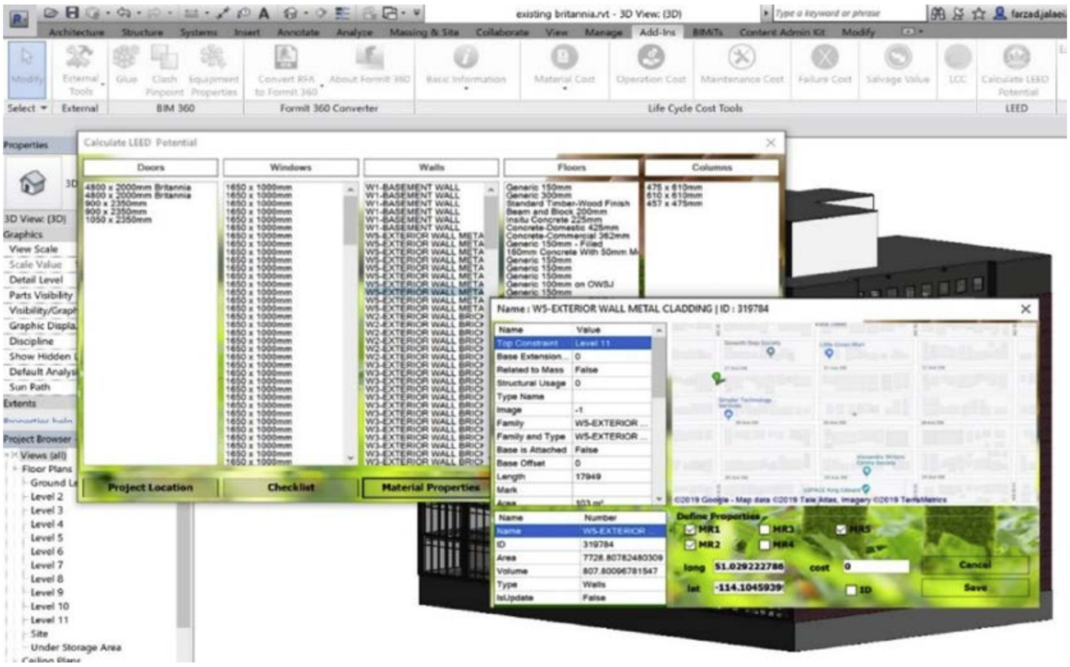

Figure 16: Plug - in in the Revit environment, Material properties and details of used materials. Source: Jalaei et al. (2019).

BIM authoring tool plug - ins have been developed for individual credit categories too (see Figure 13). Great number of publications focus on energy analysis and optimization, which is considered as a significant area in the process. BIM is seen as a helpful tool for the analysis and simulation in the process for LEED certification (Romano and Riediger, 2019). The tools for energy simulation, lighting and temperature analysis have been extensively used, researched, and proven to optimize the process (helpful in this case for obtaining points for Energy and Atmosphere and Indoor Environmental Quality credit categories). In that sense, the energy optimization topic is out of the scope of this dissertation. Thus, the following paragraphs will demonstrate particular uses of BIM for optimizing the process of applying for the following LEED credit categories:

- Sustainable sites
- Materials and resources
- Water Efficiency

Sustainable sites credit category

Chen et al. (2016) developed a plug – in specifically for achieving credit points in the Sustainable Sites category. As shown on the diagram in Figure 17, they connected BIM model with GIS server, by using Web map Service (WMS) for location and transportation analysis, Autodesk Revit API and Google

Maps API. The plug - in enables inserting information about the location directly in the authoring tool. The inserted data on Green Building standards / guidelines creates the “Green building module” to Revit environment, which enables calculating the points for the credits, doing route – planning tasks, developing submittal documents, and exporting Excel file data with the relevant information for the submission.

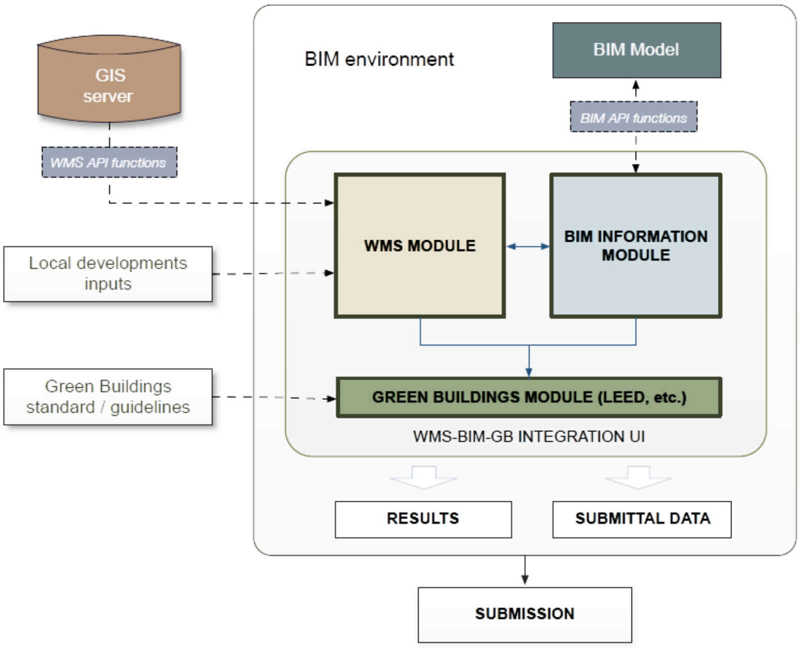

Figure 17: BIM-WMS-LEED integration framework. Source: Chen and Nguyen (2017).

Figure 18 shows the appearance of the LEED – BIM integration plug – in in the Revit environment. It contains every credit category, and the Sustainable Sites category window is opened. It lists every credit, the points obtained and if it is sufficient. The authors concluded that their integration model can be applied to any project needing site analyses, construction materials transportation and similar. Some limitations are regarding the update of WMS providers or image quality size. Nevertheless, the developed tool helps in time – saving, not having to manually analyse the location of the asset (Chen and Nguyen, 2017).

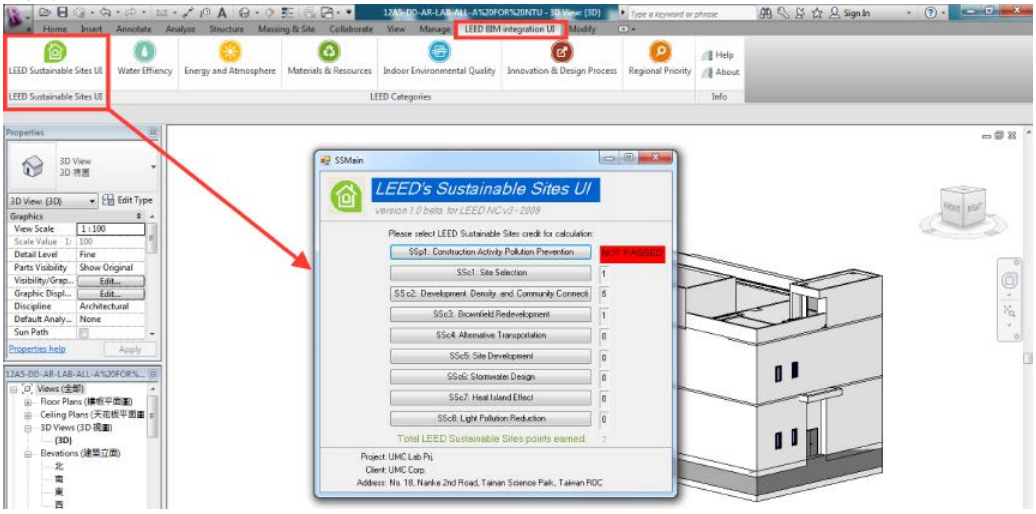

Figure 18: Plug – in for Sustainable Sites in Autodesk Revit. Source: Chen and Nguyen (2017).

Materials and Resources credit category

Cheng and Ma (2013) have developed a plug – in that extracts material and volume information from Autodesk Revit and performs waste estimation and planning, considering recycling and reuse processes as well as pick – up truck requirements and waste disposal charging fees. Extracted material information can be provided to recyclers before demolition or renovation (Cheng and Ma, 2013). Based on the flowchart in Figure 19, the system works by selecting the demolition elements in Autodesk Revit model. Then, through the integrated plug – in, the element volume information can be viewed categorized by element function, by material type, or by both. After that, material density values and recycling and reuse data from the actual site can be inserted. Then, the amount of demolition waste is automatically calculated and used to calculate waste disposal charging fee and the required number of hauling trucks for waste disposal planning.

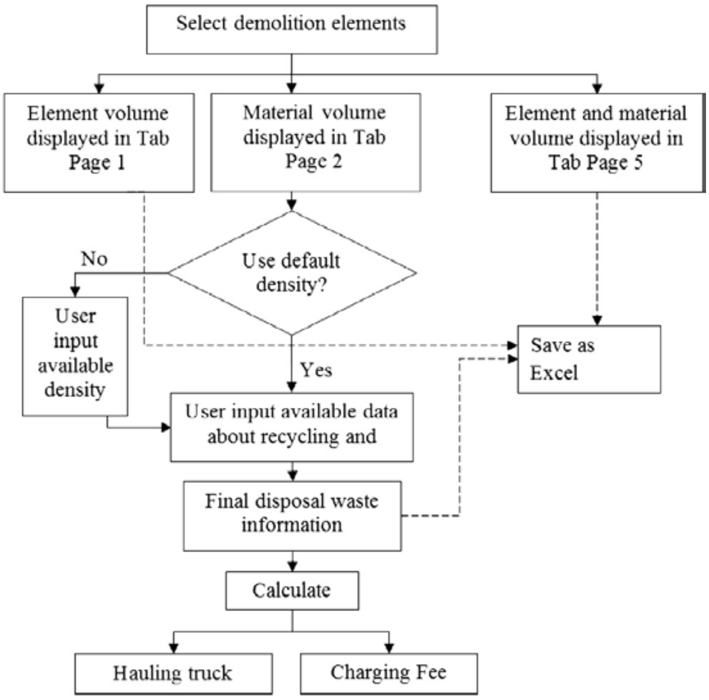

Figure 19: Flowchart of the developed system for material and waste estimation. Source: Cheng and Ma (2013).

Similar goal was considered by Jayasinghe and Waldmann (2020) when proposing a BIM - based system for storing information of the materials and components of buildings and managing the recycling and reuse in a tool called Material and Component (M&C) bank. It cosists of a web browser for M&C information extraction, with BIM model as a source. The tool can be used for waste calculation and deconstruction management, to calculate waste disposal charging fee and pickup truck requirements. The information can be exported as Microsoft Excel file for report forming (Jayasinghe and Waldmann, 2020). According to Figure 21, the Autodesk Revit model information is extracted to Excel, which is then uploaded to Web Server, so no additional plug – ins are used for this purpose. Sample of the information database in their proposed system is presented in Figure 20. Different types of component and material properties are transferred and used to perform waste estimation calculations.

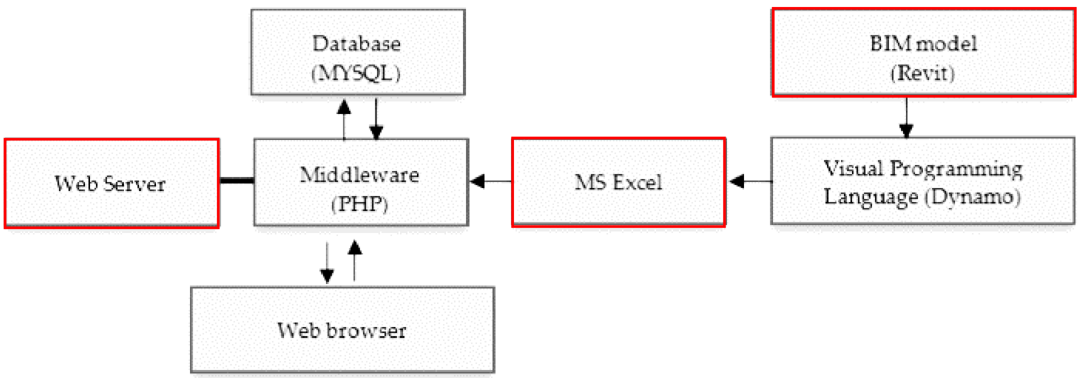

Figure 21: Material and compnents tool architecture.
Adapted from: Jayasinghe and Waldmann (2020).

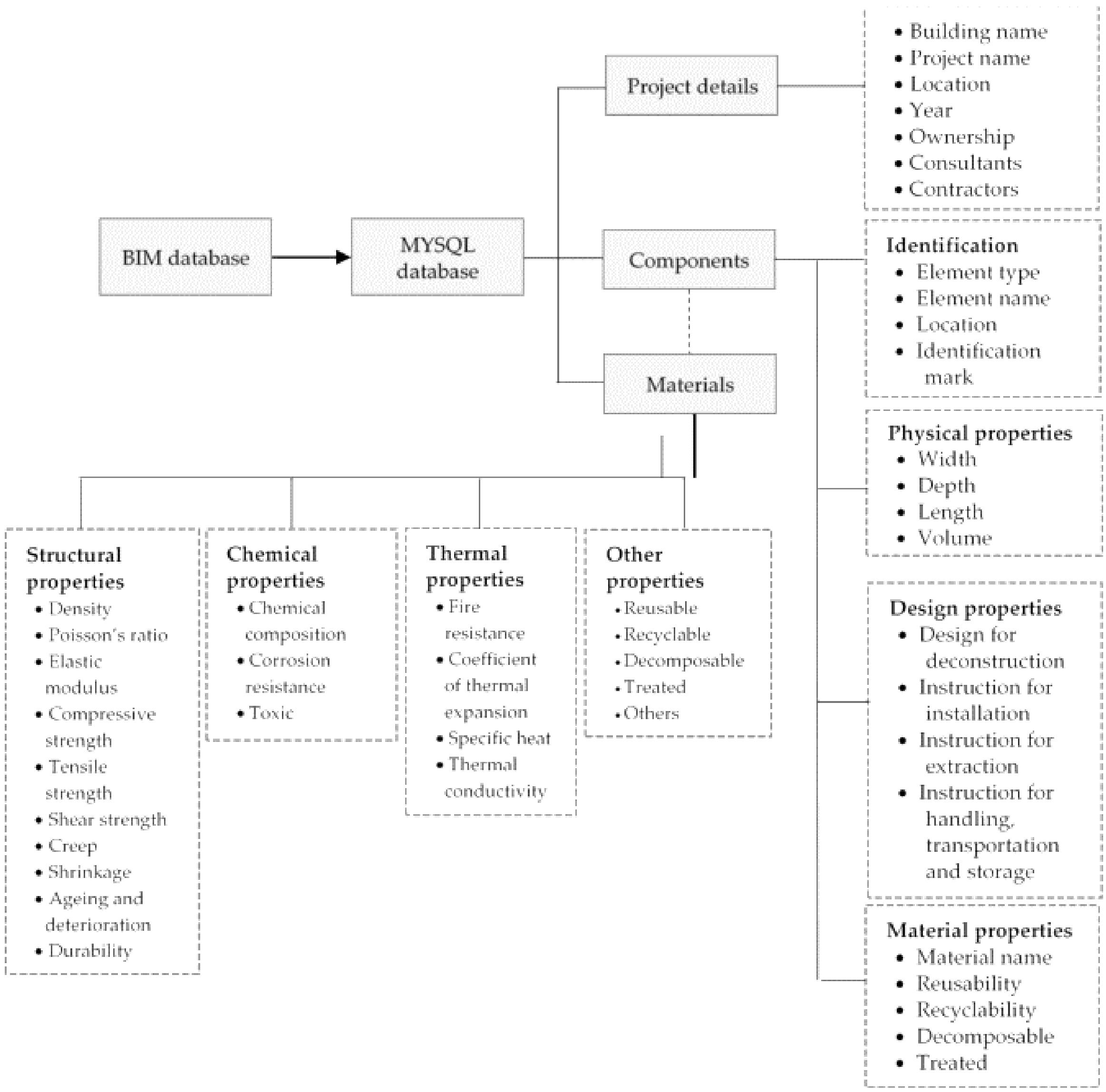

Figure 20: Database sample. Source: Jayasinghe and Waldmann (2020).

Water Efficiency credit category

By using visual programming tool in Autodesk Revit (Dynamo) to perform the required calculations for water management and analysis, Edoardo Maroder & Damiano Di Ciaccio have made graphs calculating requests for "Indoor Water Reduction" credit using the given parameters for fixture elements. The graph collects the data from proprietary software, performs needed calculations and tests if the credit has been obtained (Maroder and Di Ciaccio, 2017). The methodology is simple in terms of platforms needed, and does not require high level of programming skills. It can potentially be applied to other certification credits and categories where the calculations are requested.

Water Efficiency, Indoor Environmental Quality, Energy & Atmosphere credit categories

Riaz et al. (2017) developed a system for confined space monitoring (CoSMoS). It is based on integration of real - time monitoring of thermal conditions within confined work environments through wireless sensor network (WSN) technology integrated with BIM through the add - in. For the future, they suggest to assess how the performance of databases differs for a distributed network where data is stored on a cloud - based platforms (Riaz et al., 2017). The system can be applied to the credit categories that deal with the real – time monitoring (Water Efficiency, Indoor Environmental Quality, Energy & Atmosphere). Their framework of BIM – real time sensors integration is shown as a diagram in Figure 22. Database platform is the link between the information collected by the sensors and the BIM platforms, enabling the update of the information in the real time. The decision support system is BIM – based and provides information visualisation, analysis and data monitoring.

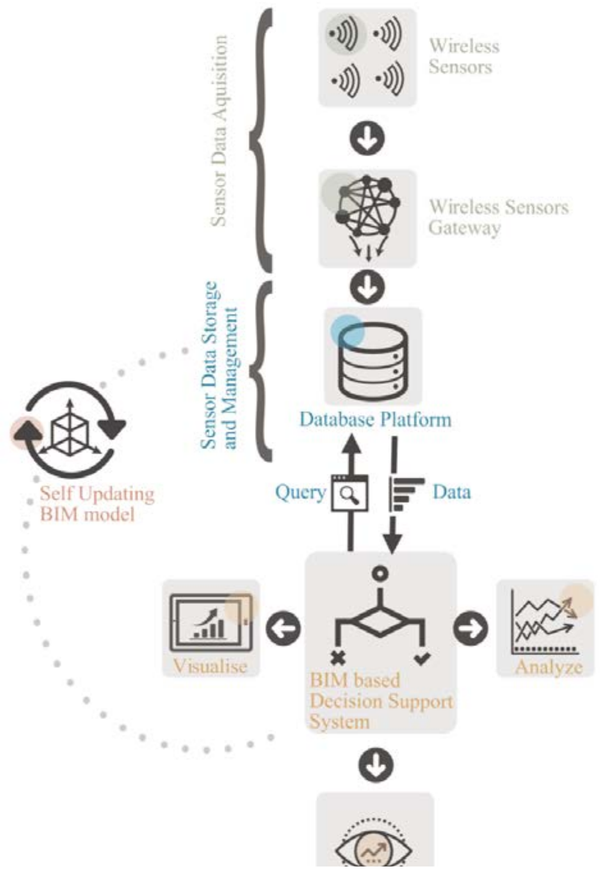

Figure 22: Framework of BIM and real – time sensors integration. Source: Riaz et al. (2017).

2.2.3. GBC Italy - Certification system

The organizations such as Green Building Council (Further referred to as GBC) are formed for leading the sustainable construction sector. This research focuses on Green Building Council Italia (GBC Italia), as a part of the World Green Building Council (World GBC) network, that promotes the certification protocols specifically for the Italian market, and defines systems and manuals to achieve these goals. The GBC protocols have been developed and are inspired by the respective LEED rating systems, but refer to the Italian and European construction and regulatory systems. In addition to US GBC, GBC certification systems in Italy apply to buildings and portions of territory (neighbourhood) and cover all development phases: from design to construction and redevelopment (GBC Italia, 2017). The protocol used for developing this thesis is GBC Historic Building ®, one of the protocols developed specifically for the Italian market. Buildings in the scope of GBC Historic Building® must be built before 1945, and demonstrate a certain level of value in terms of materials, techniques and technologies.

GBC Historic Building - introduction

The GBC Historic Building® (Further referred to as GBC HB) certification system measures the sustainability of the building according to thematic areas of the LEED ® / GBC rating systems, adding a new Category - “Historic Value”. It is made to preserve the cultural value of the built environment favoring the enchantment of its environmental sustainability. It serves as guidance for the design team to achieve these goals. All credit categories of GBC HB are shown in Figure 23. Prerequisites and credits are based on series of principles formed in the late XIX and the second half of the XX century. They start from the fact that every intervention brings modifications – introducing new tangible elements which alter current material consistency and are widely used in the field of restoration today ((Italia, 2017). Awarded certification levels are the same as the US GBC LEED certification (Figure 12).

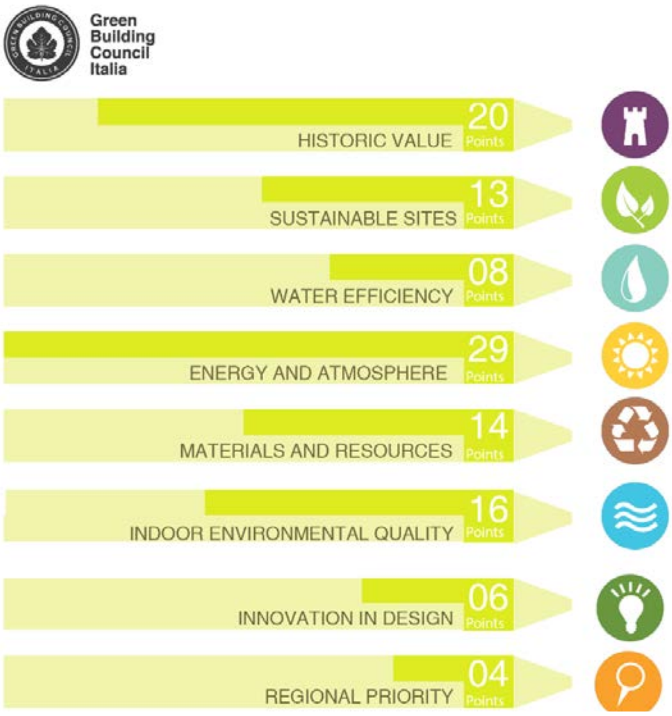

Figure 23: GBC HB Credit categories and maximum possible points. Adapted from: US GBC (2020) and GBC Italia (2020).

GBC Historic Building Manual - introduction

The GBC HB certification scheme is presented in the manual with detailed descriptions for achieving each credit. The GBC Historic Building Manual (further referred to as GBC HB Manual) is made to help the design team understand the evaluation criteria, sustainability concepts, strategies of implementation and documentation to prepare for project certification. It demonstrates practical examples to be used as a reference by designers.

The principles of certification are based on the fact that the monument is the bearer of historic and / or artistic values that have stratified over time. Respecting this complexity while ensuring sustainability, the intervention must operate by adopting the minimum measures for the re - integration of the edifice, in functional, structural and historical sense. Therefore, preserving heritage and promoting sustainability through enhancement of the positive qualities of pre - industrial construction is the main aim for this construction field (GBC Italia, 2017).

Figure 24 shows the diagram of general process for the GBC application. First step includes planning, feasibility study and assigning the responsibilities, followed by collection of information on historical evolution of the building and the on – site analysis. Next step includes registration on the LEED online website and setting up the project. Next step involves detailed credit interpretation, so the aims and objectives in terms of certification level and of the environmental sustainability strategies are clearly defined. The examination of the multiple design options is performed and the definitive project has been prepared. Next step includes the application. The documentation is prepared, mostly in the dynamic PDF form or Excel spreadsheets. Next step is the project review by the GBC, followed by the credit appeal. The final step is the awarding of the Certification.

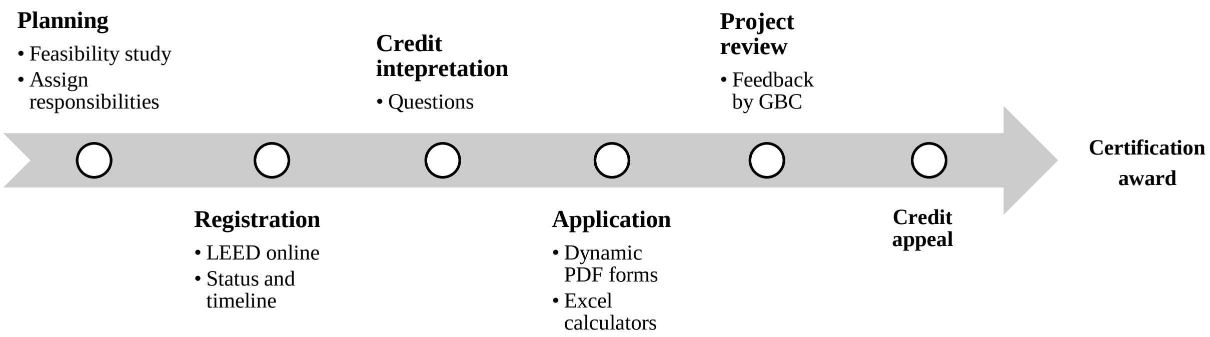

Figure 24: General process for the GBC application. Adapted from: GBC Italia, 2017.

2.2.4. Remarks on HBIM for environmental sustainability

The literature about sustainable heritage and BIM implementation is not extensive, as this topic is still considered as new. One example, BIM4REN project, considers the heritage sustainability holistically. It is being developed specifically for the sustainable restoration goals. It aims to develop a platform for BIM tools to support the energy requalification of buildings, starting with definition of typical workflows. An open platform will integrate all technologies for the end users. The impact will be ensured through standardization activities, training and demonstration (GBC Italia, 2017).

When it comes to assesing the building aspects using BIM, most of the published papers mention energy assesment and simulation tools as valuable feature for the purpose of retrofitting historical buildings. For example, Baggio et al (2017), while using the LEED certification for sustainable restoration, have first anaylsed credit values according to the project goals. Having noticed credits correlation and possibility of applying for multiple credits by using overlapping data, they have seen that energy analysis tools were the key for conservation of the asset. They concluded that sustainability issues in historic buildings can be reduced by well planned project and workframe as well (Baggio et al., 2017). Although there is a fair level of uncertainty regarding adherence to real energy performance assessed through software tools, energy modelling is seen as the optimal way to evaluate behaviour of a historic building. The main reason for the discrepancies between real and simulated performance is the volume of data, since the databases within the software are not exhaustive of the complex information that characterize historic buildings, which implies a certain approximation when inserting parameter values. Further on, the two presented models (See Figure 19, Figure 21) can be applied for GBC HB thematic areas such as Material and Resources, when performing waste and material management. As described tools (internally developed plug – ins and web – BIM integration) require certain level of programming skills, and therefore are not widely available to AEC sector, the detailed analysis is out of the scope of this research. Specific information request for the credits that include monitoring, (for structural monitoring, water metering, energy measurement, and indoor environmental quality) can be acheived by using the described method of linking sensor data with BIM platforms (See Figure 22).

As modelling all architectural elements with high detail level is not necessary in order to use the model, the greater effort should be put in the non - geometric information linked to the BIM objects. The non - geometric information should be structured in a standardised way, in order to keep the requested information consistent (Osello et al., 2018, Scherer and Katranuschkov, 2018). In this way, costly and time consuming process is simplified, and model size reduced. Non – quantifiable information specific to historic buildings, such as its value can be also inserted as a part of the model. Khodeir et al (2016) have studied classification models of heritage values, which can be used for systematic evaluation of historic building, and easily put as parameters when translating information into digital model. The classification by its cultural, use and age values are therefore a part of the holistic process. Considering the workflow, difficulties in changing the habits in the design and management phase, and moving from the traditional 2D representations to the full 3D BIM enabled management have been mentioned as a milestone (Brumana et al, 2019), as well as insufficient international collaboration (Lopez et al., 2018).

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3. GBC HISTORIC BUILDING AND BIM – CRITICAL ASSESSMENT

In this chapter, integration of BIM in the process of GBC Historic Building Certification is assessed. First, on the basis of the described Certification process by the GBC HB Manual (see 2.2.3), a BIM workflow for the holistic approach on the process is proposed. Then, the Manual for obtaining Certification for GBC Historic Building is analysed systematically, examining each of the credit in the context of BIM implementation. This had been done by displaying information requests for each credit, and BIM approach for achieving them. The analysis process is structured in two milestones (Figure 25). First is data collection and categorisation. The GBC HB Manual was revised and requirements for each credit were collected (documentation types, formats, stakeholders). Then, the data was converted into information request in BIM, followed with data categorisation to types in BIM (BIM uses, deliverables, parameters).

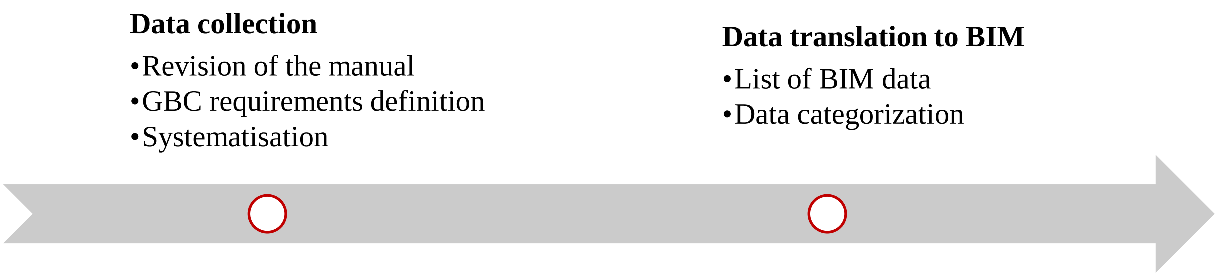


Figure 25: Steps of systematic anaysis

After that, the Historic Value category was further examined, seeing that it is newly introduced in the sustainable certification procedure, and therefore has not been specifically assessed in the found literature. Moreover, Historic Value category is the basis for developing the project for the rest of the credit categories. The examination resulted in the BIM workflow proposed for achievement of its credits. Finally, a specific focus is given to the Prerequisite 1 of the Historic Value. By examining the concrete documentation for its final deliverable, "Identity card of the historic building" and the feasibility of creating them in BIM environment, the basis was formed for its BIM framework proposal displayed in Chapter 4.

3.1. BIM approach on GBC Historic Building Certification

According to previously presented GBC Historic Building certification steps and phases from the GBC HB Manual, the process integrated with BIM is demonstrated in Table 8. Before the project starts, the BIM Execution Plan (BEP) is created, according to Employer Information requirements (EIR). The project goal and the design team are defined and the scorecard for credit achievement is formed. Information management process is established, including the tools to be used, file formats, file transferring formats and the communication environment (CDE). The authoring tool template should be formed as well as one in the CDE. The team should be equipped with skills on using the tools. The first step regarding the project is data collection about the asset, from direct and indirect sources. The analysis off site should be performed and conclusions about the building state are drawn (degradation state and causes, values, preservation needs and techniques). After the data is gathered, Step 2 includes insertion in the BIM tools. Data from the analysis is used to create the BIM model, external libraries and the properties, and form the documentation for the first reports. Third step is to create the intervention project, simulate solutions and choose the best fit option, publishing the final results. Fourth step includes checking and confirming the compliance with certification, after which the documentation can be published and archived.

Table 8: Steps for GBC HB Certification in BIM. Conclusion from GBC HB Manual (2017).

Step 0: BEP
EIR
Define project goals, design team structure, form the credit scorecard
Establish document management process
Establish tools to be used, file formats, file transfer medium, CDE
Form a data framework on established CDE and in authoring tool
Train/enable design team for the tool usage
Step 1: On – site analysis and collecting existing data
Direct information
Indirect information
Analysis in laboratories
Conclusions: state of materials, elements, structure, degradation causes, historical values; Preservation needs and techniques
Step 2: Categorize data an insert in BIM environment
Insert data from analysis
Create external libraries
3D model creation
Prepare analysis results in requested forms (visualizations, reports)
Step 3: Intervention project
Create solutions
Analyze options, perform simulations
Optimize solutions, choose best fit option
Prepare reports
Step 4: LEED compliance
Verify LEED compliance and publish

Step 5: Archive documentation for further use

The holistic BIM workflow for GBC Historic Building Certification was derived using these GBC HB Manual instructions. It is presented in Figure 26. First, the project team should retrieve all the inputs: on – site information, documentation on the building, regulations and relevant product information. Then, the process of forming external database and libraries can start, controlled by the project templates and using the Common data environment (CDE). From there, the HBIM model of the existing state is formed, using the BIM authoring tool and controlled by the authoring tool Template formed for that purpose. When the model of the existing state (Digital twin) is created, the project for the intervention can start. Using the corresponding BIM tools, simulations and analysis for specific categories should be performed. They include: Design analysis, Energy analysis, LCA assessment, Cost analysis, and LEED credit assessment. The analysis results are the feedback for the HBIM model, which is updated until the project meets the satisfactory level. When the final check for the LEED credit application is confirmed, the output – documentation can be published and the project can officially apply for the Certification. Output includes Architectural design, Structural design, Energy analysis, LCA analysis, cost analysis, Construction site design and Operation and Maintenance project (O&M).

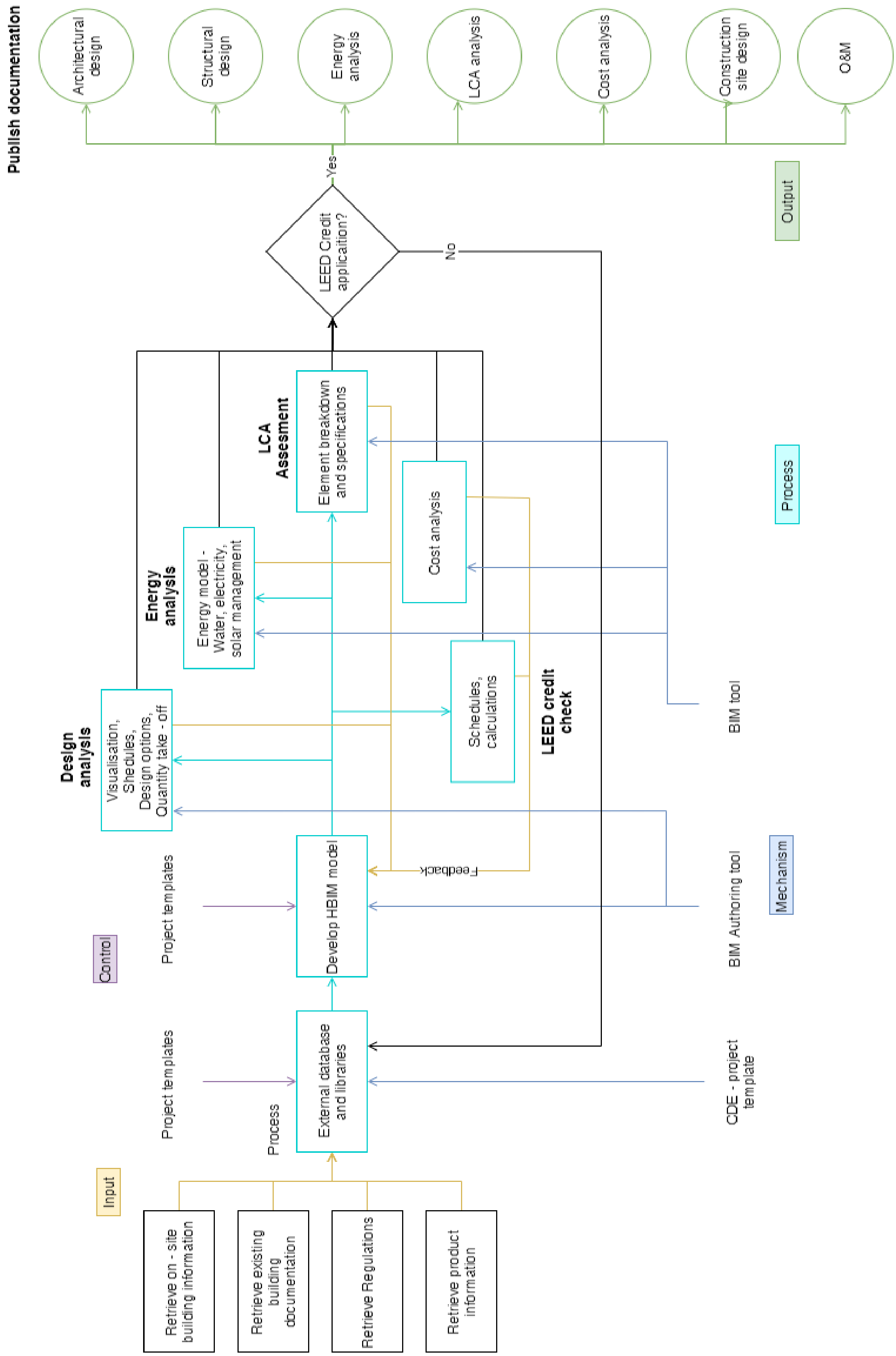


Figure 26: BIM workflow for GBC HB certification.

3.2. Certification Credits – data collection

Next phase of BIM application to GBC HB Certification is analysis of the specific credit requests. All of GBC Historic Building prerequisites and credits are sorted in the credit categories, and are listed in Figure 27. Each prerequisite / credit represents an aspect of the building functionality to be evaluated. Therefore, each of them demands a specific process for design, construction, monitoring or multiple phases, and documenting the achieved results for the submission. The common goal for all the credits is proposing sustainable design solutions while respecting historical value of the building. Each of the thematic areas of credit categories approaches this goal in a different way. In that sense, the analytical table for each credit regarding its approach to design solution has been made. From there, BIM approaches, deliverables and information types were derived. Then, the BIM – GBC integration for each credit can be evaluated and feasibility of implementing BIM can be estimated.

Furthermore, it is important to note that information requested for different credits can overlap, be closely related, and have mutual influence. Credits can have mutual relationship which is described in detail in the GBC HB Manual. Graphical representation of connections between each credit is presented in Figure 28, sorted by colour according to credit category (Legend shown in Table 9), which is based on the information from the GBC Historic building Manual. From the diagram, it is possible to have an overview, estimate the connections between credits in general and decide on the approach for their application. The credits are represented with circles, grouped by their belonging category (one category = one colour) and positioned in one area of the network. Sizes and positions of the circles within the network correspond to the number of connections, which are represented with lines between them. Circles in the centre, for example, have more connections than circles in the rim.

From the diagram, it can be seen that:

- “Innovation in design” (ID) credit category has the most connections (the circle in the centre of the diagram)
- Energy & Aatmosphere (EA) and Historic Value (HV) credit categories have more connections than rest of the categories
- Prerequisites (PR) have more connections than the credits

If the credits are observed chronologically, the first category in the Manual and in design process is Historic Value. It is the core of decision - making process for the subsequent phases. The credits which come as last after each credit assessment in any category belong to the Innovation in design credit category, which enables creative solutions for most of the credit achievements, and are the last step of the assessment, which is the reason of it being at the centre of the network. As the prerequisites are mandatory part of the Certification, and not formed to award any points, it is logical to conclude that they are roots for the application, and therefore have more influence on greater number of the credits.

YES	?	NO			
YES	?	NO	**Historic Value**	Maximum score:	20
YES			Prereq. 1	Preliminary analysis	Mandatory
			Credit 1.1	Advanced analysis: energy audit	1 - 3
				I Level Analysis	*1*
				Advanced analysis: thermography	*2*
				Advanced analysis: thermography and thermic conductance	*3*
			Credito 1.2	Advanced analysis: diagnostic tests on materials and degradation	2
			Credito 1.3	Advanced analysis: diagnostic tests on structures and structural monitoring	1 - 3
				Diagnostic tests on structures	*1 - 2*
				Diagnostic tests on structures and structural monitoring	*2 - 3*
			Credit 2	Project reversibility	1 - 2
			Credit 3.1	Compatible end-use	1 - 2
			Credit 3.2	Chemical and physical compatibility of integrated materials	1 - 2
				Compatibility evaluation with fulfillment of the basic requirements	*1*
				Compatibility evaluation with fulfillment of the basic requirements and at least two complementary requirements	*2*
			Credit 3.3	Structural compatibility	2
			Credit 4	Sustainable restoration site	1
			Credit 5	Scheduled maintenance plan	2
			Credit 6	Specialist in restoration of architectural heritage and landscape	1
SI	?	NO	**Sustainable Sites**	Maximum score:	13
YES			Prereq. 1	Construction activity pollution prevention	Mandatory
			Credit 1	Brownfield redevelopment	2
			Credit 2.1	Alternative transportation: public transportation access	1
			Credit 2.2	Alternative transportation: bicycle storage and changing rooms	1
			Credit 2.3	Alternative transportation: low-emitting and fuel-efficient vehicles	1
			Credit 2.4	Alternative transportation: parking capacity	1
			Credit 3	Site development: open spaces recovery	2
			Credit 4	Stormwater design: quantity and quality control	2
			Credit 5	Heat island effect: non-roof and roof	2
				Outdoor paved surfaces	*2*
				High reflentance roofs	*2*
				Vegetated roofs	*2*
				Combination of high reflectance roofs and vegetated roofs	*2*
			Credit 6	Light pollution reduction	1
YES	?	NO	**Water Efficiency**	Maximum score:	8
YES			Prereq. 1	Water use reduction	Mandatory
			Credit 1	Water efficient landscaping	1 - 3
				Outdoor or irrigation water consumption reduction 50%	*1*
				Outdoor and irrigation water consumption reduction 50%	*2*
				No irragation required	*3*
			Credit 2	Water use reduction	1 - 3
			Credit 3	Water metering	1 - 2
				Mixed use building separated water meter	*1*
				High efficiency appliances and process water systems	*1*
YES	?	NO	**Energy & Atmosphere**	Maximum score:	29
YES			Prereq. 1	Fundamental commissioning of building energy systems	Mandatory
YES			Prereq. 2	Minimum energy performance	Mandatory
YES			Prereq. 3	Fundamental refrigerant management	Mandatory
			Credit 1	Optimize energy performance	1 - 17
				Procedura semplificata per la determinazione della prestazione energetica dell'edificio	*1 - 3*
				Simulazione energetica in regime dinamico dell'intero edificio	*1 - 17*
			Credit 2	Renewable energies	1 - 6
			Credit 3	Enhanced commissioning	2
			Credit 4	Enhanced refrigerant management	1
			Credit 5	Measurement and verification	3
YES	?	NO	**Materials & Resources**	Maximum score:	14
YES			Prereq. 1	Storage and collection of recyclables	Mandatory
YES			Prereq. 2	Demolition and construction waste management	Mandatory
YES			Prereq. 3	Building reuse	Mandatory
			Credit 1	Building reuse: maintaining existing technical element and finishing	3
			Credit 2	Demolition and construction waste management	1 - 2
				Reduction of 75%	*1*
				Reduction of 95%	*2*
			Credit 3	Materials reuse	1 - 2
				Reused materials for the 15%	*1*
				Reused materials for the 20%	*2*
			Credit 4	Building product environmental optimization	1 - 5
				Third part certification	*2*
				Multicriteria certification	*1 - 3*
			Credit 5	Regional materials	1 - 2
YES	?	NO	**Indoor Environmental Quality**	Maximum score:	16
YES			Prereq. 1	Minimum indoor air quality performance (IAQ)	Mandatory
YES			Prereq. 2	Environmental Tobacco Smoke (ETS) control	Mandatory
			Credit 1	Air monitoring	2
			Credit 2	Outdoor air delivery monitoring	2
			Credit 3.1	Construction IAQ management plan: during construction	1
			Credit 3.2	Construction IAQ management plan: before occupancy	1
			Credit 4.1	Low-emitting materials: adhesives and sealants	1
			Credit 4.2	Low-emitting materials: paints and coatings	1
			Credit 4.3	Low-emitting materials: flooring systems	1
			Credit 4.4	Low-emitting materials: composite wood and agrifiber products	1
			Credit 5	Indoor chemical and pollutant source control	1
			Credit 6.1	Controllability of systems: lighting	1
			Credit 6.2	Controllability of systems: thermal comfort	1
			Credit 7.1	Thermal comfort: design	1
			Credit 7.2	Thermal comfort: verification	2
YES	?	NO	**Innovation in design**	Maximum score:	6
			Credit 1	Innovation in design	1 - 5
			Credit 2	GBC Accredited Professional	1
YES	?	NO	**Regional priority**	Maximum score:	4
			Credit 1	Regional priority	1 - 4
			Total	Maximum score:	110

Figure 27: GBC Histroic Building credit list. Source: GBC Italia, 2016.

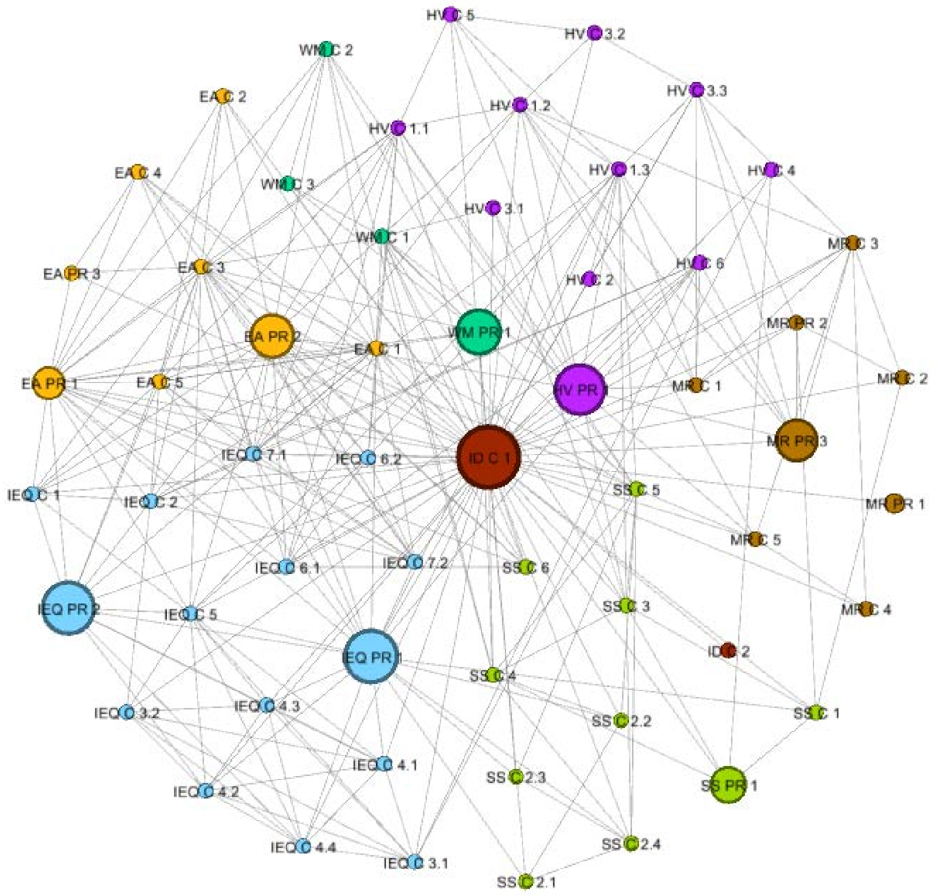


Figure 28: Diagram, network of the credits.

Table 9: Diagram legend, representation of credits by the color of the corresponding credit category.

GBC HB Credit Categories	Abbreviation	Color
Historic value	HV	
Site sustainability	SS	
Water Efficiency	WE	
Energy and Atmosphere	EA	
Materials and Resources	MR	
Indoor environmental quality	IEQ	
Innovation in Design	ID	

Prerequisite	PR
Credit	C

3.3. Certification credits – systematic analysis

3.3.1. Introduction to systematic analysis

In order to map the information requests from the GBC HB Manual to BIM information types, the requests have been analysed systematically, by each credit, using the Exel sheet table to extract key information, categorizing it according to various criteria. Each criteria is represented by a column. Columns are grouped by the topic analysed. First group (Table 10), GBC HB Manual requests, contains columns with information regarding credit names, project phase they belong to, their purposes, required information (what should be delivered) and deliverable formats (drawings, calculations, reports and similar) to be listed. Deliverables are in this case the outputs for BIM software.

Table 10: First group of systematic analysis. Example for HV PR 1. Source: author.

GBC HB Manual requests					
No	**Name**	**Project phase**	**Purpose**	**Requested information by GBC HB**	**Requested information formats = output**
01 Historic Value					
HV PR 1	Preliminary analysis	D	Recognize and characterize value of the historical building and its elements.	Construction phases and existing functions; Structural schemes; Material consistency and construction techniques; Matrix of stratigraphic successions; Macroscopic forms of degradation; System schemes;	Dynamic PDF Form with attachments; Schematic (2D) drawings; Photographs;

Next column group is shown in Table 11 and represents the main stakeholders in the application process. It checks if any of the listed stakeholders in each column needs to be involved in the particular credit application. For the purspores of this dissertation, only the stakeholderts which are considered to be crucial for the process are listed. They represent specific fields that are included in the process of application for the certification, and are, by the column order: Archaeologist (ARCHAE.), Laboratory specialist (LAB. SPEC.), Restoration architect (RA), Urban Planner (UP), Specialist engineer (SPEC. E.), Structural Engineer, Mechanical engineer (MEP), External bodies (EB). If the stakeholder is involved in the particular credit application process, the corresponding cell is marked with an “x”. Otherwise, the cell is left blank.

Table 11: Second group of systematic analysis. Example for HV PR 1. Source: author.

Stakeholders							
ARCHAE.	LAB. SPEC.	RA	UP	SPEC. E.	SE	MEP	EB
x		x			x	x	x

Table 12 contains the third and fourth group. "BIM Uses" group contains BIM uses according to Penn state, and BIM excellence. Penn State listed and explained 25 uses from the BIM Project Execution Planning Guide (Penn state, 2019), which have been used to fill the "BIM uses by Penn State" column. BIM excellence had different approach for defining BIM model uses, by grouping them into three categories: General, domain and Custom model uses (BIM excellence, 2020). Since doman uses are industry specific, they have been used for the systematic analysis of this disseratation. The domain uses by BIM excellence include the following areas: Capturing and representing, Planning and Designing, Simulating and Quantifying,Constructing and Fabricating, Operating and Maintaining, Monitoring and Controlling, Linking and Extending (BIM excellence, 2020). If the BIM use published by the mentioned sources is recognized as useful for the credit application, it is written in the corresponding column cell. The "Example" column contains listed distinguishing BIM solution for particular credit found in the published literature.

Table 12: Third and fourth group of systematic analysis. Example for HV PR 1. Source: Author.

BIM Uses								Example
	Domain model uses by BIM excellence							
BIM uses by Penn State	Capturing and Representing	Planning and Designing	Simulating and Quantifying	Constructing and Fabricating	Operating and Maintaining	Monitoring and Controlling	Linking and Extending	Specific solution from the literature
Existing Condition modelling; Programming; Record keeping;	Laser Scanning, Photogrammetry , Surveying, 2D Documentation, Record Keeping	n/a	n/a	n/ a	n/a	n/a	BIM/We b extension ; BIM/ER P Linking	Semantic-web integratio n in BIM model;

Table 13 contains the “BIM aspects” group. It first lists the general BIM approach for the credit. Then, BIM information structure is listed (e.g. weather if it is model – based, object – based, element – based or similar). After that, the Information managing process is described briefly, followed by the BIM Platforms list needed to complete the process. Next column checks if external documents (not – BIM – based) need to be inserted (such as Excel, pdf, xml). The last column of the group, “BIM result” lists the expected results the BIM process provides.

Table 13: Fifth group of systematic analysis. Example for HV PR 1. Source: author.

BIM aspects					
BIM Approach	**BIM Information structure**	**Information managing process**	**BIM Platforms**	**Excel calculator, xml**	**BIM Result**
Collect, organize and manage information in a digital database.	Model - based	Conversion of numerical model to parametric model, insertion and categorization of collected information from multiple databases;	Point cloud software, authoring tool; Model viewer;	x	Digital twin with indications for refurbishment.

Sixth group, represented in Table 14, analyses BIM instruments more closely. Columns check if there is calculation in authoring and / or external platform needed, if there is any analysis tool involved, and if the credit comprises multiple project stages. If any of the information is needed for the credit application process, the corresponding cell is filled with an “x”. If it is not, the cell is left blank.

Table 14: Sixth group of systematic analysis. Example for HV PR 1. Source: author.

BIM instruments				
Calculation in BIM Authoring platform	**Calculation in external platform**	**BIM Analysis tool**	**Multiple BIM software**	**BIM for Multiple project stages**
x				

Table 15 containst the seventh and the last group, “Notes”. It consists of personal comments and evaluation of BIM integration for each credit. Evaluation has been formed based on personal conclusions from the systematic analysis and its scale ranges from 1 – 5. The evaluation scale legend is shown in Figure 29. Grades “1” and “2” are serving as negative evaluations. Grade “1” is given if BIM is not helpful in the process of credit application. Grade “2” is given when it is noticed that BIM is helpful only for the record keeping and retrieval purposes, but not for tthe design process or analysis. Grade “3” gives neutral value. It is given when it appears that BIM can help in a part of the credit application process, because some information can be retrieved from the model for the previous credits, or in similar situations when BIM optimization is not crucial for the particular credit, but can be performed since there are other credits that already benefit from BIM greatly. Grades “4” and “5” serve as positive evaluations. Grade “4” is given when BIM is helpful in the process of the credit application, but mostly for linling external information sources (e.g. manufacturer information, historical data). Grade “5” is given when BIM is helpful in the whole process, for collecting and sorting large amount of data from multiple sources into one environment and manipulating it for the purposes of the credit application.

1 — BIM is not helpful in the process of credit application

2 — BIM is helpful for record keeping and retrieval purposes only

3 — BIM can help in a part of the credit application process (e.g. some information can be retrieved from the model of the previous credits)

4 — BIM is helpful in the process of credit application, mostly by linking external information sources

5 — BIM is helpful in the whole process, collecting and sorting large amount of data from multiple sources into one

Figure 29: Evaluation scale legend. Source: author.

Table 15: Seventh group of systematic analysis. Example for HV PR 1. Source: author.

Notes	
Comments	**BIM - GBC HB credit compatibility**
HBIM model can be the structured information base point for further project development. It can be used as a record of a stage of building's life as well. Requires collaboration between multiple stakeholders.	5

The result of categorizing information in more detail should allow the GBC consultant to discuss with the IT professional or BIM expert using the same language. Thus, the following paragraphs will demonstrate the data collection phase of the analysis process more closely.

3.3.2. Brief revision of each credit category

Next paragraphs will describe the purposes and needs of each credit, grouped by the corresponding credit category. The description is structured in the tables, to give a clear overview.

1. *Historic Value (HV)*

Purpose of this category is identifying, categorizing and preserving the original historical and cultural value. Historic Value category has been made to encourage design solutions that are: non-invasive, reversible, consistent, compatible, and durable (GBC Italia, 2017). Table 16 shows information requests for each credit of Historic Value category.

Table 16: GBC HB Manual - information requests for each credit of Historic Value category. Source: author.

No	Name	Phase	Purpose	Requested information by GBC HB
HV PR 1	Preliminary cognitive investigations	D	Recognize and characterize value of the historical building and its elements.	Construction phases and existing functions; Structural schemes; Material consistency and construction techniques; Matrix of stratigraphic successions; Macroscopic forms of degradataion; System schemes;
HV C 1.1	Advanced analysis: energy audit	D	Know the energy status of the building in order to guide the design strategies for performance improvement and architectural conservation. Recognize and characterize existing systems to preserve, improve and optimize, contributing to the reduction of energy consumption and increasing occupant comfort.	Building systems typology, classification, degradation state and potential mainenance;
HV C 1.2	Advanced analysis: diagnostic tests on materials and degradation	D	Recognize and characterize the chemical-physical nature of historical material by identifying the main causes of degradation, in order to improve quality occupant comfort and durability	Analysis results; graphical representation of analysis location and the result summary; Materials categorization;

HV C 1.3	Advanced analysis: diagnostic tests on structures and structural monitoring	D	Recognize and evaluate the static-resistant characteristics of the building: materials, static patterns and global behaviour, for further interventions - static consolidation and any strengthening seismic interventions. Minimize replacement of historical elements with new structures or materials (e.g. foundations, load-bearing walls, arches, vaults, wooden structures, metal and reinforced concrete, anchor plates etc.).	Structural elements geometry, classification (types, material properties..), detail and deformation classification
HV C 2	Project reversibility	D	Minimize insertions, replacements or additions, and the signs of suture between historical and new structures.	Checklists, Calculation and analysis results, sums of cost;
HV C 3.1	Compatible end-use	D	Identify compatible intended uses with conservation and positive effects on the settlement dynamics from a social, cultural, economic and human health perspective, creating spaces for the community.	Space usage compatibility, Calculation results, Report;
HV C 3.2	Chemical and physical compatibility of integrated materials	C	Evaluate the compatibility of restoration mortars and original materials, considering the aesthetic, chemical-mineralogical and physical-mechanical requirements.	Check list of diagnostic investigations of materials: type of investigation, standard followed, instruments used; Report: results od laboratory and on – site analysis, attaching relevant information Technical sheets of restoration materials, from manufacturer (attached to report)
HV C 3.3	Structural compatibility	C	Minimize invasiveness of intervention and resources by making the most of the static characteristics of existing structures – considering loads and maintenance.	State of structure degradation - analysis results; Design solutions and compatibility demonstration; Estimated metric calculation; Cost estimation; Schematic drawings;
HV C 4	Sustainable restoration site	C	Reduce the negative environmental effects of activities by adopting strategies for restoration techniques and reducing the use of non - renewable resources during construction.	Construcion site sustainable restoration plan; Techniques;
HV C 5	Scheduled maintenance plan	C	Reduce long-term intervention costs (referring to site management) lowering economic impact of small maintenance interventions. Ensure durability of the building by providing the occupants adequate information and maintenance measures.	Risk Assesment, Maintenance Plan;

2. Site Sustainability

Focus of this category is relationship between the building and the surrounding environment, namely the impacts that the building can generate. The credits aim to mitigate the damages resulting from a previous inattentive planning. The buildings' re - functionalization can constitute an important opportunity to revitalize degraded urban areas by introducing sustainable design and management practices (GBC Italia, 2017). Table 17 shows information requests for each credit of Site Sustainability category. Category topics are:

1. Construction activity pollution prevention
   Definition of sustainable construction site activities.
2. Brownfield redevelopment
   Recovering polluted spaces and designing sustainable landscape.
3. Alternative transportation
   Encouraging the use of public and alternative transport.
4. Rainwater Management
   Controlling the rainwater flow rate, favouring ground infiltration and rainwater reuse.
5. Heat island effect
   Using adequate materials for external surfaces.
6. Light pollution reduction
   Decrease night light pollution and negative impact of artificial light on the façade.

Table 17 : GBC HB Manual - information requests for each credit of Site Sustainability category. Source: author.

No	Name	Phase	Purpose	Requested information by GBC HB
SS PR 1	Construction activity pollution prevention	C	Reduce pollution from construction activities by controlling soil erosion, waterway sedimentation, outflow of pollutants into the sewer or on the ground, airborne dust, protection of acoustic comfort and the health of the users during the processing phases.	Erosion and Sediment Control Plan; Photographic and inspection Report; Report on work progress and implemented measures of ESC plan;
SS C 1	Brownfield redevelopment	C	Correct the causes of degradation or pollution and restore the health and safety of the site.	Official environmental specification on site liabilities; Technical report on identified materials; Complete pollutant management plan documentation; Reports on performed measures;
SS C 2.1	Alternative transportation: public transportation access	D	Reduce pollution caused by car traffic.	Official documentation on public transportation project; Documentation on parking area of car sharing service; Site plan indicating public transport station / car sharing service parking distance from the buildings' entrances; Neighborhood plan indicating pedestrian relevant paths;
SS C 2.2	Alternative transport: bicycle racks and changing rooms	D	Promote the use of environmentally sustainable transportation.	Plan indicating the location and quantity of bicycle and locker rooms; Graphical presetation of bycicle storage; Number of storage rooms according to occupant number; Documentation of agreement with the bike sharing service (optional);

SS C 2.3	Alternative transport: low - emitting and fuel - efficient vehicles	D	Reduce environmental impact generated by car traffic.	Floor plan of designed parking space; Number of designed parking spaces / alternative fuel vehicles / filling stations, occupancy number (FTE); Documentation of usage procedures (equipment use, discounts..); Equipment information;
SS C 2.4	Alternative transportation: parking capacity	D	Reduce environmental impact generated by car traffic.	Amount and type of existing and project parking places; Type of infrastructure and / or support programs for carpooling and vanpooling; Information on the planned parking capacity, number of preferential parking spaces, number of FTEs, zoning requirements of the local regulations or copies of brochures that provide support structures for the carpooling and vanpooling;
SS C 3	Site development: open spaces recovery	D	Recover historical parks and gardens by restoring the original conditions for native plants, natural habitats, wetlands and surface water bodies altered by human action.	Amount of open space expected / required; Calculation results; Intervention plan;
SS C 4	Stormwater design: quantity and quality control	D	Llimit disruption of natural cycle by managing the outflow of rainwater, reducing waterproof covering surfaces, increasing of infiltrations on site, reducing pollution from the stormwater outflow and the elimination of contaminants. Enhance the recovery of existing historical management systems.	Rainwater Management Plan, Best Management Practices (BMPs); Volume of the surface runoff; Rainwater assessment report; List of rainwater management strategies in relation to weather events; List of the structural control systems; Description of the pollutants removed; Percentage of annual precipitation treated and how it does not compromise the historical value; Optional narrative description of each particular circumstance;
SS C 5	Heat island effect: non-roof and roof	D	Reduce the effects of the local heat island with adequate design respecting the existing typological-morphological balance.	Plan highlighting shaded paved surfaces; Quantities of paved surfaces contributing to credit; Information of compliant surfaces (e.g. SRI values for reflective flooring materials); Elaborate roof graphics highlighting all surfaces covered with reflective materials or with green roof systems; List of covering materials the project and their coefficient of solar reflection, emittance, the solar reflection index (SRI) and the inclination in which they are arranged with respect to a horizontal surface; Documentation that certifies the characteristics of the product;
SS C 6	Light pollution reduction	C	Retain architectural character of the building, minimize the light scatters generated by the building and the site, reduce sky-glow to increase night sky access, improve nighttime visibility through glare reduction and reduce development impact from lighting on environment.	Use the digital model to demonstrate the achievement of the expected lighting parameters, both within the area and at the boundary of the project site and beyond. Calculate the vertical illuminance levels at the site boundary up to a height equal to the highest lighting fixture on the site;

3. Water Efficiency

Through this category, in addition to reducing water consumption, it is possible to enhance the contribution of restored pre - industrial systems for water management, including the collection and management of rainwater, and improvement of the efficiency of fountains and games of water in external spaces. Restoration of the technical components in historic systems requires the knowledge of traditional techniques, linking them with modern culture of saving water resources. Thus, the options include renovating the existing systems or adequately integrating new technologies. Table 18 shows information requests for each credit of Water Efficiency category. Category topics are:

1. Water use reduction
2. Water efficient landscaping
3. Water metering

Table 18: GBC HB Manual - information requests for each credit of Water Efficiency category. Source: author.

No	Name	Phase	Purpose	Requested information by GBC HB
WE PR 1	Water use reduction	D	Increase water efficiency in buildings to reduce the burden on municipal water supply and wastewater systems.	Type and number of occupants; Manufacturer data showing the water consumption indexes, the manufacturer and model of each equipment and accessory; List of plumbing fixtures by usage groups, if applicable. Each usage group defined; Flow rates calculations results.
WE C 1	Water efficient landscaping	D	Limit the use of drinking water, surface or subsoil water near the building, for irrigation / ornamental purposes. Restore the original rainwater collection systems (cisterns, tracing of channels and drains, etc).	Soil analysis (soil and climate) - plant species and landscape design that uses native and adaptable plants capable of reducing or eliminating the need for irrigation; Water consumption levels calculations; Calculations (percentage of water use reduction); irrigation management plan; Rain water collection plan; Manufacturer data and maintenance information;
WE C 2	Water use reduction	D	Further increase water efficiency within buildings to reduce the burden on municipal water supply and wastewater systems.	Type and number of occupants. Manufacturer data showing the water consumption indexes and the model of each equipment and accessory; List of plumbing fixtures by usage groups; Each usage group defined; Flow rates calculations results;

WE C 3	Water metering	D	Support the management of water resources, monitor losses and identify additional water saving opportunities thanks to the accounting of the volumes of water consumed	Summarized water consumption for each system; Protocol for data collection procedures and schedules; Manufacturer data; Calculations results;

4. *Energy and Atmosphere*

GBC Historic Building® innovatively considers energy efficiency and retrofit as a form of building protection rather than alteration of the original value. They consider that it is possible to improve the building performance respecting its value. The level of improvment depends on the asset, and even the slightest moderations represent a step towards reducing energy consumption and improving the health of its users. In the intervention on the historical context, the energy systems have a critical role. If they can achieve a significant improvement in overall energy performance, they must be integrated compatibly with the asset. Table 19 shows information requests for each credit of Energy and Atmosphere category. Category topics are:

1. Commissioning of building energy systems
   Deepening the knowlege gained from the systems analysis for Historic Value category - designing a holistic project for optimizing energy performance, including commissioning actions demonstrating correct instalation and operation of the systems, as well as their monitoring, controlling and maintaining.
2. Refrigerant fluids management
   This topic rewards projects which limit the use of appliances with polluting chemicals.
3. Renewable energies
   Aim is to integratie elements which use renewable energy (solar, wind, biofuels and similar). It is suggested to use renewable energy produced off site, through contracts of certified supply (green energy), as an alternative to physical integration.

Table 19: GBC HB Manual - information requests for each credit of Energy and Atmosphere category. Source: author.

No	Name	Phase	Purpose	Requested information by GBC HB
EA PR 1	Fundamental commissioning of building energy systems	C	Verify that the energy-related systems are installed, calibrated and perform according to the OPR, BOD and construction documents.	OPR; List od systems to be commissioned; BOD; Specific Requests for Commissioning activities; Commissioning plan; Final report on Commissioning activities; Systems manuals;
EA PR 2	Minimum energy performance	D	Establish a minimum level of improvement of energy efficiency r to reduce the economic and environmental impacts of energy	ASHRAE reference forms; Project climate zone; Calculated energy consumption by type of building (project and reference); Compliance with current

			consumption, respecting the cultural value.	legislation; Final report of annual energy consumption;
EA PR 3	Fundamental refrigerant management	D	Reduce the destruction of stratospheric ozone.	Where applicable - plan for the elimination of CFC and HCFC based refrigerants; Manufacturers documentation for HVAC & R systems;
EA C 1	Optimize energy performance	D	Establish a minimum level of improvement of energy efficiency r to reduce the economic and environmental impacts of energy consumption, respecting the cultural value.	ASHRAE reference forms; Project climate zone; Calculated energy consumption by type of building (project and reference); Compliance with current legislation; final report of annual energy consumption;
EA C 2	Renewable energies	C	Promote production of renewable energy sources, in order to reduce the environmental and economic impact.	Types of renewable energy on and off - site; Calculated produced energy of each renewable energy source on site; Documentation of any incentive that was provided to support the installation of renewable energy systems in place. Contract for the purchase of certified green energy product; For complex of buildings for which certified renewable energy is purchased by others, documentation showing that the quantity of renewable energy purchased is sufficient to meet credit requirements;
EA C 3	Enhanced commissioning	C	Start the Commissioning process in the early design stages and carry out additional activities after the performance checks of the systems.	OPR; List od systems to be commissioned; BOD; Specific Requests for Commissioning activities; Commissioning plan; Final report on Commissioning activities; Systems manuals;
EA C 4	Enhanced refrigerant management	D	Minimize direct contributions to global warming.	Where applicable - a plan for the elimination of CFC and HCFC based refrigerants; Manufacturers documentation used for HVAC & R systems;
EA C 5	Measurement and verification	C	Provide monitoring of the building's energy consumption during operation.	Measurement and verification plan; Indications of meters positions;

4. *Materials and Resources*

The objective of this category is preserving historical material, in compliance with the principles of sustainability - reducing extraction of virgin materials and soil consumption. If the restoration project involves integration or partial replacement of technical elements, compliance with the credits of this credit category ensures that the materials have virtuous impacts from an environmental, economic and social point of view, and if possible, are procured from the neighbouring locations. Table 20 shows information requests for each credit of Materials and Resources category. Category topics are:

1. Waste reduction and management
   Implementing plans that control material movement during construction – selection, separation, storage, diversion from landfilling or incinerators with the goal of their recycling.
2. Buildings reuse

Minimization of using new sources and elements.

3. Materials reuse
   Minimization of using new materials by reusing the ones from the building or with compatible characteristics.
4. Sustainable materials selection
   Using products with defined life cycle information that meets the set criteria, and have been extracted, processed and produced at a limited distance, in order to reduce the impacts of transport and support local economies.

Table 20: GBC HB Manual - information requests for each credit of Materials and Resources category. Source: author.

No	Name	Phase	Purpose	Requested information by GBC HB
MR PR 1	Storage and collection of recyclables	D	Reduce the amount of waste produced by occupants, which are transported and disposed in landfills.	Floor plan highlighting areas for the collection and storage of recyclables, containers with the related capacities, routes for the collection of waste; Calculations according to the tables provided by the local authorities (where possible); Alternatively - documentation certifying the quantity of waste produced and that the container and the number of withdrawals are appropriate for the quantities of waste produced; Demonstration that collection frequencies of the provider;
MR PR 2	Demolition and construction waste management	C	Divert demolition and construction waste from landfilling or incineration facilities. Redirect recyclable resources back to the manufacturing process and reusable materials to appropriate sites.	Demolition and Construction Waste Management Plan; Waste schedule - types, quantities sent to landfills or diverted; Percentage of diverted waste;
MR PR 3	Building reuse	C	Extend the life cycle of the existing building stock, in relation to the production and transport of materials.	Identity card of the historic building (HV PR 1); Structural elements scheduling and categorization;
MR C 1	Building reuse: maintaining existing technical element and fi nishing	C	Extend the life cycle of the existing building stock, in relation to the production and transport of materials.	Identity card of the historic building (HV PR 1); Structural elements scheduling and categorization;
MR C 2	Demolition and construction waste management	C	Divert demolition and construction waste from landfilling or incineration facilities. Redirect recyclable resources back to the manufacturing process and reusable materials to appropriate sites.	Demolition and Construction Waste Management Plan; Waste schedule - types, quantities sent to landfills or diverted; Percentage of diverted waste;

MR C 3	Materials reuse	C	Reuse building materials and products to reduce the demand for virgin materials and the production of waste, limiting the impacts associated with the extraction and processing of raw materials.	List of reused or recovered materials used in the project and the related costs; Construction costs for the materials or of actual material costs, excluding labour and equipment costs;
MR C 4	Building product environmental optimization	C	Encourage the use of products and materials with known information of impacts on the life cycle and virtuous impacts from an environmental, economic and social point of view.	EPD or LCA with third - party verification or manufacturer declaration; Multi-criteria certifications (FSC, PEFC, etc.);
MR C 5	Regional materials	C	Support the use of indigenous resources and reduce the environmental impacts of transportation. Encourage the use of transport with limited environmental impact such as rail or ship transport.	List of purchased products that are extracted, processed, produced or recovered at a limited distance; Product specification (manufacturer names, costs, distances between the site and the production site, distances between the site and the extraction site); Where appropriate, material certificates documenting that the origin and processing of the material occurred within the adequate radius; Where appropriate, list of the costs of materials, excluding labour and equipment, according to the local standards;

5. *Indoor Environmental Quality*

To achieve points for this category, it is possible to follow one of two paths: maximum protection of historical architecture or maximization of occupants' comfort. This dual approach respects historic elements simultaneously reaching the maximum comfort level and quality of the indoor air, making the most of the potential offered by the surrounding conditions. To control the air quality, design team is requested to monitor and improve the ventilation of the rooms, through natural, mechanical or hybrid ventilation based on the context of application and the objectives to be achieved. Table 21 shows information requests for each credit of Indoor Environmental Quality category.

Category topics are:

1. Indoor air quality improvement
   Introducing ventilation systems to guarantee the defined air flow rate and control of contaminants.
2. Control of contamination sources
   Control the sources such as tobacco smoke, carbon - dioxide concentration, humidity, radon, radioactive gas from the subsoil.
3. Low – emitting materials

Favour the use of materials and products with reduced release of volatile organic compounds (VOC). Provide adequate programming, to facilitate the decontamination of the rooms before occupation.

4. Controllability of systems
   Allow the occupants to customize the conditions of thermal comfort and lighting, choosing the settings within a certain range of values.

Table 21: GBC HB Manual - information requests for each credit of Indoor Environmental Quality category. Source: author.

No	Name	Phase	Purpose	Requested information by GBC HB
IEQ PR 1	Minimum indoor air quality performance (IAQ)	D	Achieve air quality in confined spaces to protect the health of the occupants, the conservation of the building, satisfy the comfort and cultural value.	Demonstration of compliance with the applicable sections of UNI EN 15251:2008;
IEQ PR 2	Environmental Tobacco Smoke (ETS) control	D	Prevent / minimize exposure of building occupants, indoor surfaces and ventilation air distribution systems to environmental tobacco smoke (ETS).	Anti-smoking policy, identifying areas where smoking is prohibited; Documentation (e.g. floor plans and renderings) visually indicating areas where the smoking policy is active; Monitor and record data for each smoking area;
IQ C 1	Air monitoring	D	Provide capacity for ventilation system monitoring to help sustain building conservation and occupant well-being.	CO2 monitoring sensors in plans, with diagrams, elevations (if necessary), and data sheets; Ventilation systems specifications, with monitoring; Alarm system according to UNI 10339 for mechanical ventilation systems; Manufacturer's guidelines for system calibration;
IQ C 2	Outdoor air delivery monitoring	D	Evaluate minimum external air flow rate according to a contaminant or reference parameter, conserving the building or quality of indoor air.	*Follow the chapter 8.3 of UNI 10339;* Mechanical equipment scheme / ventilation design project;
C IQ 3.1	Construction IAQ management plan: during construction	C	Reduce problems of IAQ deriving from restoration process; guarantee conservation / comfort and well-being of construction workers and occupants.	Indoor Air Quality Management Plan (IAQ) for demolition and construction phase; Photographic documentation of the practices of IAQ followed and implemented;

IQ C 3.2	Construction IAQ management plan: before occupancy	C	Reduce problems of IAQ deriving from restoration process; guarantee conservation / comfort and well-being of construction workers and occupants.	Indoor Air Quality Management Plan (IAQ), the replacement of all air filtration systems; Indoor air quality test results and HVAC systems control; For projects that complete a flush-out procedure, record dates, occupancy, air flow rates, internal temperature and humidity and other special considerations; For projects that complete the Indoor Air Quality Test, a copy of the test report and verification that all the required contaminants respond and are reported in the correct unit of measurement;
C IQ 4.1	Low-emitting materials: adhesives and sealants	C	Reduce contaminants in the building that are odorous, irritating and / or harmful to comfort and well-being of installers and occupants.	List of each interior adhesive, sealant, cement product, parquet paint and primer used in the project, manufacturer's name, product name, specific VOC data for each product (in g / m3), and the corresponding VOC value allowed by the reference standard; If the VOC budget approach is used, indicate the quantity of product used; Material safety data sheets (MSD cards), certificates and test results;
C IQ 4.2	Low emissive materials: paints and coatings	C	Reduce contaminants in the building that are odorous, irritating and / or harmful to comfort and well-being of installers and occupants.	List of each interior adhesive, sealant, cement product, parquet paint and primer used in the project, manufacturer's name, product name, specific VOC data for each product (in g / m3), and the corresponding VOC value allowed by the reference standard; If the VOC budget approach is used, indicate the quantity of product used; Material safety data sheets (MSD cards), certificates and test results;
IQ C 4.3	Low emissivity materials: flooring	C	Reduce contaminants in the building that are odorous, irritating and / or harmful to comfort and well-being of installers and occupants.	List of each interior adhesive, sealant, cement product, parquet paint and primer used in the project, manufacturer's name, product name, specific VOC data for each product (in g / m3), and the corresponding VOC value allowed by the reference standard; If the VOC budget approach is used, indicate the quantity of product used; Material safety data sheets (MSD cards), certificates and test results;
IQ C 4.4	Low emission materials: composite wood products and vegetable fibers	C	Reduce contaminants in the building that are odorous, irritating and / or harmful to comfort and well-being of installers and occupants.	List of each interior adhesive, sealant, cement product, parquet paint and primer used in the project, manufacturer's name, product name, specific VOC data for each product (in g / m3), and the corresponding VOC value allowed by the reference standard; If the VOC budget approach is used, indicate the quantity of product used; Material safety data sheets (MSD cards), certificates and test results;
IEQ C 5	Indoor chemical and pollutant source control	D	Minimize the contaminants identified as problematic for building conservation or for occupant comfort and IAQ.	Documentation on the location, dimensions of permanent dirt barriers and doormats; Tabular list of dirt barriers; Building maintenance plan that indicates the cleaning and maintenance of the permanent dirt barriers and doormats, necessary to intercept the contaminants brought inside the building; List that identifies areas or premises that need to be partitioned; Detail the partitions from the floor ceiling or ceiling conditions in rooms where contaminants are known; Updates during project phases;

IEQ C 6.1	Controllability of systems - lighting	D	Provide users the possibility of adjusting the lighting system compatible with their needs, compatible with the protection of the building.	Floor plan indicating the location, zoning, and the type of lighting control provided; Include furniture layouts, individual and / or shared work areas; Information of the lighting design, of sensors and lighting controls;
IEQ C 6.2	Controllability of systems: thermal comfort	D	Provide a high level of thermal comfort system control, by individuals or groups in multi-occupant spaces, compatible with the protection of the building.	For the controls of the individual workstations - list of the total number of single workstations and the devices for regulating thermal comfort; For spaces shared by multiple occupants - list of the total number of spaces shared by multiple occupants and a description of the thermal comfort adjustment devices installed;
IEQ C 7.1	Thermal comfort: design	D	Provide a thermally suitable environment for the building conservation / occupants well-being.	Client requests regarding thermal comfort; Level of metabolic activity; Criteria adopted for the maintenance of environmental conditions aimed at the conservation of the building; Summarized operational procedures for construction systems; General information, replacement plans, maintenance, operating instructions and a maintenance and control program; Mechanical design project, highlighting initial hypotheses and the calculation of the loads of the HVAC systems; Documentation (functional diagrams, plans, sections, calculations) of all registers and room terminals, specifying type, flow rate, radiant value; Elements that can have a significant effect on thermal comfort and storage conditions; Spaces outside controlled comfort zone and the location of all the adjustment controls;
IEQ C 7.2	Thermal comfort: verification	D	Provide monitoring of the environmental parameters of the building.	If 20% of the occupants of the building express dissatisfaction with the conditions of thermal comfort, a written plan containing the corrective action; Survey on thermal comfort to be administered to the occupants of the building.

3.4. Data translation to BIM

The following tables explain second part of systematic analysis – data translation to BIM and categorisation of information types. For demonstration purposes, the table for the Historic Value category will be presented, and the rest of categroies are part of the Appendix 1 - 4. The tables are divided according to the previously described column groups (See section 3.3.1).

It can be seen in Table 22 that all the listed stakeholders are involved for this credit category in general. Each credit involves different combination of the stakeholders.

Table 22: Historic Value – Stakeholders. Source: author.

Credit		Stakeholders							
No	**Name**	**ARCHAE.**	**LAB. SPEC.**	**RA**	**Urban planner**	**SPEC. E.**	**SE**	**MEP**	**External bodies**
01 Historic value									
HV PR 1	Preliminary analysis	x		x			x	x	x
HV C 1.1	Advanced analysis: energy audit		x					x	
HV C 1.2	Advanced analysis: diagnostic tests on materials and degradation	x	x	x			x	x	
HV C 1.3	Advanced analysis: diagnostic tests on structures and structural monitoring		x				x		
HV C 2	Project reversibility			x			x		
HV C 3.1	Compatible end-use			x	x				x
HV C 3.2	Chemical and physical compatibility of integrated materials		x	x					
HV C 3.3	Structural compatibility						x		
HV C 4	Sustainable restoration site			x			x	x	x
HV C 5	Scheduled maintenance plan			x			x	x	x
HV C 6	Specialist in architectural and landscape heritage	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table 23 shows the noticed BIM uses for Historic Value category. “Record keeping” and “2D documentation” are involved in each credit, and Linking and Extending group of the uses is noticed to be useful for the process as well. Monitoring and capturing group can be used for the existing condition monitoring and documenting the results. Most of the observed uses for this category involve documenting, monitoring, representing and sharing. Simulating and designing BIM uses are found to be on a general level, and take the primary role in the further credit categories.

Table 23: Historic value - BIM uses.

		BIM Uses						
		Domain model uses by BIM excellence						
No	BIM uses by Penn State	Capturing and Representing	Planning and Designing	Simulating and Quantifying	Constructing and Fabricating	Operating and Maintaining	Monitoring and Controlling	Linking and Extending
HV PR 1	Existing Condition modelling; Programming; Record keeping;	Laser Scanning, Photogra mmetry, Surveying , 2D Document ation, Record Keeping	n/a	n/a	n/a	n/a	n/a	BIM/Web-services Extension; BIM/ERP Linking
HV C 1.1	Existing Condition Modeling; Programming; Record keeping	2D Document ation; Record Keeping	n/a	Clash Detection	n/a	n/a	Performan ce Monitorin g, Real-time Utilization	BIM/IOT Interfacing
HV C 1.2	Existing Condition Modeling; Programming Record keeping	2D Document ation; Record Keeping	n/a	n/a	n/a	n/a		BIM/IOT Interfacing

HV C 1.3	Existing Condition Modeling; Programming; Record keeping	2D Documentation; Record Keeping	n/a	n/a	n/a	n/a	Performance Monitoring, Real-time Utilization, Structural health monitoring	BIM/IOT Interfacing
HV C 2	Design Authoring, Design Review; Programming; Cost Estimation, Construction System Design*	Record Keeping;	Conceptualization, Design Authoring, Selection and Specification, Lean Process Analysis	Clash Detection, Cost Estimation, Quantity Take-Off (QTO),Constructability Analysis	n/a	n/a	Performance Monitoring, Real-time Utilization, Structural health monitoring	n/a
HV C 3.1	Site analysis, Programming, Cost Estimation;	2D Documentation; Record Keeping	Space Programming		n/a	n/a		BIM/GIS Overlapping
HV C 3.2	n/a	2D Documentation; Record Keeping	n/a	n/a	n/a	n/a	n/a	BIM/Spec Linking
HV C 3.3	Structural analysis, Cost Estimation	2D Documentation; Record Keeping	Design Authoring (Structural)	Structural Analysis, Cost Estimation, Quantity Take-Off (QTO)				

HV C 4	Phase Planning, Site Utilization Planning, Design Authoring,	2D Documentation; Record Keeping	Construction Planning	Constructability Analysis, Cost Estimation (Labor, Equipment), Quantity Take-Off (QTO)	Site Set-out		Field BIM	
HV C 5	Maintenance Scheduling;		Operations Planning	Clash Detection		Handover and Commissioning, Asset Management,	Building Automation, Field BIM	BIM/FM Integration (BIMFMI)
HV C 6	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table 24 shows the BIM approach to Historic Value credits. As found in literature and displayed in Chapter 2, some of the noticeable examples represent Semantic-web integration in BIM model, Damage ontology design and real – time monitoring. The general approach proposed for these credits is to collect, organize and manage information in a digital database. Most of the information structure is model – based, with parameter insertion about the analysis results and linking to the external sources or web – publications. Since multiple stakeholders are involved, model viewer or online database is recommended in addition to the authoring tool. A lot of the non - graphic information can be listed or calculated in the spreadsheet format as an input or addition to the modelling process. Each credit results application results in the different output, depending on the credit request. In every case, it is an updated BIM model, linked to external or online database, and enriched with the useful data that should form the documentation for the deliverables.

Table 24: Historic value - BIM approach.

Example	**BIM aspects**					
Specific solution from the literature	**BIM Approach**	**BIM Information structure**	**Information managing process**	**BIM Platforms**	**Excel calculator, xml**	**BIM Result**

Semantic-web integration in BIM model;	Collect, organize and manage information in a digital database.	Model - based:	Conversion of numerical model to parametric model, insertion and categorization of collected information from multiple databases;	Point cloud software, authoring tool; Model viewer;	x	Digital twin with indications for refurbishment.
/	Collect, organize and manage information in a digital database.	Element - based:	Inserting parameters in the model elements about summarized analysis results and external links (as parameter values); taging;	Authoring (MEP) tool; Model viewer;		Information linked to model elements as parameters, links and tags.
Patch-Type Damage/Inspection overlay objects in open format; web - based DOT (Damage Topology Ontology)	Collect, organize and manage information in a digital database.	Element - based; Custom families;	Inserting parameters in the model elements about summarized analysis results and external links (as parameter values); taging;	Authoring tool; Model viewer;	x	Library of historic materials; Information linked to model elements as parameters, links and tags.
Real-time monitoring through wireless sensor network (WSN) technology integrated with BIM;	Collect, organize and manage information in a digital database.	Structural Model - based:	Inserting parameters in the model elements about summarized analysis results and external links (as parameter values); taging;	Authoring (Structure) tool; Model viewer;	x	Information linked to model elements as parameters, links and tags.
n/a	Design solutions, simulate and compare results	Model - based:	Model design solutions, inserting element parameters; export results	Authoring (Structure) tool; Structural analysis tool*; Model viewer;		Model/s with estimated costs, and reversibility assessments;

/	Design solutions, simulate and compare results	Model - based;	Integrated with GIS; Model design solutions, inserting element parameters, classifications, and schedules; perform calculations and cost estimations; export results	Authoring tool; Space analysis tool; Model viewer;		Model/s with analysis of external space usage and assessment
/	Collect and organize information in digital database	Element - based:	Insert additional parameters to relevant elements; export results	Authoring tool; Model viewer;		Information enriched model.
/	Design solutions, simulate and compare results	Structural Model - based:	Authoring tool - structural model, analysis and simulations; export results	Authoring (Structure) tool; Structural analysis tool*; Model viewer;		Structural model with relevant parameters
/	CoSIM development	Model - based:	CoSIM development process;	CoSIM Software; Authoring tool (terrain / landscaping); Model checking software; Scheduling software; 4D model integration software; Model viewer;		CoSIM model with instructions for treating water, vegetation and energy.
/	BIM for Facility Management	Model - based:	BIM for Facility Management procedure	Design Review Software, Building Automation System (BAS) linked to Record Model • Computerized Maintenance Management System (CMMS) linked to Record Model • User-Friendly Dashboard Interface linked to Record Model to provide		Facility Management BIM

				building performance information and/or other information to educate building users; FM Software; Model viewer;		
n/a	n/a	n/a	n/a	n/a		n/a

Table 25 shows the possible BIM instruments to use for the credits application. There is minor amount of calculations to be performed at this stage, in authoring or in an external tool. There is few of the many BIM software necessary to use, and the authoring tool linked with the external databases (such as online repository) is the main one. There is a division when it comes to the project stages of the credit application, the most being applied to one project stage. When it comes to the information type, almost every credit involves creation or usage of both geometric and non – geometric data.

Table 25: Historic value - BIM elements.

BIM instruments					
No	**Calculation in BIM Authoring platform**	**Calculation in external platform**	**BIM Analysis tool**	**Multiple BIM software**	**BIM for Multiple project stages**
HV PR 1	x				
HV C 1.1	x				
HV C 1.2					
HV C 1.3					
HV C 2			x		
HV C 3.1					
HV C 3.2					x

HV C 3.3			x		x
HV C 4			x		x
HV C 5			x		x
HV C 6	n/a	n/a	n/a	n/a	n/a

Lastly, Table 24 shows the personal notes on the analysis. It is concluded that the application of BIM would be beneficial for the application process of each credit, except the HV C 6, where it is only requested to hire a professional in heritage restoration. For the Prerequisite 1, HBIM model can be the structured information base point for further project development. It can be used as a record of a stage of building's life as well. For the Credits 1.1 – 1.3, the model would be the basis for the design project, as a representation on existing state where the critical areas and potential for the project possibilities can be shown. The second credit can benefit from quick quantity and cost generation of elements. The credit 3.1 requires connection to GIS data. The credit 3.2 does not benefit BIM by itself, but the analysis results can surely be connected to the model and function as a part of a large information repository. All in all, each of historic value credit would benefit from BIM for collecting large amount of data in one collaborative environment, and forming the basis for the decision making in the earliest stages.

Table 26: Historic Value - notes.

Notes		
No	**Comments**	**BIM - GBC HB credit compatibility**
HV PR 1	HBIM model can be the structured information base point for further project development. It can be used as a record of a stage of building's life as well. Requires collaboration between multiple stakeholders.	5
HV C 1.1	Base for project development. Model elements can be connected to detailed analysis results via links, with only general conclusions / instructions inserted (as parameter values, images or visualisation, depending on the need) for further model development. In the case of the credit, it is only necessary to insert test locations in the 2D drawings.	5
HV C 1.2	Base for treatment of materials for each element, but detailed schedules / analysis results and the rest of deliverable documentation can interfere with the rest of the model. The suggestion is inserting and using in the model only needed parts of analysis for next project phases, and keeping the whole documentation in a separate model or folder for example.	4

HV C 1.3	The base for further structural development. Useful for keeping large amount of data in one place. The suggestion is inserting and using in the model only needed parts of analysis for next project phases, and keeping the whole documentation in a separate model, for example.	4
HV C 2	Quck quantity and cost generation of elements to form early decisions; useful for later 4D schedules too;	3
HV C 3.1	Authoring tool should be connected to GIS to evaluate sites. Local urban plans should be considered during design of solutions.	5
HV C 3.2	Detailed material analysis to be performed by specialists in the field, not necessary to be connected with the BIM model; Summary of results such as material classification, characterization, durability and treatments can be inserted as element properties in the model, for documenting / visualising purposes.	2
HV C 3.3	/	3
HV C 4	Collaboration of multiple stakeholders required;	4
HV C 5	Collaboration of multiple stakeholders required; COBiE specifications are recommended for information structuring.	4
HV C 6	n/a	0

3.5. Historic Value (HV) credit category

The following paragraphs analyse the application process for “Historic value” category. The phases of the application are described following with the and BIM approach. Based on that, an overall BIM workflow for the credits of the Historic value category is proposed. Afterwards, the closer examination is addressed to the Prerequisite 1: Preliminary analysis. General BIM workflow for achieving the prerequisite is presented. Finally, a concrete deliverable requested for the prerequisite, the “Historic Building identity card” is examined in the context of BIM implementation for preparing the related documentation. The Historic building identity card examination is the basis for the BIM framework development in Chapter 4.

3.5.1. Process of achieving Historical Value Category credits

According to GBC HB Maual, there are three phases of acheiving the Historic Value category credits: Preliminary cognitive phase, Design phase, and Construction phase. The phases will be briefly described, with the further focus on the preliminary cognitive and design phase.

1. The preliminary cognitive phase

Figure 30 shows a diagram of the phase steps. GBC HB Manual names four steps: Study, Diagnose, Understand and Inform. First step is a thorough direct study of the asset (metric and photographic survey, material and structural analysis) simultaneous with the study of historical insights (bibliographic, archivists, archaeologists, etc.). Based on this, diagnostic investigations (laboratory or on - site analysis, mechanical tests, etc.) are performed. This integrated study allows understanding of the building construction process, resulting in information about the forms of degradation (material, structural, morphological), interpreting the causes.

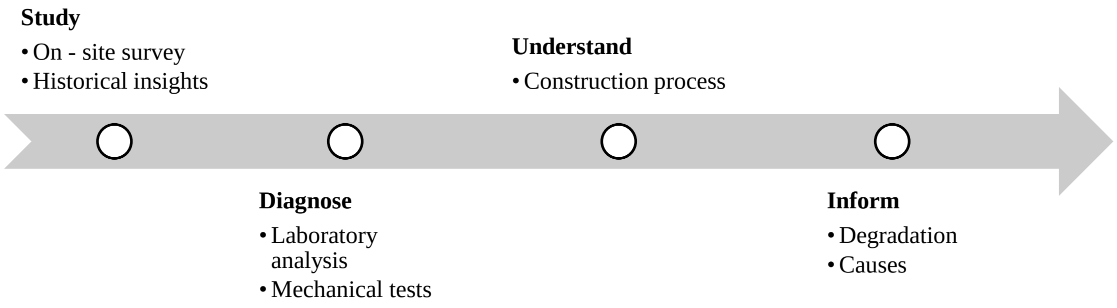


Figure 30: Steps of the preliminary cognitive phase. Adapted from: GBC Italia (2017)

2. Design phase

This phase is consisting of three steps, as shown in Figure 31: Analysis synthesis, Proposal and Adaptation according to the new on – site discoveries. First step is the synthesis of all analyzes when the specialists should represent the critical aspects of the building (material, structural, morphological, system engineering, etc.). Second step is the intervention proposal. It needs to be flexible, expecting possible corrections in the case of new discoveries at the building site.

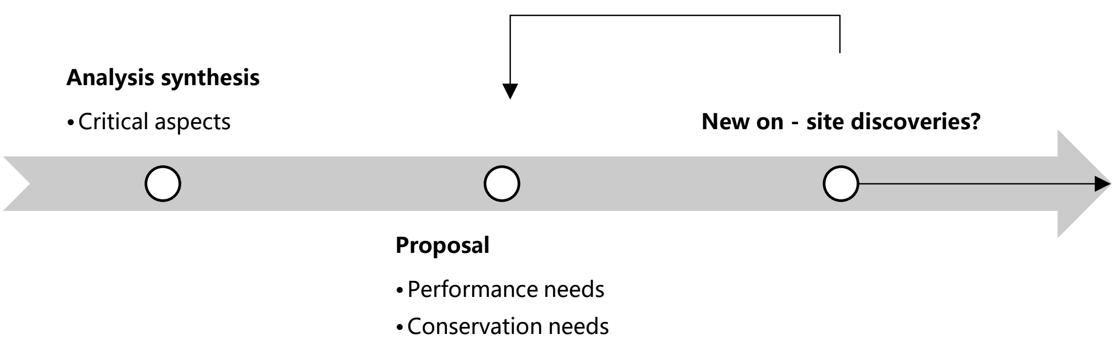


Figure 31: Steps of the project phase. Adapted from: GBC Italia (2017)

3. **Construction phase**

This phase can be considered as an extension of preliminary cognitive phase, since unexpected events may emerge from the start of the first demolitions or removals, and requires experience and knowledge both of the object and materials and construction traditional systems.

3.5.2. BIM workflow for Historic Value

Overall approach for BIM integration in the preliminary cognitive and design phase is to:

1. Collect, manage and store information using digital database
2. Represent and share between stakeholders

Figure 32 represents a simplified shcematic diagram of the input – process - output of the HBIM approach. When the inputs (information from direct and indirect sources) are collected, the HBIM modelling can process can start. It is controlled by the standards and regulations, naming conventions and the project template. The authoring software, with the integrated tools and collaborating environment, should be used for the model development. The result is a digital twin with the infomration structured to be useful and clear when shared between the different software of the project stages. For that, the open format standards should be used.

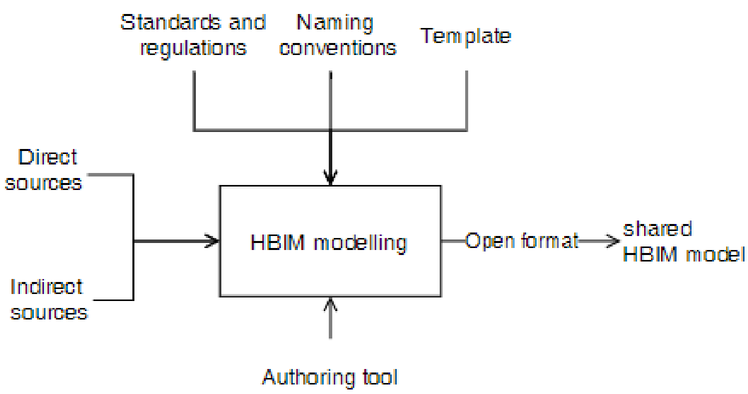


Figure 32: IPO for HBIM modelling.

The general BIM workflow for the Historic Value credit category is proposed based on the GBC HB Manual instructions (see Table 8) and the detailed analysis of the Historic Value credits. The workflow for each credit is presented in Appendix 5. The principle is shown here on the Prerequisite 1: Preliminary analysis (Figure 33). It starts with the pre - defined BIM Execution Plan (BEP), which is made based on the information requirements. It basically defines the plan for the project, the credits to apply to, the point number aimed to obtain, the project team and the standards to use. In general, there are two main phases according to the GBC HB Manual: Preliminary cognitive phase and Project Phase. The first one includes information collection, performing and inserting the requested analysis results of the building aspects. The project phase starts with the data publishing on the Common Data Environment (CDE) and making the model according to the requested information for the credits. After the results are exported into the appropriate report format, BIM Manager revises and coordinates the documentation, checking the compliance with the credit to obtain as well. When the result is satisfactory, the documentation can be published for the Certification application. In the case of Prerequisite 1: Preliminary analysis, preliminary cognitive phase consists of the on – site study and diagnostic investigations, which include activities such as archaeological investigations, analysis performed by the restoration architects and engineers. Likewise, the team collects the information from the indirect sources, such as the data from the archives or current standards and regulations in this phase. The project phase starts with sorting the gathered data in the CDE, formatting them according to the adopted standards. Then, the HBIM model creation can start, using the pre – made template. The historical elements should be represented, as well as the areas that need to be preserved, repaired, or any additional interventions that is planned to be performed. The parameters requested in the GBC HB Manual should be inserted in an appropriate way. The project team includes professionals from various fields, so the stakeholders for each credit are defined in Table 22. When that process is finished, the reports can be exported and revised for potential changes or corrections. If the documentation is satisfactory, it can be published for the final revision by the BIM Manager, when the compliance with the credit request is also checked. If there are any corrections to be made, the model is updated and corrected documentation is published again. The described steps are repeated until the final revision confirms the deliverables, when they can be officially published for the credit application. The software used for the implementation of the proposed process is also shown in Figure 33, and include MS Excel, Autodesk Revit (with the use of Dynamo) and exporting to .ifc file format.

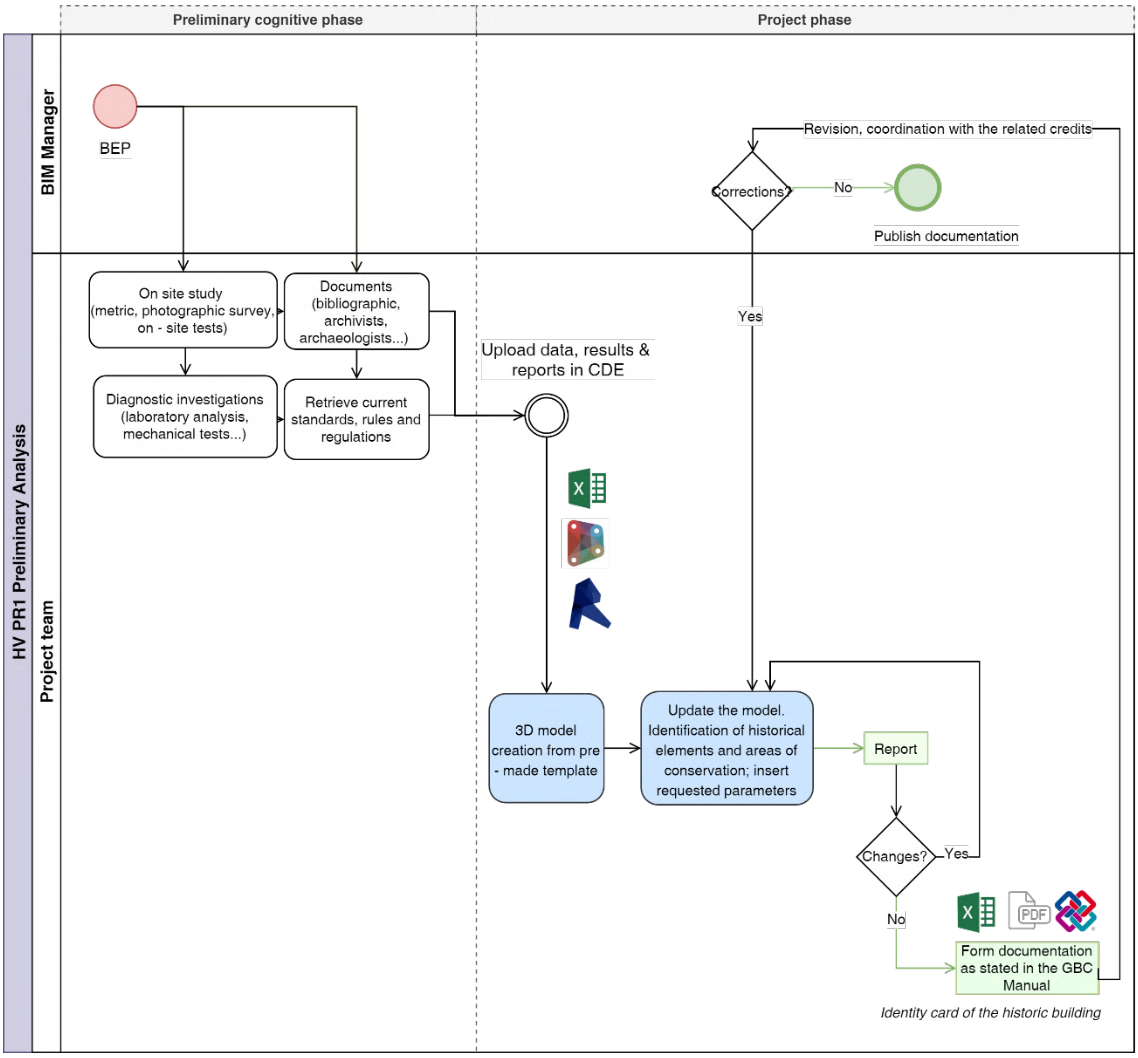


Figure 33: Proposed BIM workflow for the PR 1: Preliminary analysis. Source: author.

3.6. Historic Building identity card

Since the deliverable for the Prerequisite 1 of the Historic value is Historic Building Identity card, the infromation requests have first been identified. The list of general requests for HV PR 1 - Preliminary analysis is:

- Identification of historic structures and materials
- Identification of areas of sustainable conservation
- Identification of necessary work for the conservation
- Attaching additional documents of technological units
- For each documented element, highlighted critical areas
- Formulation of “Identity card of the historic building” as a result

Figure 34 shows the steps for acheiving the HV Prerequisite 1, according to the GBC HB Manual. They include: Identification, Explanation, Formulation and Sharing. The first step includes identification of historic structures and materials, building areas to conserve and the conservation work to be done.

Second step includes explanation of the tecnological units of the building, on a general level. Third step is to formulate the deliverable “Identity card of the historic building” (further referred to as HB ID Card). The last step is to share the gathered information as a basis for obtaining the further credits.

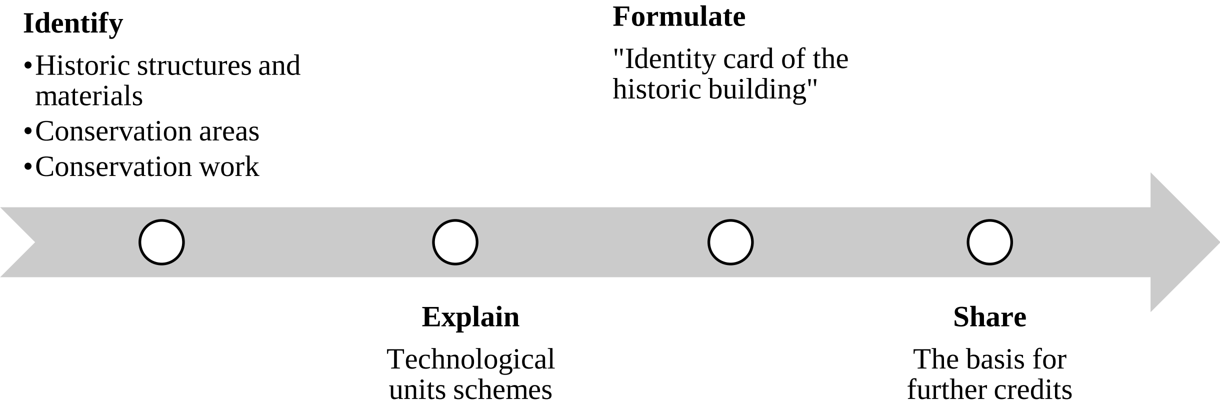


Figure 34: Steps for HV PR 1: Preliminary analysis. Source. Adaptation from GBC Italia (2017).

Historic building identity card is a document in .pdf format which synthesizes the basic knowledge of the building and directs the future of the project. Documentaiton requested for this deliverable consist of three aspects:

1. Project information
2. Technological units information (bearing, shell and mechanical systems)
3. Graphical documentation (drawings)

1. Project information

This section of HB ID card requests general information about the project, including its name, location, and overall quantities. The sample of the project information in the HB ID Card is shown in Figure 35.

2. Technological units information

This section requests general information about the three classes of technological units. The sample of the HB ID card for technological unit information is shown in Figure 36. It requests information on their types, historical feature, overall amounts, and percentages of historic structures. In this section, the classes of building technological systems of the building are defined. They are represented in Table 27, and are: bearing structure, shell and mechanical systems. Each system consists of the technological units.

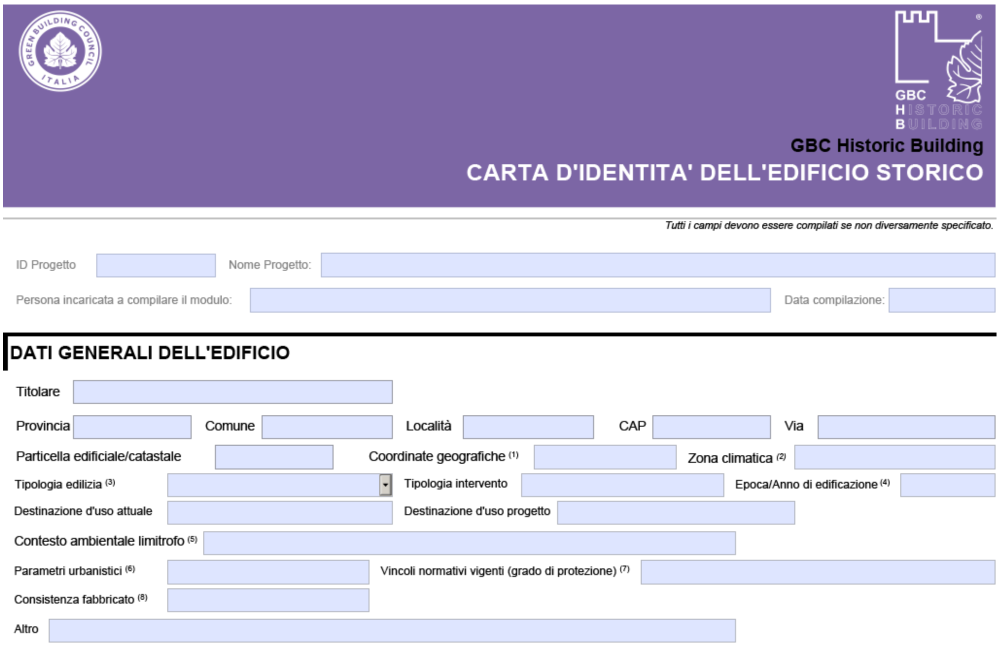

GBC Historic Building
CARTA D'IDENTITA' DELL'EDIFICIO STORICO
Tutti i campi devono essere compilati se non diversamente specificato.
ID Progetto
Nome Progetto:
Persona incaricata a compilare il modulo:
Data compilazione:
DATI GENERALI DELL'EDIFICIO
Titolare
Provincia
Comune
Località
CAP
Via
Particella edificiale/catastale
Coordinate geografiche (1)
Zona climatica (2)
Tipologia edilizia (3)
Tipologia intervento
Epoca/Anno di edificazione (4)
Destinazione d'uso attuale
Destinazione d'uso progetto
Contesto ambientale limitrofo (5)
Parametri urbanistici (6)
Vincoli normativi vigenti (grado di protezione) (7)
Consistenza fabbricato (8)
Altro

Figure 35: Project information sample of the HB ID Card PDF form. Source: GBC Italia (2016)

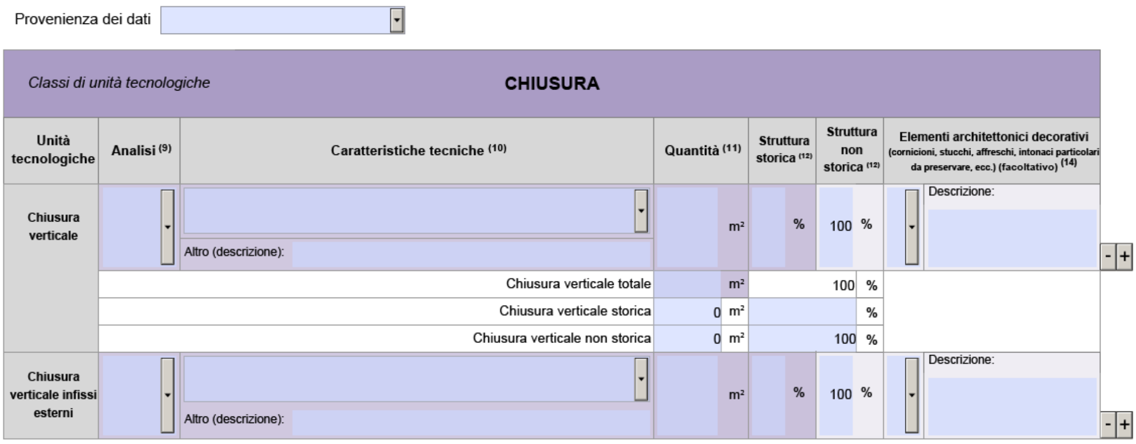

Provenienza dei dati
Classi di unità tecnologiche
CHIUSURA
Unità tecnologiche
Analisi (9)
Caratteristiche tecniche (10)
Quantità (11)
Struttura storica (12)
Struttura non storica (12)
Elementi architettonici decorativi (cornicioni, stucchi, affreschi, intonaci particolari da preservare, ecc.) (facoltativo) (14)
Chiusura verticale
m² % 100 %
Descrizione:
Altro (descrizione):
Chiusura verticale totale m² 100 %
Chiusura verticale storica 0 m² %
Chiusura verticale non storica 0 m² 100 %
Chiusura verticale infissi esterni
m² % 100 %
Descrizione:
Altro (descrizione):

Figure 36: Sample of the HB ID PDF form for technological units. Source: GBC Italia (2016)

Table 27: Classes of technological units. Adapted from: GBC Italia, 2017.

	Class	Technological unit
Technological system of historic building	**Bearing Structure**	Foundation
		Vertical structure
		Restraint
	Shell	Walls
		Windows and doors
		Bottom floors
		External floors
		Roofs

	Mechanical systems	Hydro-sanitary
		Aero - form disposal
		Rainwater collector
		Passive heating
		Passive cooling

3. Drawing requests

Table 28 presents the list of topics that should be graphically represented for the HB ID card. There are six topics to assess and represent. Considering the time and amount constraints, three were chosen to asses and demonstrate for this dissertation: Construction phases and existing functions, Material consistency and construction techniques, and Macroscopic forms of degradation. The principle for documenting each of them involves specific instruments, thus it can serve as a reference for applying the framework on the complete documentation set.

Table 28: List graphical documentation topics. Adapted from: GBC Italia, 2017.

1. Construction phases and existing functions
a. Planimetric / altimetric schemes at macroscopic level (additions, renovations, and similar) differentiated by colours corresponding to phases and compared to the functions;
2. Structural schemes
a. Symbolic representation of the structure
b. Structure types, operation and nature highlighting the pre - industrial structures
c. Information about dimensions, visible irregularities and similar
3. Material consistency and construction techniques
a. Elevations highlighting the presence of finishes (external and internal plasters, decorative systems, floorings, ceilings and similar)
b. Graphical (photographs as aids) presentation of material nature and installation type
c. Laying systems and possibility of material removal / reuse
d. Diagnostic analysis to be carried out
e. Potential compatible / reversible materials
f. Historic window survey
4. Matrix of stratigraphic successions
a. Detailed elaborations on 1, 2, 3
5. Macroscopic forms of degradation
a. Instability of materials and structures (basis for HV C 1.2 and HV C 1.3)

	b. Planimetric and altimetric drawings
	c. Identification of material alterations through poly - sensory analysis of macroscopic effects: Filling the simplified forms for each technological unit, about characteristics, conservation state and most evident degradation causes
6. Systems schemes	
	a. General description of operation and system components
	b. Plans and / or sections with marked paths of the systems with any further indications of the sizing and current operation.
	c. Identification of all characteristic systems, documentation divided by system type (water and drainage systems; heating systems; dividing the potential system and the existing branches and connections)
	d. Represent: System location, type, connections

Through Historic Value category, all elements of the building are documented and decisions can be made for the further actions. The information about construction, decoration and mechanical components, geometrical and alphanumerical data should be clearly demonstrated in the HBIM model. Buildings' critical aspects and the state of degradation should be explained, and construction methods to be taken defined. The complexity of the certification process entails careful planning, organization, and multiple stakeholders in order to create a holistic framework for its optimization. In that sense, a BIM framework can be developed in order to optimize the management of that complex information structure. Since it is the first prerequisite and the basis of the Certification process, a BIM framework is developed, implemented and demonstrated for the Prerequisite 1 of the Historic Value category, in Chapter 4.

4. BIM FRAMEWORK PROPOSAL

4.1. Introduction

This chapter contains the BIM framework proposal for acheiving the Prerequisite 1 of Historic Value Credit category, the “Preliminary analysis”. It includes creation of initial settings for the BIM authoring tool, based on the particular requests for the Prerequisite deliverable, the “Historic Building Identity Card”. The settings are made to manage and perserve data outside the authoring tool too, by using open data format (IFC) standards. The created framework is set to optimize the prerequisite application process by functioning as a set of guidance tools for the users (the project design team), enabling the fluent, consistent and user – friendly environment for the creation of deliverables.

Authoring tools are commonly used by design offices in order to systematize the project procesess. They are updated using the initial setting files, called “Template files”, filled with information useful to start the project (such as line styles, weights, naming rules, etc.). In this case, the Template file can be additinally populated with information specific to the certification process – non graphic and graphic information. It can be used as initial guidance for the team to create and transfer information to be accesible during any project phase. The characteristic aspects of the project template for the Prerequisite 1 application were considered for the framework formation, assuming that typical project requests (such as line weights, text, font and similar) are already being used to create individual office templates. The the properties in the Template file were structured to be useful when exported to an open file format (.ifc), as well as formats requested by the GBC HB Manual (.xml and .pdf). In that way, the deliverables for the Prerequisite application can be prepared, and BIM software interoperability can be achieved, ensuring the information management during the rest of the project stages too.

Specifically, the framework creation consists of responding to the information requirements by translating them to BIM content - properties and visual representation. The general BIM response to the HB ID Card requests is represented in Figure 37. The three topics from the Historic Building identity card: “Project information”, “Technological units information” and “Drawing documentation”, are requiring graphical and non – graphical data. Each of them contains information that can be translated to BIM contents. BIM properties are non – grapical data that are used to provide information for each of the three topics (e.g. building address, area, etc.). Classes of objects, as well as object and material libraries are BIM contents used to create and document building elements, and therefore, the requested “Technological units” (e.g walls, roofs, etc.). Drawing templates are the rules for creating the “Drawing documentation”, and used in BIM for keeping the graphical data consistent (e.g. color schemes, paper size, etc.). The response results in the framework for information management process, consisting of the files set to be used as project template, filled with the information useful for the project initiation.

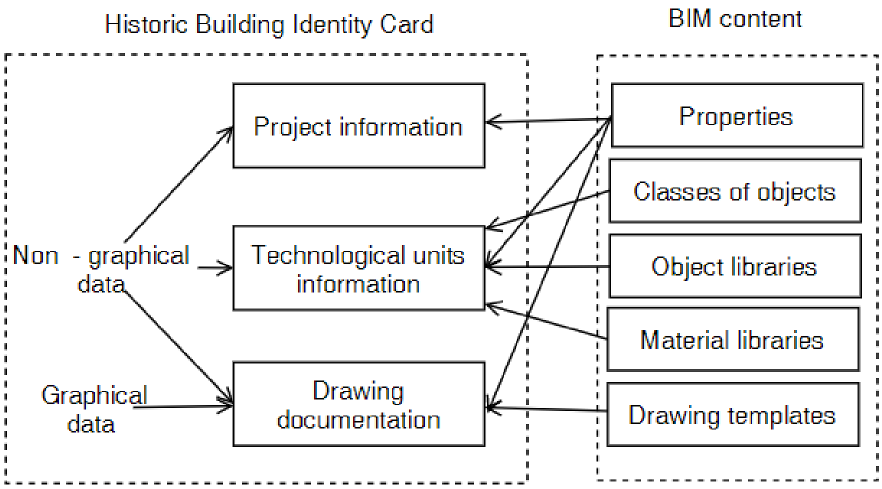


Figure 37: BIM contens as a response to HB ID Card requests. Source: author.

Scope

Considering the time and volume limitations, this dissertation is not focusing on every HB ID request, but on creating the basic principle for managing different types of requested information, that can serve as a reference to follow for the framework extension on the complete certification project requirements. In that sense, the scope is made out of two parts, as shown in Table 29. One part is defining the property management scope. It consists of the project information and technological unit requests. Project information, (See Figure 35) represents one entity of the project requests and is fully inside the scope of the framework implementation. Technological unit information (See Figure 36Figure 35) requests represent the information about the three types of building units, each consisting of different elements (Table 27) Since information types requested for each unit are the same, and can be inserted into BIM software using the same principle, the scope is narrowed down to implementing the information mapping for one of the technological units – shell: walls. The second part is graphical documentation scope. From the list shown in Table 28 of Chapter 3, it can be seen that there is a great number of graphical documentation types requested. The scope is narrowed down to the four different drawing requests involving the arthitect for their creation. The drawings that will be demonstrated as a part of project template application cover the following topics: Construction phases, Functions, Historic materials used for the shell (defined by the Manual), Degradation forms of the materials. The degradation forms representation has also been narrowed down to one material, stone, since the principle for documenting and representing one material can be applied to documentation and representation of any material or element degradation.

Table 29: Framework demonstration scope.

Property management scope
Project information: all
Technological unit information: shell
Graphical documentation scope
Construction phases
Functions
Materials used for the shell (defined by the Manual)
Degradation forms of the materials: stone degradation

4.2. Framework proposal

Figure 38 shows the map of the framework creation. In order to achieve the described goal, the steps have been made, and they represent the basis for enabling the framework usage. Each step is named a “BOX”. There are seven main steps, which go from BOX A to BOX E. The process starts with the BOX A. It consists of listing all the requested data and mapping it to BIM content types using a spreadsheet. The requested is graphical and non – graphical. The non – graphical data is called “Properties”. The property types are then defined using the spreadsheet columns to list: property name, property source (where is the property found or created - if it can be found as an IFC property or have to be custom – made), and property location in the open format - which is the IFC Element the property applies to, and in which property set (basically a group of IFC properties) it belongs to. Regarding the drawing view – port, at this stage, the naming rules are to be set and the needed views and documentation formats should be listed. The view types and templates to apply to each view should be listed accordingly.

Next milestones involve the steps of the BOX B, BOX C, and BOX D - preparation of the template files. BOX B represents preparing the Excel file template with the properties and graphical documentation list to be inserted in the authoring tool. Following the mapping and naming rules from the previous step, the information is to be inserted in the corresponding spreadsheet column. The property values are later inserted in the project design stage, by the BIM manager or project design team. Some values, such as project information can be filled inside these Excel template files, while others (e.g. wall area) can be inserted in the authoring tool during the modelling process. BOX C includes preparing the method for inserting the Excel data in the authoring tool. In this case, the computational design tool has been used to transfer the data. The tool is set that, when used by the project team, it does not require computational design knowledge, following the user – friendly principle of the workflow. BOX D consists of preparing the Template in the authoring tool. The template serves as a guidance for the object classification, graphical documentation creation, and parameter exporting rules. Therefore, it includes three main parts.

The first one is setting the object classification rules, and the rules for documenting and naming element, material and family objects. It is based on the object libraries creation that can be supplemented by the project design team during the modelling process. The second one is setting the graphical documentation guidance - drawing rules, previously listed in the Excel spreadsheets. The set – up for the drawing templates is made in this part. Third part is setting the export procedure for the IFC format. It is important to map the information to appropriate IFC elements and location in order for it to be accessible in any project stage or software to be used.

The following stage represents the template application. It is planned that the project design team can now use the Excel template and the authoring tool template for the project creation. First, the Excel template should be filled following the pre – set rules (BOX E). The parameter values and the view list should be completed and the data should be inserted in the authoring tool, using the already set computational script (BOX F), When the information is imported in the authoring tool template the BIM model can be created (BOX G). At this point, the libraries, schedules and parameter values can be extended and supplemented as needed, following the template guidelines. The information export is performed when the necessary content is created. The PDF form of the HB ID card can then be filled automatically, by setting a Macro script in the Excel spreadsheet (BOX H).

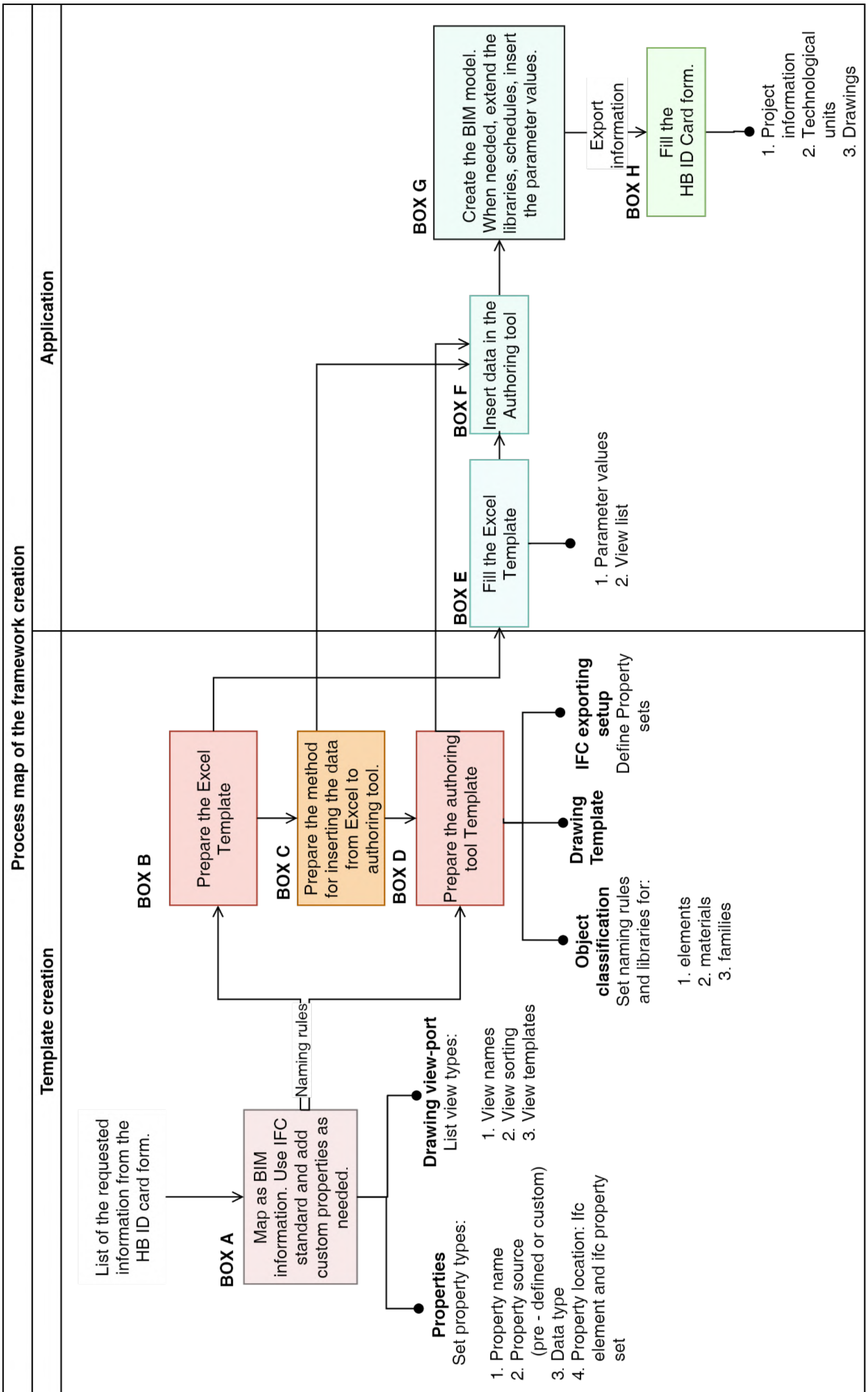


Figure 38: Process framework creation map.

4.2.1. Proposed process

The process for the design team is shown in Figure 39. It is formed based on the results of the framework creation. The results are the tools created during the process described in Figure 38: Prepared Excel template, Method for inserting the data from Excel to authoring tool and Prepared authoring tool template (boxes in the BIM manager lane of Figure 39). BIM Manager should adapt them according to the project and office needs. Information such as official object standards to follow, naming rules, view list, view template list and similar can vary, so the BIM Manager decides and changes these rules accordingly. Their final creation is planned to be performed only once, before the project file is created. The application process then starts with the design team filling the adapted templates. First, the available values are filled in the spreadsheets (BOX E). The data is then inserted in the authoring tool. For this step, computational design skills are not needed, since the graphs are already set to be used and adpated for the authoring tool users. Then, the model is created in the authoring tool (BOX G), the created libraries are extended, and the property values inserted. The proposed process is finished with exporting the information as .xml and .pdf file formats, and the HB ID Card form is filled (BOX H).

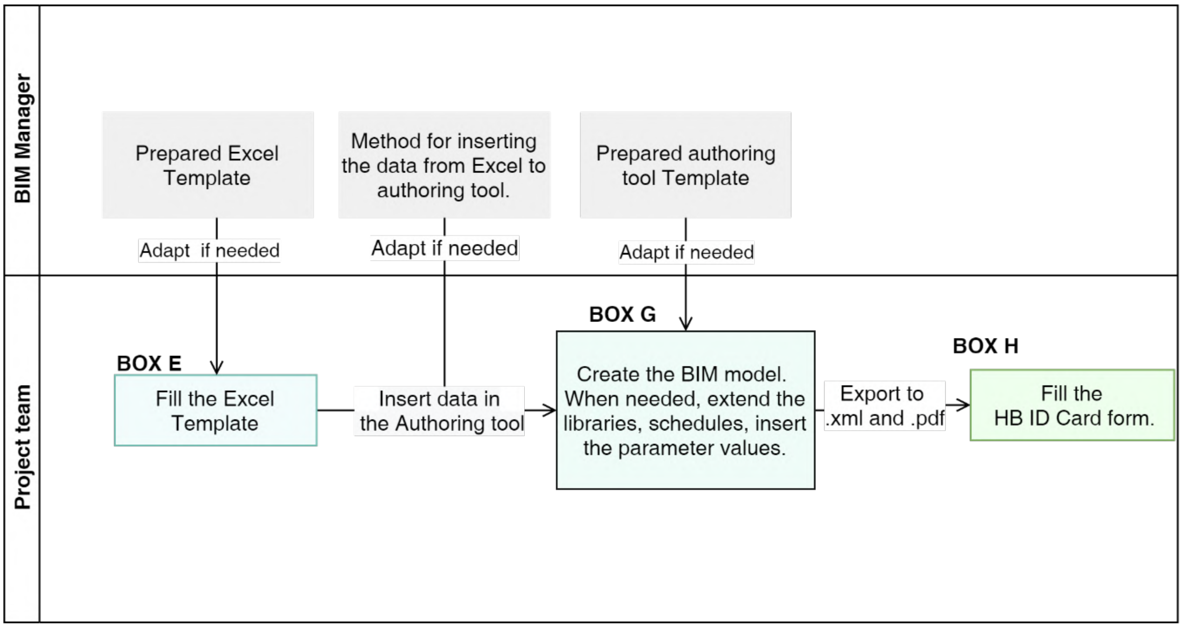


Figure 39: Proposed process for the design team. Source: author.

4.2.2. Framework Impementation

After the method had been established, the implementation was performed. It is addressing to the specific software used to apply the proposed framework. The software files used to implement the proposed framework are shown in Figure 40. First, project data is collected and sorted by the pre – set rules using the Excel spreadsheets. The authoring tool used is Autodesk Revit, and the computational design tool, Dynamo, as a mediator between Excel and the authoring tool. From Revit, the information is set - up to be exported to Excel file format (For the documentation of the ID Card), and IFC file format

(For further project stages). From the Excel file, it is possible to set automatic insertion of the results in the PDF form of the HB ID Card, by designing a an algorithm rules called macro script in Excel. Therefore, proposed path for the preliminary cognitive phase consists of using three key file format types:

1. .xml (MS Excel)
2. .rvt (Autodesk Revit)
3. .ifc (open format)

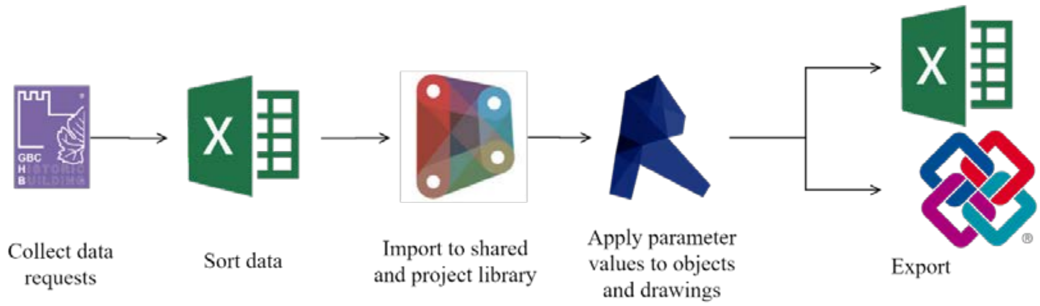


Figure 40: Proposed file path for the preliminary cognitive phase.

Revit vocabulary

Before describing the framework implementation, for explanation purposes to the non – Revit users, the clarification of the particular Revit content used in the framework implementation is presented in the following paragraph. The authoring tool Template is called the Revit template file. It is populated with the information useful for starting the project. The elements used for the Revit template creation are shown in Table 30. Revit project Browser includes the project documentation set lists, such as views, sheets and schedules. It is fundamental part of managing the documentation creation process, because serves as a project documentation map where the team can find and open the appropriate document (e.g. view, sheet, schedule). Schedules and check – lists are used for the documentation process and project control checks. Next content, the object libraries are called Families in Revit (e.g. degradation types family), while the element libraries are used as Revit categories (e.g. walls, doors, slabs, etc.) and category types (e.g. masonry wall). Revit categories are mapped as the corresponding IfcElements. The concept of schematic families is that elements are located in one place, accesible and usable in multiple contexts, and keeping the early design stage model light. Sometimes reffered to as “Placeholders”, these elements are documenting places for objects to be inserted at later stages, so they can be clashed with other elements to determine if the correct amount of space has been accounted for. In this case, placeholder elements can be used to represent specific historic elements in lower level of detail: Specific historic elements which do not require detailed geometrical modelling, Damage representation and Elements that will be developed in later design stages. The Damage representation schematic family is used to apply and demosntrate its usage for the Cerfiication application. Moreover, material library is Shared material library in Revit, containing the graphical and non -graphical information of the materials. Shared material library was used to document the historic material typology and representation. Each material and category type can be assigned with a unique code. Many offices use official standards (e.g. NBS object standard) for object and material coding, for the consistency and collaboration purposes. That information is stored in keynoting libraries in Revit. The libraries are editable .txt files with the information on the library content inserted in the authoring tool. Using the keynotes, any element, object or material can be assigned with a code. The code can also be graphically represented as a tag in Revit. Further on, non – graphical information in the form of properties are called parameters in Revit. They can exist in the project file, as project parameters, and in the shared file, as shared parameters. Shared parameters are structured as a form of an extendable library in the .txt format, inserted in the Revit file, so they can be used in multiple Revit projects. There are official standard shared parameter files, such as IFC shared parameter file used for this dissertation. When inserted in the Revit file, shared parameters are sorted in the groups according to the topic they belong to. They are then applied in the project so the Revit project file uses only the imported parameters of the shared parameter library. When applied in the Revit project, the parameters are mapped to the selected element category (e.g. walls). In Revit project, the parameter can describe all the elements belonging to a type (type parameter), or only an instance of the type (instance parameter). For this dissertation, IFC shared parameter file was used as the basis for parameter use, and the custom parameters were added when needed, sorted in the custom – made shared parameter groups. When exported to IFC, parameters are sorted in Property sets. Pre – existing IFC parameters are automatically grouped in the pre – defined property sets. When the custom parameters are made, the appropriate naming styles and grouping in custom property sets should be defined in order to keep consistency in the project. Finally, the View templates in Revit are used to apply the standard view settings. In this case, they are used to control the visibility of requested information. Color schemes were created to form View templates and apply Legends and Filters for the graphical documentation deliverables. The graphical documentation deliverables in Revit interface are called sheets.

Table 30: Elements examined for Revit Template.

Project Browser organization	**Schematic families**
Sheet list	Material degeradation types
Drawing view naming	**Prarameters**
Check – list	IFC Parameters and Property sets
Schedules	Custom Parameters and Property sets
Schematic Libraries	**View templates**
Element, material and damage keynotes	Color schemes
Material shared library	Filters and legends

Dynamo is a visual programming tool connected with Revit, and Dynamo player is a tool in Revit which performs execution of Dynamo graphs in simple manner, enabling usage of Dynamo graphs without the computational design skills. In Dynamo Player, the users can choose the Dynamo script to run and define variables – inputs for the script.

Mapping the requests as BIM information using Excel spreadsheets

As shown in the BOX A of Figure 38, the data is first categorised as BIM information, based on the IFC standard compatibility. The Excel spreadsheets were used for this step. The application of this step of the framework is shown in the Table 33 (project information) and Table 34 (technological unit – shell: wall). The requested information is listed in the first column. Second column names the Ifc Property, which is here used as Revit parameter name too. The parameters that were found and mapped to the existing IFC parameters, are highlighed in grey.

Before listing the custom properties, the naming rules have been set. As there is currently no official standard concerning all the properties that are requested by GBC Historic Building, custom parameters and property sets have been made as a part of the dissertation work. First, the groups of parameters were created according to the topics they cover. The groups are shown in Table 31. To cover the defined scope, five shared parameter groups were created: Project information, Sheets, Sorting, Historic technological systems, Materials. Every custom parameter belongs to one of these shared parameter groups. Then, the naming rules have been set for the custom parameters and custom materials libraries. As seen in Table 32, abbreviations of the office, the group or category the custom content belongs in, and its name are used to form the naming principle, in order to keep the consistency. In that way, the custom content is sorted by its owner (the office) and location (group / category), so the theam can read the property background based on its name and manage it more easily.

Table 31: Shared parameter groups created and added to the IFC shared parameter file.

PRJ – Project information	SHT – Sheets	SRT – Sorting
HTS – Historic technological systems	MAT - Materials	

Table 32: Naming principle for custom parameters and materials.

Custom parameter naming principle
{office name abbreviation}_{shared parameter group abbreviation}_{PropertyName}
Example of a property name: GBC_PRJ_HistoricFramework
Custom material naming principle
{office name abbreviation}_{material category}-{Material name}-{Code}
Example material name: GBC-HB_Mansonry-Block-MB01

Third column lists the sources of the property. The property can be found as an existing IFC parameter, Custom parameter or a default Revit parameter. As mentioned, if the required property had been found as an IFC parameter, it was used as such to set its value. If there was no IFC parameter to deliver the requested information, the custom parameter had been made. Third case is the project information existing as built - in Revit set – up, (e.g. coordinates, calculated values) or export set – up for IFC. It has been noticed that IFC export setup information, Building street addres, gets exported as an Ifc property, instead of the default Revit parameter called “Building Address”. Fourth column names the Ifc element the parameter is reffering to, and the fifth, last column names the Ifc property set the parameter belongs to.

Table 33: Project information data mapping.

Project Information				
Requested information	**Revit parameter name / Ifc Property name**	**Property source**	**Ifc Element**	**Ifc Property set**
Project ID	GBC_AUT_ProjectID	Custom parameter	IfcProject	HB ID Card_Project Information
Project Name	Project Name / Project Number	Revit default parameter	IfcProject	Project
Person filling the ID card form	GBC_AUT_IDCResponsible	Custom parameter	IfcProject	HB ID Card_Project Information
Date (of filling the form)	/	/	/	/
Building Name	Building Name	Revit default parameter	IfcBuilding	Summary
Building Province	GBC_PRJ_BuildingProvince	Custom parameter	IfcProject	HB ID Card_Project Information
Building Commune	GBC_PRJ_BuildingCommune	Custom parameter	IfcProject	HB ID Card_Project Information
Building Locality	GBC_PRJ_BuildingLocality	Custom parameter	IfcProject	HB ID Card_Project Information
Building CAP	GBC_PRJ_BuildingCAP	Custom parameter	IfcProject	HB ID Card_Project Information
Building street Address	Site Address / Building Address	Ifc export settings	IfcSite, IfcBuilding	Summary
Building Cadastral Parcel	GBC_PRJ_BuildingCadastralParcel	Custom parameter	IfcProject	HB ID Card_Project Information
Building Coordinates	Latitude	Revit location setup	IfcSite	Location
	Longitude	Revit location setup	IfcSite	Location
Building Climate Zone	GBC_PRJ_BuildingClimateZone	Custom parameter	IfcProject	HB ID Card_Project Information
Building Position Type	GBC_PRJ_BuildingPositionType	Custom parameter	IfcProject	HB ID Card_Project Information
Intervention Type	ConstructionMethod	IFC Parameter	IfcBuilding	Pset_BuildingCommon
Year of construction	YearOfConstruction	IFC Parameter	IfcBuilding	Pset_BuildingCommon
Building Current Use	GBC_PRJ_BuildingCurrentUse	Custom parameter	IfcProject	HB ID Card_Project Information
Building Indended Use	GBC_PRJ_BuildingIndendedUse	Custom parameter	IfcProject	HB ID Card_Project Information
GBC_PRJ_Context	GBC_PRJ_Context	Custom parameter	IfcProject	HB ID Card_Project Information

Urban Parameters	PlanningControlStatus	IFC Parameter	IfcBuilding	Pset_BuildingUse
Building Protection Level	GBC_PRJ_BuildingProtectionLevel	Custom parameter	IfcProject	HB ID Card_Project Information
Building Consistency	Average height (eaves)	Custom level height	IfcBuildingStorey	Location
	Gross covered area	Calculated value	Ifc Space	
	Overall gross volume	Calculated value	Ifc Space	
Other - additional notes	GBC_PRJ_Other	Custom parameter	IfcProject	HB ID Card_Project Information
Historic Framework	GBC_PRJ_HistoricFramework	Custom parameter	IfcProject	HB ID Card_Project Information
Previous Intervention Date	YearOfLastRefurbishment	IFC Parameter	IfcBuilding	Pset_BuildingCommon
Previous Intervention Type	GBC_PRJ_PrevInterventionType	Custom parameter	IfcProject	HB ID Card_Project Information
Previous Intervention Description	GBC_PRJ_PrevInterventionDescription	Custom parameter	IfcProject	HB ID Card_Project Information
Information source	GBC_HTS_InformationSource	Custom parameter	IfcProject	HB ID Card_Project Information

When it comes to the "Technological unit" sector (Table 34), for the information that is automatically calculated when filling the given PDF form (Non - Historic Structure Percentage and Total Structure Quantity), the parameters were not used nor created.

Table 34: ID card information mapping to BIM information types. Source: author.

HB Technological unit - wall				
Requested information	**Ifc Property name / Revit parameter name**	**Property source**	**Ifc Element**	**Ifc Property set**
Direct information	GBC_HTS_DirectInformation	Custom parameter	IfcWall	Pset_TU-Wall
Technological Features	GBC_HTS_TechnologicalFeatures	Custom parameter	IfcWall	Pset_TU-Wall
Quantity (Historic Structure)	Area	Revit default parameter	IfcWall	Pset_TU-Wall
Historic Structure Percentage	GBC_HTS_HistoricStructurePercentage	Custom parameter	IfcWall	Pset_TU-Wall
Non - Historic Structure Percentage	/	Automatically calculated in the pdf form	/	/
Total Structure Quantity	Calculated value	Calculated value	/	/
Non - Historic Structure Quantity	Area	Revit default parameter	IfcWall	Pset_TU-Wall
Presence of decorative elements	GBC_HTS_DecorativeElementsPresent	Custom parameter	IfcWall	Pset_TU-Wall
Decorative Element Description	GBC_HTS_DecorativeElementDescription	Custom parameter	IfcWall	Pset_TU-Wall

When the requested information is mapped to BIM properties, it needs to be prepared in order for the user to easilty insert it into the authoring tool. The spreadsheets formed as Excel templates are the second step of the framework, reffered to as BOX B in the process map in the Figure 38. First, all the properties that have been recognized as custom parameters should be categorized in order to be inserted into Revit as shared and project parameters, and applied to corresponding elements. The template spreadsheets for custom properties cagetorization are shown in Table 35 (Project information spreadsheet template), Table 36 (Shell element categories sreadsheet template), and Table 37 (Sheets and views spreadsheet template). First column of the spreadsheet is made for listing the parameter names. Second column reffers to the shared parameter group the parameter belongs to. Third column requires the parameter data type (Text, Integer, Number, Length, Area, Volume, Slope, Angle, Currency, Mass density, URL, Material, or Yes / No), followed by the column requesting the project parameter group. The two last column request defining if parameters are instance or type and if they are reporting or not.

A few areas that could further be developed have been noticed when mapping and inserting the properties for the Project information (Table 33 and Table 35). First example is “Project Name” in IFC comes from “Project Number” in Revit. The “Building consistency” property requests average building height (eaves), gross covered area and volume. The height can be derived by setting up a custom level object in Revit and reading the result. When it comes to gross covered area and volume, both parameter values can be read from the calculations of the modelled 3D elements – spaces or zones, which require creating and respecting precise modelling rules in order for the automatic calculation to be valid. “Project Address” property does not schedule, or map to IFC as it is not a shared parameter in Revit, but a built – in property in Project information sector. That information is transferred to IFC through IFC setup options in Revit. “Building coordinates” do not map to Revit schedule, since they are simple tags that cannot be scheduled. The Revit solution could be creating an adaptive component family with parameters of the points with defined distance from the origin point and schedule it as a reporting parameter, which could be useful when multiple location coordinates need to be scheduled. In this case, this particularity does not have to present a major issue, since the information is gathered before entered in the proprietary tool, and does not need to be scheduled for this purpose. The “Date” can be extracted by Dynamo at the time of filling the form, or from filling the Revit parameter manually. There is no need to insert additional parameters just for that purpose. “YearOfLastRefurbishment” needs additional custom parameters if there have been multiple major refurbishments.

Table 35: Excel spreadsheet template for custom properties of project information.

Shared Parameter Name	Shared Parameter Group	Parameter Type	Parameter Group	BIP Name (Automatic)	Instance	Reporting
GBC_AUT_IDCResponsible	AUT - Authoring	Text	Identity Data	PG_IDENTITY_DATA	Yes	No
GBC_AUT_ProjectID	AUT - Authoring	Text	Identity Data	PG_IDENTITY_DATA	Yes	No
GBC_PRJ_BuildingCadastralParcel	PRJ - Project Information	Text	Identity Data	PG_IDENTITY_DATA	Yes	No
GBC_PRJ_BuildingCAP	PRJ - Project Information	Text	Identity Data	PG_IDENTITY_DATA	Yes	No
GBC_PRJ_BuildingClimateZone	PRJ - Project Information	Text	Identity Data	PG_IDENTITY_DATA	Yes	No
GBC_PRJ_BuildingCommune	PRJ - Project Information	Text	Identity Data	PG_IDENTITY_DATA	Yes	No
GBC_PRJ_BuildingCurrentUse	PRJ - Project Information	Text	Identity Data	PG_IDENTITY_DATA	Yes	No

GBC_PRJ_BuildingIndendedUse	PRJ - Project Information	Text	Identity Data	PG_IDENTITY_DATA	Yes	No
GBC_PRJ_BuildingLocality	PRJ - Project Information	Text	Identity Data	PG_IDENTITY_DATA	Yes	No
GBC_PRJ_BuildingPositionType	PRJ - Project Information	Text	Identity Data	PG_IDENTITY_DATA	Yes	No
GBC_PRJ_BuildingProtectionLevel	PRJ - Project Information	Text	Identity Data	PG_IDENTITY_DATA	Yes	No
GBC_PRJ_BuildingProvince	PRJ - Project Information	Text	Identity Data	PG_IDENTITY_DATA	Yes	No
GBC_PRJ_Context	PRJ - Project Information	Text	Identity Data	PG_IDENTITY_DATA	Yes	No
GBC_PRJ_HistoricFramework	PRJ - Project Information	Text	Identity Data	PG_IDENTITY_DATA	Yes	No
GBC_PRJ_InformationSource	PRJ - Project Information	Text	Identity Data	PG_IDENTITY_DATA	Yes	No
GBC_PRJ_Other	PRJ - Project Information	Text	Identity Data	PG_IDENTITY_DATA	Yes	No
GBC_PRJ_PrevInterventionDescription-1	PRJ - Project Information	Text	Identity Data	PG_IDENTITY_DATA	Yes	No
GBC_PRJ_PrevInterventionType-1	PRJ - Project Information	Text	Identity Data	PG_IDENTITY_DATA	Yes	No

When it comes to the “Shell” technological unit, the custom parameters in the shared parameter groups “HTS – Historic technological systems” and “MAT – Materials” are inserted. The ones requiring numerical data and calculations also require defining specific modelling rules in order to get the appropriate values. There are three numerical values to be inserted: Element area, Percentage of the elements’ historic structure, and Total area of all element categories of historic value.

Table 36: Excel spreadsheet template for custom properties of technological unit: shell - walls.

Shared Parameter Name	Shared Parameter Group	Parameter Type	Parameter Group	BIP Name (Automatic)	Instance	Reporting
GBC_HTS_ConstructionPhase	HTS - Historic Technological System	Text	Identity Data	PG_IDENTITY_DATA	No	No
GBC_HTS_DecorativeElementsDescription	HTS - Historic Technological System	Text	Identity Data	PG_IDENTITY_DATA	Yes	No
GBC_HTS_DecorativeElementsPresent	HTS - Historic Technological System	YesNo	Identity Data	PG_IDENTITY_DATA	Yes	No
GBC_HTS_DirectInformation	HTS - Historic Technological System	YesNo	Identity Data	PG_IDENTITY_DATA	No	No

GBC_HTS_HistoricStructurePercentage	HTS - Historic Technological System	Number	Identity Data	PG_IDENTITY_DATA	No	No
GBC_HTS_IsExternal	HTS - Historic Technological System	YesNo	Identity Data	PG_IDENTITY_DATA	No	No
GBC_HTS_IsHistoric	HTS - Historic Technological System	YesNo	Identity Data	PG_IDENTITY_DATA	No	No
GBC_HTS_TechnologicalFeatures	HTS - Historic Technological System	Text	Identity Data	PG_IDENTITY_DATA	No	No
GBC_MAT_MacroscopicDescription	MAT - Materials (Walls)	Text	Materials and Finishes	PG_MATERIALS	Yes	No
GBC_MAT_DegradationType	MAT - Materials (Walls)	Text	Materials and Finishes	PG_MATERIALS	Yes	No
GBC_MAT_DegradationCause	MAT - Materials (Walls)	Text	Materials and Finishes	PG_MATERIALS	Yes	No
GBC_MAT_DegradationSubType	MAT - Materials (Walls)	Text	Materials and Finishes	PG_MATERIALS	Yes	No

Additional custom parameter have been made for the sheets and views, as shown in Table 37. They are created in order to sort them in the Project Browser of the authoring tool, and form the Certification application checklist schedule that can be used to control the application status. They include: points to obtain, maximum possible points and if that credit is being applied to, and are grouped in the shared parameter group called “Sorting”.

Table 37: Excel spreadsheet template for custom properties of views and sheets. Source: author.

Shared Parameter Name	Shared Parameter Group	Parameter Type	Parameter Group	BIP Name (Automatic)	Instance	Reporting
GBC_SRT_DrawingGroup	SRT - Sorting	Text	Identity Data	PG_IDENTITY_DATA	Yes	No
GBC_SRT_CreditCategory	SRT - Sorting	Text	Identity Data	PG_IDENTITY_DATA	Yes	No
GBC_SRT_PossiblePoints	SRT - Sorting	Number	Identity Data	PG_IDENTITY_DATA	Yes	No
GBC_SRT_PointsToAchieve	SRT - Sorting	Number	Identity Data	PG_IDENTITY_DATA	Yes	No
GBC_SHT_CreditApplication	SHT - Sheets	YesNo	Identity Data	PG_IDENTITY_DATA	Yes	No

After the custom properties were named and categorized to be inserted in the authoring tool, the underlying Excel template for inserting the available project infromation values is prepared. It is assumed that a lot of the of the information is generated either in the on – site analysis phase or can be found in the project documentation. This means that some parameter values are gathered before the modelling starts (such as project information and view documentation), and can be inserted in the authoring tool automatically from the spreadsheet, without the need of manually re – entering the same information. For that purpose, the underlying Exel template was extended to guide the team to structure property values insertion in authoring tool. The values include both IFC and custom propeties. The part of the template for assigning values to properties includes a spreadsheet with only two columns: one for the parameter name and the other for its value.

When it comes to the drawing view - port setup, the spreadsheet template consists of two sub parts: one is for the drawing view list and sorting, and the second one is for the view sheets creation. The example in the Table 38 shows the template sheet for the floor plan view creation. In the first column, the view name is to be inserted. Second column asks for the level of the view. Third and fourth column serve for the view sorting and template. Each view is assigned to a credit category it is applying for, and the view template that should be assigned to it in order to filter only the necessary information for the graphical representation.

Table 38: Excel spreadsheet template for floor plan views.

View Name	LEVEL NAME	Credit category	View Template
Ground floor_HV PR 1 - Construction Phases and Functions	GROUND FLOOR	01 - Historic Value	HV PR 1_Construction Phases and Functions

Table 39 shows Excel spreadsheet template for the sheet creation. The first two columns request the user to list the Sheet numbers and their names. In the third column, the user lists the credit category the sheet is associated to, while in the fourth column they list the maximum potential points that can be obtained, and in the fifth one they define if the sheet is being used to apply for the Certification. Sixth column is the list of the points number that are being aimed to achieve. Last three columns add general information from the default Revit parameters (example here are: “Drawn by”, “Checked by” and “Approved by”), so a rough outline of the certification control sheet is created as part of the pre - design phase. This table can be formated as a checklist for GBC credit application in the authoring tool, as a Revit schedule and keep control of the application status.

Table 39: Excel spreadsheet template for sheet creation.

Sheet Number	Sheet name	GBC_SRT_CreditCategory	GBC_SRT_PossiblePoints	GBC Historic building	GBC_SRT_PointsToAchieve	Drawn By	Checked By	Approved By

Dynamo for data transfer

After compiling the data in Excel, Dynamo graphs were used to tranfer them to Revit. Reffering to the process map in Figure 38, this is the application of the next step, named BOX C. It includes preparing the method for inserting the data form Excel to the authoring tool. The Dynamo set – up graphs associated with the created Excel files are designed to be used only to set up new project template files. Since they have been set – up, the team can later use only Dynamo Player in order to input the variable information. The team needs to choose the script to run, and input the information on: corresponding Excel file location and its sheet name, and Revit element categories to apply the properties to. Then, they can run the Player to get the Dynamo to insert the compiled data from Excel. One deficiency of Dynamo Player is that if a user presses the “play” button for a script that contains editable inputs, the script runs using the previous settings, without checking if the inputs were correct. The solution can be to clearly indicate when the inputs should be inserted or changed.

There are numerous uses of Dynamo for the purposes of automating repetitive tasks. The application adopted during this research is for creating the following outputs:

1. Project information (Custom parameters and values insertion)
2. Sheets, and project checklist (Custom parameters and values insertion)
3. Element parameters (Custom parameters)
4. Floor plan sheet views (Inserting, Custom parameters and values insertion)

The following parahraphs explain each Dynamo graph created and implemented for the data transfer. The legend shown in Table 40 explains the graph phases. Dynamo player input is the information the user needs to provide in order for the script to run. Process is the phase od the dynamo graph calculation and the Result is the final output of the Dynamo graph process.

Table 40: Dynamo graph legend.

Dynamo graphs legend					
	Input for Dynamo Player		Process		Result

1. Project information

One Dynamo graph was made to insert the custom parameters, and second one to add values to both the existing and custom parameters. The possibility of making one Dynamo graph for both actions was not excluded, and can be seen as potential for future development. The first Dynamo graph (Figure 42) takes the Excel list and applies the custom parameters to the shared parameter file, in a shared parametres group defined in the Excel list, and maps them to the selected categories of the Revit project. In this case, it is "Project information" category. The second graph (Figure 41) inserts the values for Project information requests, to the pre – existing and custom made parameters. It follows the same principle of using the Excel file. The user chooses the Excel file(s) to extract the data from and Revit element category to map the information to.

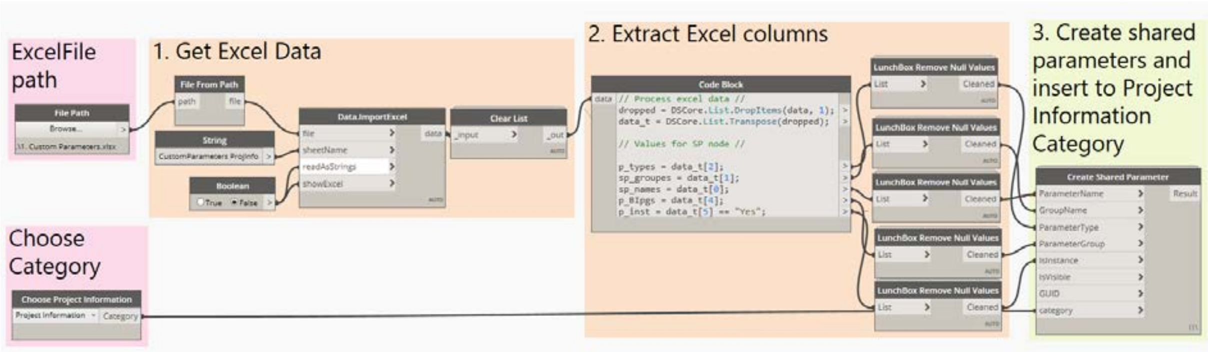


Figure 42: Dynamo graph for inserting project information parameters. Source: author.

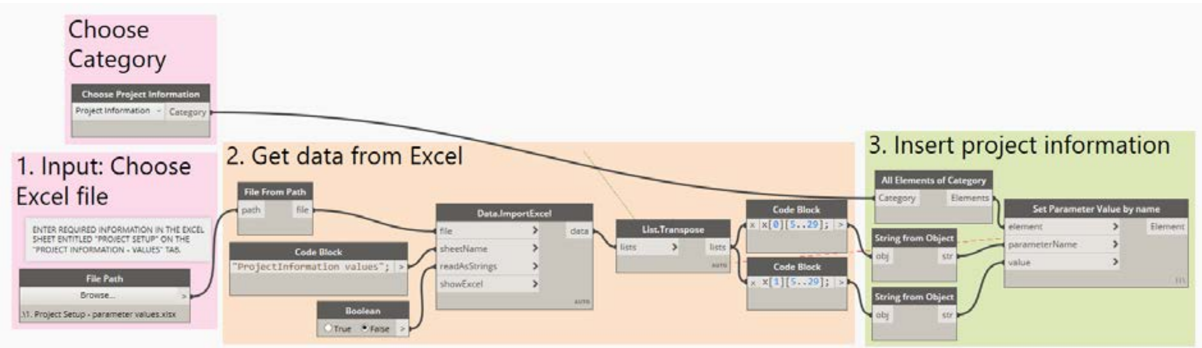


Figure 41: Dynamo graph for inserting project information values. Source: author.

2. Element Categories parameters

Following the same principle as for the project information, the graph for applying the custom parameters to the elements, as shown in Figure 43, enables choosing the element categories to apply the custom parameters to, using the selected Excel file. In this case, the element categories chosen belong to the shell category of the building (walls, windows, doors, floors, roofs).

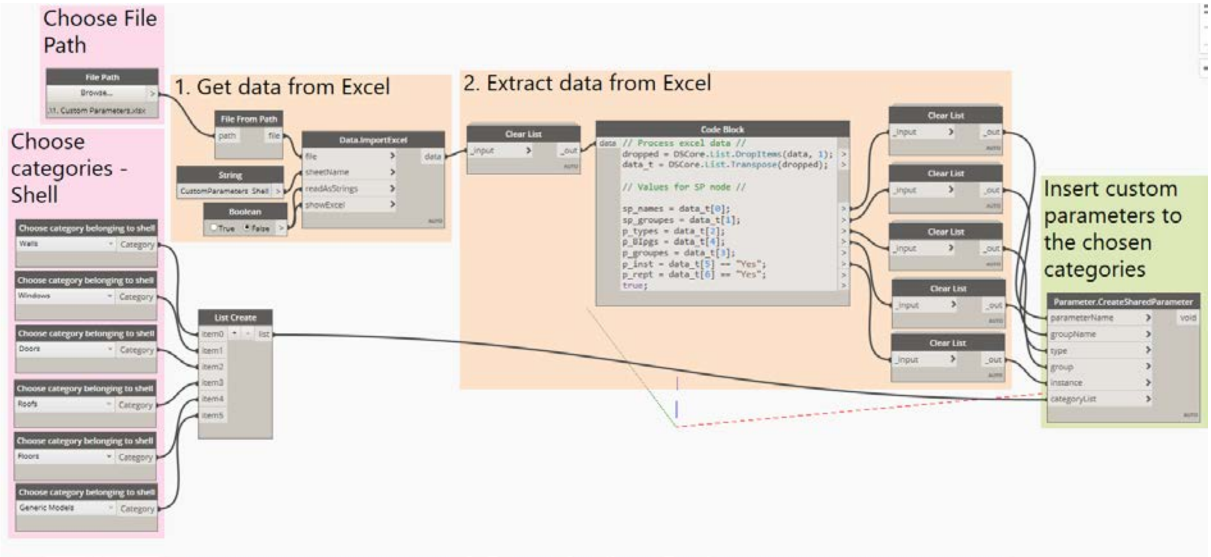


Figure 43: Applying custom parameters to selected element categories. Source: author.

3. Sheets / Checklist

The graph for sheet generation (Figure 44) takes the previously shown Excel file to create the sheets and associated existing and custom parameters with their values. The results are used to make drawing sheets, and GBC Historic Building checklist schedule in Revit, in order for the project team to observe and control the application status.

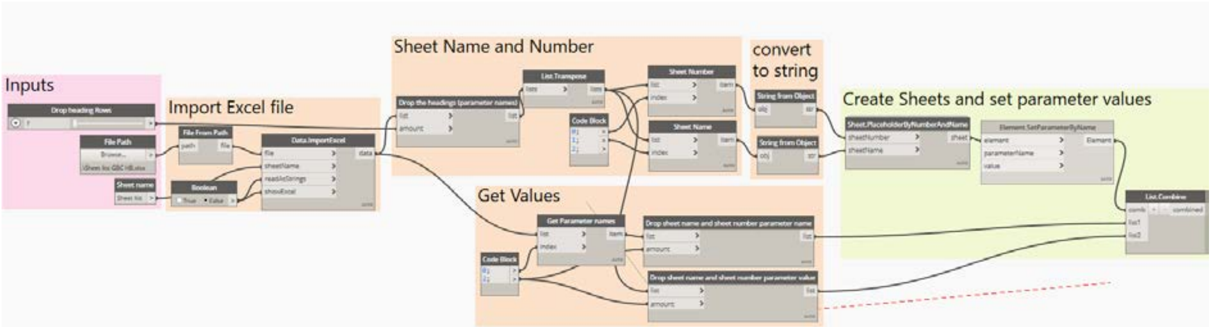


Figure 44: Dynamo graph for sheet generation. Source: Author.

4. Floor plan sheet views

The graph for the floor plan sheet views (Figure 45) graph applies floor plan views to the selected level types in Revit, and adds the pre – made Revit view templates and custom parameter ("View group") with its value to the corresponding view. In this way, all the listed sheet views are inserted in the project automatically, and can be fastly sorted in the Revit project browser. In this case, for demonstration purposes, floor plans have been made for "Phases and Functions" and "Structural schemes" drawing groups.

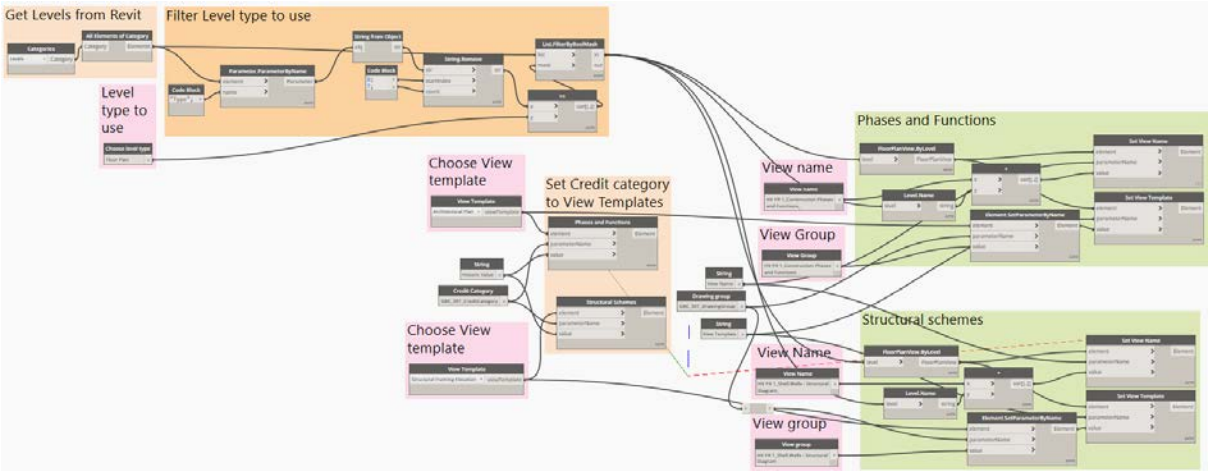


Figure 45: Floor plan views creation. Source: Author.

Revit for template creation

Next step of the process is named BOX D of the process map in Figure 38. The authoring tool template should be prepared, which is implemented using Autodesk Revit. The template is formed combining the information inserted from Excel files and using the tools available in Revit. Revit tools used for implementing the template creation steps are described in Table 30. Described Revit tools implemented in the proposed framework contents are shown accordingly in Table 41. For the implementation of object classification, Schematic families, Keynoting library, and Material shared library were used. To set up the Drawing template, View template, Filters and Color schemes were used. To define the IFC property mapping, IFC exporting setup has been established.

Table 41: Framework implementation in Autodesk Revit Template. Source: author.

Object classification	Drawing template	IFC exporting setup
1. Keynoting library (elements and materials) 2. Material shared library 3. Schematic families (degradation types)	4. View template: Filters Color schemes (construction phases and building functions)	5. IFC exporting setup

1. Keynoting library

In order to document them, the specific historic elements and materials that have been named in the GBC HB Manual had been put into a keynoting library. Reference and the basis for the library creation was Uniclass Standard 2015 file. Based on the file, the elements and materials defined in the GBC HB Manual were added. In that way, the new library called “Historic building systems – GBC” was formed. Element and material typology can be easily accessed, scheduled, checked and visually represented. The editable .txt file enables the supplementation of the library as needed. The sample of the file is shown in Figure 46, as well as the samples from the Revit library keynotes. The newly created library abbreviation is HB, for historic building systems. It consists of the four element categories, according to the classes of technological units (see Table 27) and one material category:

- HB_10: Shell
- HB_20: Bearing
- HB_30: Mechanical
- HB_40: Interior
- HB_A: Materials

Each of the element contains a type (e.g. Masonry, Wooden, Stone walls), and a subtype (e.g. Brickwork of raw earth, Brickwork of raw clay), as listed in the HB ID card. The materials likewise consist of a type (e.g. Stone, Plaster, Brick) and a subtype (e.g. Natural stone type 1, Brickwork type 1). Each of the category, its type and subtype are assigned a unique code which is designed to be used for tagging and scheduling.

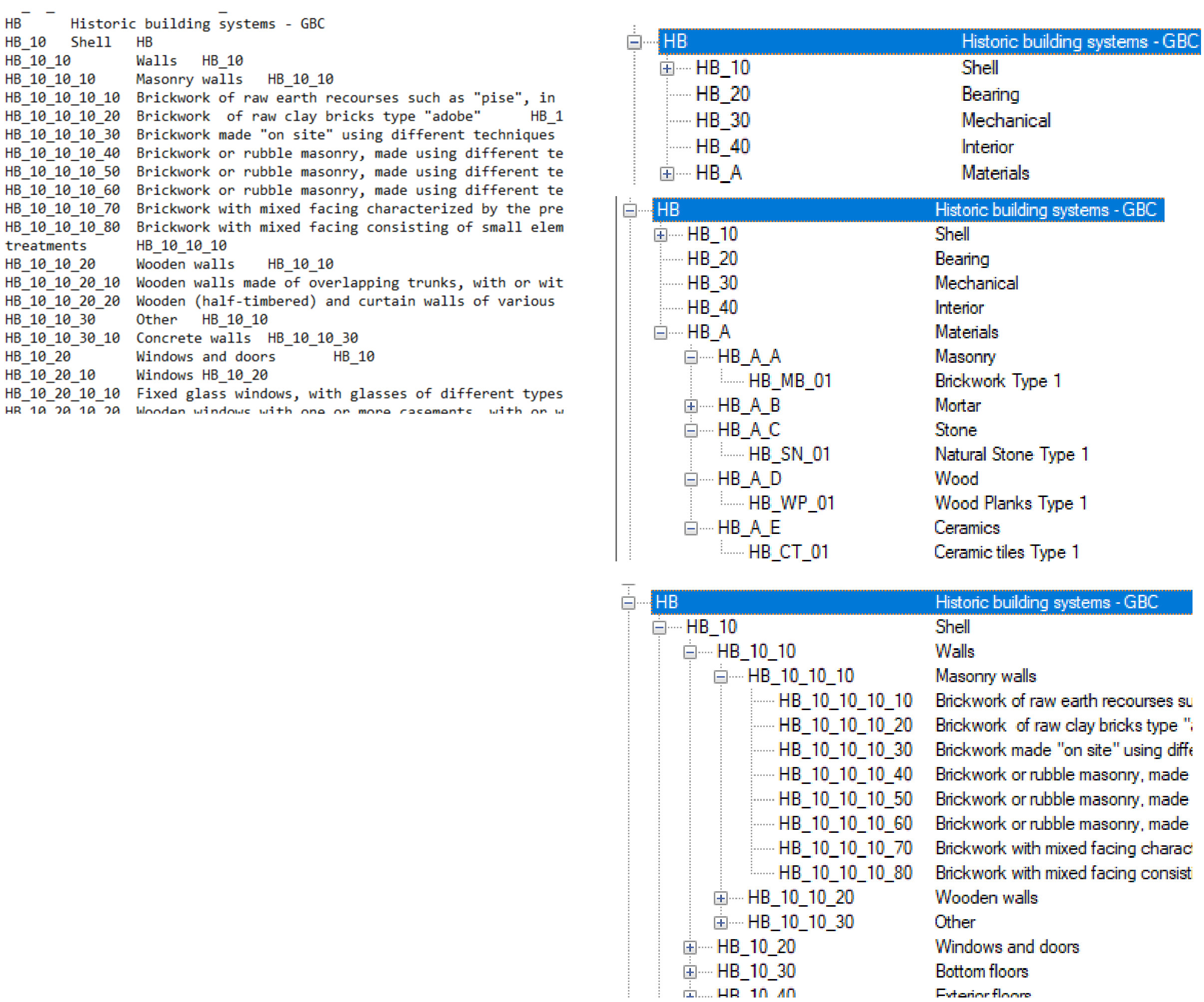


Figure 46: Element and matrial keynote library samples, opened in Notepad and in Revit keynote.

2. Shared material library

Materials used on historic buildings are distinct, and there are currently no official material libraries for the purposes of BIM usage. Official material classifications can be translated to be used in BIM environment, making the updatable material library. The keynoting library was created in order to document the material applied to any element and demonstrate its code. The material library was created to form the graphical representation of materials itself, as well as to enable users to insert the non – graphical information on the materials. The library would serve to design team as a sharable database which can be supplemented when necessary. Using that approach, for the purposes of this dissertation, basic typology of materials defined in the GBC HB Manual was used to form a shared library for Autodesk Revit. GBC HB Manal divides materials to masonry, stone, mortar, ceramics and wood. It is shown in Figure 47. Each material is represented by a unique name, color and a pattern. Each material can contain non – grahic information in the form of parameters. For this Prerequisite, GBC HB Manual requests information about material typology, macroscopic description and visible degradation. When this information is inserted in Revit as material properties, there is a noticable complication for their export to IFC. As materials are not element categories, exporting their properties through IFC export options from Revit has shown to result in information loss and would require programming skills in order for the export to be complete. Since the properties required for this project stage are including material classiffications and description, the chosen solution was not to use material properties, but to map the material information to the “Materials and finishes” group of the “Shell” (Wall, Roof, and Floor) element categories.

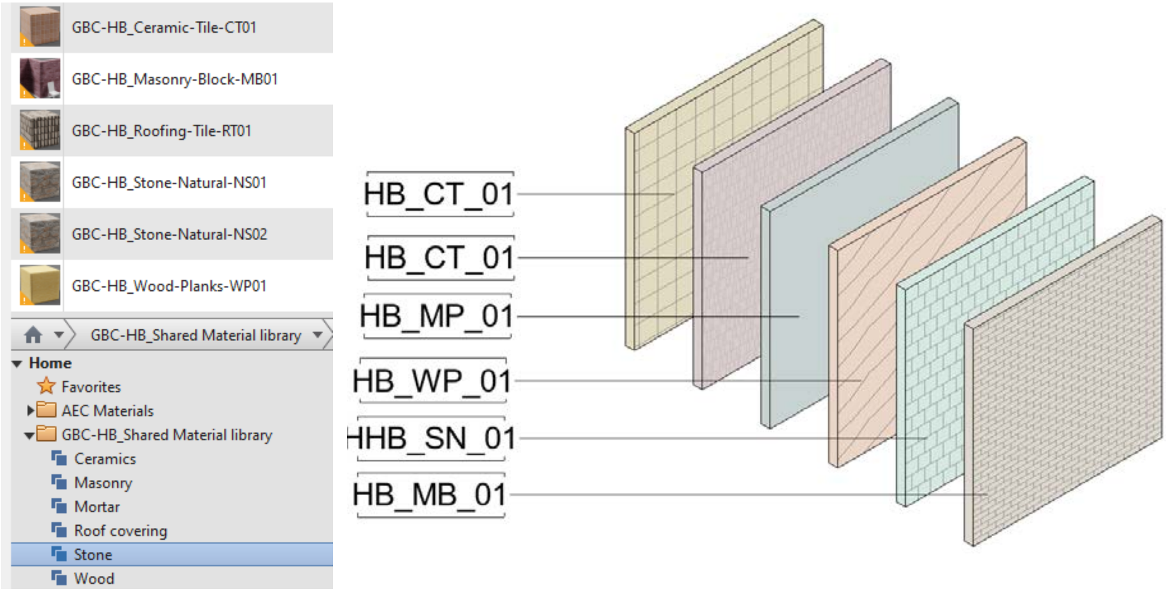


Figure 47: Proposed shared material library and representation in Revit model. Source: author.

3. Schematic families

The adaptive component Revit families were used to represent and classify damage types. Degradation forms were represented using the same principle as Carlo Andrés Alarcón Bahamondes for his Master’s thesis in structural analysis of monuments and histrorical construcitons, in University of Minho, Portugal, 2018. Different kind of materials can have different sorts of damages, causes and symptoms, and therefore can be represented by different families. For the purposes of the dissertation, an adaptive component family was created to represent stone deterioration. The reference used was ICOMOS-ISCS: Illustrated glossary on stone deterioration patterns (Figure 48). They have set up a common language for representing stone degradation patterns, naming and describing them to be clearly recognised and managed in conservation investigation (Cartwright et al., 2008).

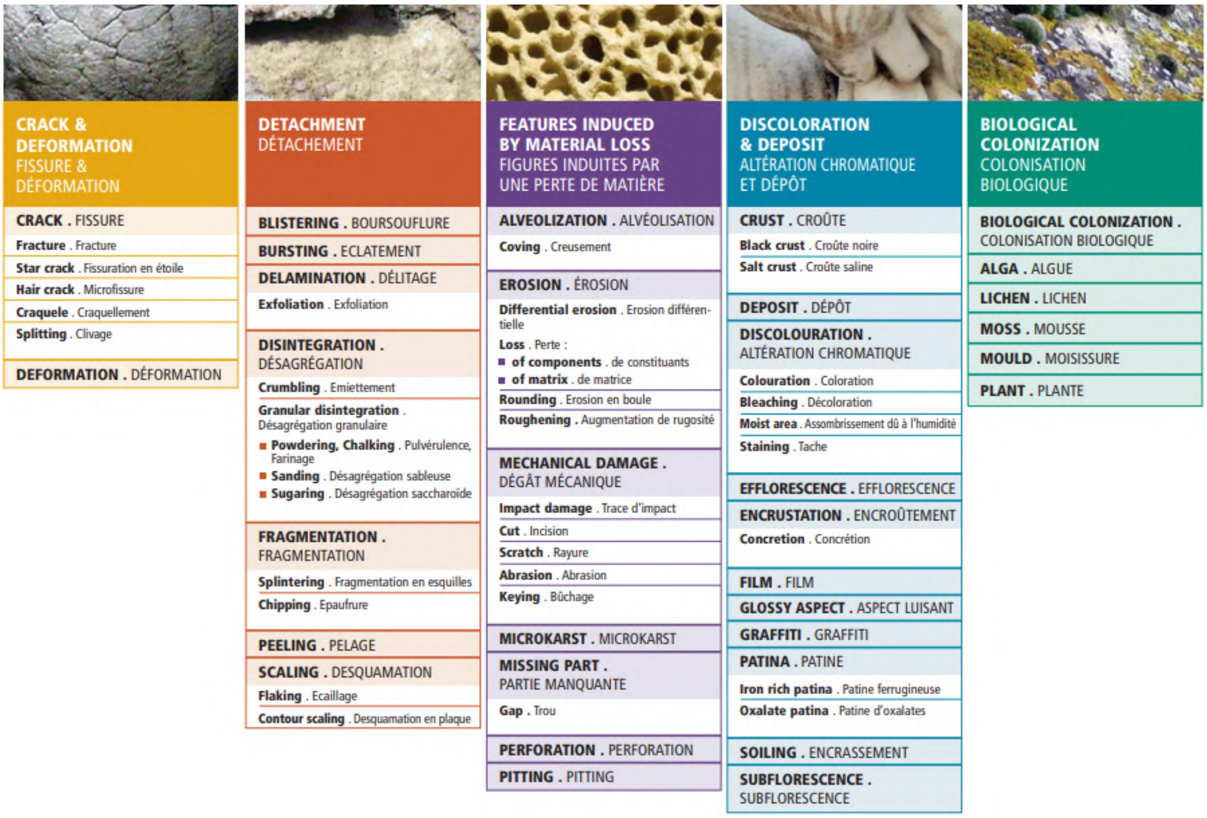


Figure 48: Stone deterioration classiffication. Source: Cartwright et al. (2008)

Each degradation type is a Revit Generic Family type represented with the colour determined by the glossary. The sample of the element is shown in Figure 49**.** The shape of the element is a circle, representing the overall area of the damage, and the user can control its size according to the damage size. The sub – types of the damages, (e.g. algae or moss in the case of “biological colonization”), can be defined in the family parameter, as well as any additional parameters requested by the GBC HB Manual. In addition, the photographic image can be inserted in the element, as shown in the Figure, representing the exact element and its condition if needed. The link in the URL parameter enables the user to directly access the online repository that can be used for the project.

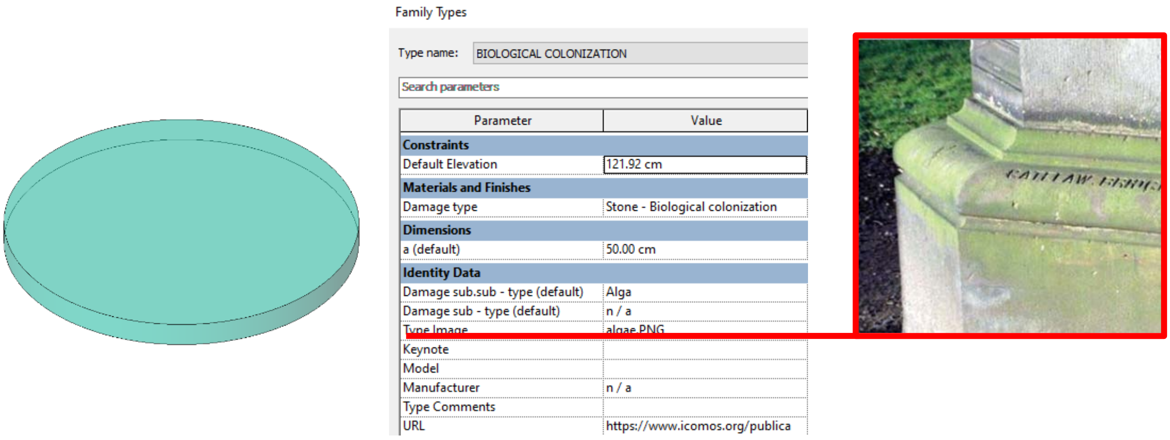


Figure 49: Generic family that represents the stone degradation types.

4. View template: Filters and Color schemes (construction phases and building functions)

Revit View templates were set to show particular building aspects required by the Prerequisite topic. For that, Filters the color schemes have been used. For the chosen scope of the prerequisite, four topics were covered (Table 29). For representing construction phases, a Filter was set for the team to later apply the defined color to the external elements (walls, slabs and roofs), corresponding to the construction phase the building elements have been built. To show the functions of a building floor, the "Room" category was used, which enabled the room naming, automatically showing its area and number. A color scheme had been made in advance for each of the room that can be part of the building type. The user should then pick the appropriate room name, and the corresponding color will fill the room area. For the representation of material degradation view, the Filter was used to show the degradation family colors and keep the rest of the model black and white. Moreover, each sheet is pre - set with the titleblock with the information to insert about the project, by inserting the corresponding projecti nformation parameters (such as project name, number, etc.). Information values are automatically filled in the titleblock when the "Project information" values were inserted from Excel using Dynamo graph.

5. Exporting setup

Next part of preparing the authoring tool template consists of defining the property export from Revit. One setting reffers exporting the information to .xml format, in order to fill the PDF form of the HB ID card. This can be done by exporting the graphical documentation set, the sheets in .pdf format. The non - graphical information was sorted by setting up a Revit schedule, which can be used by the team to export into .xml format. This format can be opened in the Excel file, and from there, by using a macro script, automatically fill the PDF file. In this way, the "Project information" and "Historic technological systems" of the HB ID card information is tranferred to the requested form. The "Project information" section is listed in the Excel file before the model is created, and therefore can be inserted in the PDF form even before being inserted in the model. For the "Historic technological systems" section, the Revit schedule has been set and it gets filled automatically when the team inserts the parameter values of the scheduled elements. The schedule template is presented in Figure 50.

<Pset_Technological unit_Shell - walls>					
A	B	C	D	E	F
Direct Information	Technologica lFeatures	Area	Historic Structure Percentage	Decorative Element	Decoration Descrip

Figure 50: Revit schedule template for technological unit Sell: walls. Source: author.

Second segment of this part includes formatting the parameters according to the rules of the IFC standard. It means that appropriate IFC export setup needs to be defined in Revit in order for the parameters to be mapped properly when the model is exported to IFC. The IFC export setup contains an option called “Property sets”, that was adjusted according to the project needs. Four options were tested for creating the appropriate property adjustment:

1. Revit property sets
   When exporting Revit property sets to IFC, the parameters get exported to the property sets (Pset) according to Revit parameter groups. It successfully transfers even the material properties to IFC, which was not possible by using the rest of the tested exporting options. Nevertheless, there is no consistency in this exporting approach or control of information flow. This means that the result is usually overloaded information and the unnecessarily large size of the exported model. Therefore, this kind of exporting was not used in the further process.
2. IFC common property sets
   In this case, the parameters get exported by matching the attribute names to the pre – defined IFC Pset. If the original IFC parameters are used in the project, they get transferred via the IFC exporter, and structured automatically. Normally, this exporting option has been used for the IFC parameters export.
3. Schedules as property sets
   The possibility of Autodesk Revit schedules to be set as the IFC Pset gives certain level of control to the process. Each schedule represents an IFC Pset, or specifically named schedules can be exported instead of all the schedules. This option had been tested on Historic Technological unit information for the ID card of the historic building. Nevertheless, this approach does not give the user full control. Namely, certain elements, such as IfcBuilding or IfcProject that cannot be scheduled in Revit in a way that the information gets transferred to the IFC. Furthermore, the created property set applies to all the elements containing the scheduled parameters, so the excess of information gets created in that way.
4. User defined property sets
   User defined Psets can be created using custom Pset mapping files. The mapping file is in .txt format. It is structured in two parts – definition of the Pset (the first row of the file), and definition of the parameters (the rest of the rows). First row is shown in Figure 53 - the property set is named the type or instance class of the parameters is set, and the category of element to map the parameter to is defined. Properties are then set, as shown in Figure 52: IFC parameter name, type and Revit parameter names are entered. Using the custom property sets, chosen parameters can be mapped directly to the IFC file and appropriate property set. It means that Revit parameter names are not influencing the exporting, since they can be modified to fit any IFC or further project needs and therefore are independent on the whole process. More importantly, using custom Psets, the user sets a parameter sorting in the IFC as preferred. Therefore, this option was chosen as most fit for the research purpose. Custom Psets are seen as

the most flexible, since there is the biggest amount of control given to the users. For this dissertation, custom property sets were made for the HB ID Card, for defining systematic export of custom properties for Project Information (Figure 51). The same principle can be used to export any parameter sets.

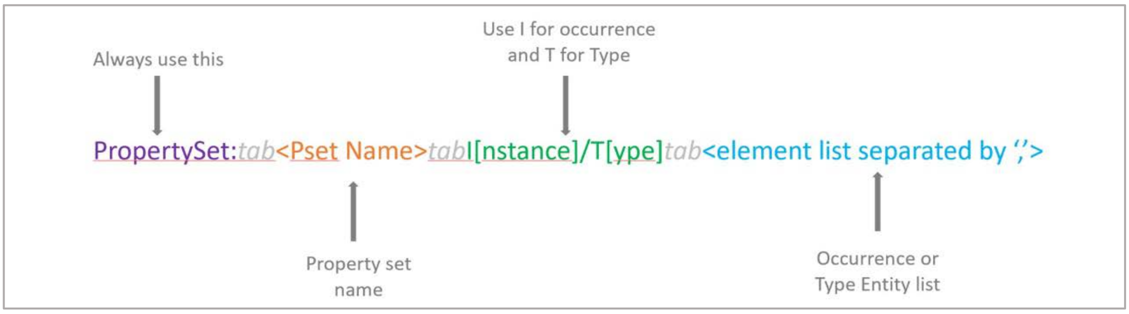


Figure 53: Property set setup. Source: Bond Bryan BIM n.d.

Figure 52: Properties setup. Source: Bond Bryan BIM n.d.

```
PropertySet:    ProjectInformation      I       IfcBuilding
                                        GBC_AUT_IDResponsible   Text    GBC_AUT_IDResponsible
                                        GBC_AUT_ProjectID       Text    GBC_AUT_ProjectID
                                        GBC_PRJ_BuildingCadastralParcel Text    GBC_PRJ_BuildingCadastralParcel
                                        GBC_PRJ_BuildingCAP     Text    GBC_PRJ_BuildingCAP
                                        GBC_PRJ_BuildingClimateZone     Text    GBC_PRJ_BuildingClimateZone
                                        GBC_PRJ_BuildingCommune  Text           GBC_PRJ_BuildingCommune
                                        GBC_PRJ_BuildingCurrentUse      Text            GBC_PRJ_BuildingCurrentUse
                                        GBC_PRJ_BuildingIndendedUse     Text    GBC_PRJ_BuildingIndendedUse
                                        GBC_PRJ_BuildingLocality        Text    GBC_PRJ_BuildingLocality
                                        GBC_PRJ_BuildingPositionType    Text    GBC_PRJ_BuildingPositionType
                                        GBC_PRJ_BuildingProtectionLevel Text    GBC_PRJ_BuildingProtectionLevel
                                        GBC_PRJ_BuildingProvince        Text    GBC_PRJ_BuildingProvince
                                        GBC_PRJ_Context Text    GBC_PRJ_Context
                                        GBC_PRJ_HistoricFramework       text    GBC_PRJ_HistoricFramework
                                        GBC_PRJ_Other   Text    GBC_PRJ_Other
                                        GBC_PRJ_PrevInterventionDescription- 1  Text
GBC_PRJ_PrevInterventionDescription- 1
                                        GBC_PRJ_PrevInterventionType- 1 Text    GBC_PRJ_PrevInterventionType- 1
```

Figure 51: Project information Property set mapping file opened in Notepad. Source: author

With this step, the Template creation phase of the framework process (Figure 38) is finished. The results are the inputs for the application phase of proposed process that involves BIM Manager and the project team for starting the certification application project. Those inputs include, as shown in Figure 39: Proposed Excel template, Method for connecting the Excel data and authoring tool and the proposed authoring tool template. They can be adapted by the BIM Manager and used by the design team as guidelines for the project documentation creation. The second stage, the application, will be demonstrated in the next chapter on the case study.

5. DEMONSTRATION ON THE CASE STUDY

This chapter contains demonstration of the proposed framework on the case study. When referring to the framework described in Chapter 4 (Figure 38), the application phase is when the design team uses the implemented tools. Figure 39 shows the proposed process for the design team. Demonstration of the process is applied to the adopted Autodesk Revit model of Paço dos Duques de Bragança, in Guimarães. Since this dissertation is focusing on information management and interoperability, the purpose of the demonstration is showing the feasibility of the proposed framework, by using the set template files to create and transfer requested information in the needed forms. The modelling process itself is outside of the scope, and would not influence the framework creation, which is the reason for using the already existing model. Nevertheless, based on the property values to be created from the model, observed notions of the modelling rules (for the wall elements), that could be established during the proposed process will be mentioned briefly.

First, the general summary of the case study is presented, followed by the description of the adopted model elements that were used for the demonstration. After that, the implemented framework is demonstrated on the case study, according to the proposed process from the Chapter 4 (Figure 39). The collected data on the project information is inserted in the pre - made Excel spreadsheet templates and transferred to the authoring tool using the pre – set visual scripting tool. Then, the model was updated according to the Historic Building Identity card requirements and deliverables requests. The property values were inserted and the views were placed to the corresponding sheets. In the end, from the authoring tool, deliverables in the scope of the dissertation (Table 29) are created and exported. The whole model was finally exported to the IFC format to test the IFC exporting setup.

5.1. Case study description

The model adopted for the demonstration represents the section of the museum and the former medieval residence, Paço dos Duques de Bragança in Guimarães (Figure 54). The model had been created by Carlo Andrés Alarcón Bahamondes for his Master's thesis in structural analysis of monuments and histrorical constructions, in University of Minho, Portugal, 2018. The building itself is a fortified palace of vast dimensions, with strong sloped roofs and numerous cylindrical chimneys that show the influence of the Northern European architecture. ("Palace of the Dukes of Bragança :: Guimarães Turismo," n.d.). Most of the material used for its construction was stone, and much of the stone used is granite. The building is structured around a central rectangular courtyard with six tall chimneys. The first floor has a covered balcony running along the inside of the building. When it comes to its functions throughout the history, ground floor contained the kitchen and store rooms and was mainly used by the servants. The first floor held the rooms of the Duke and Duchess and the chapel. After the renovations during the "Estado Novo" period, the house became an official residence of the President of the Republic. The second and highest floor is now used for temporary exhibitions. The interior contains collections of furniture, carpets and copies of the Pastrana tapestries, attributed to the 15th century painter Nuno Gonçalves. These depict the Portuguese invasion of North Africa ("Palace of the Dukes of Braganza in Guimarães," n.d.)

Figure 54: Paço dos Duques de Bragança, Guimarães.
Source: "Paço dos Duques de Bragança," n.d.

The adopted model, shown in Figure 55, represents a section of the existing building. It includes external and internal historic elements: masonry walls, windows, slabs, and roof construction and roof cover, with the related custom libraries of families that represent specific historic elements. These elements were used to collect and represent the geometric information of the BIM model. The adopted model additionally contains the family of the degradation types, which was used as a basis for the material degradation typology application and representation (Figure 56).

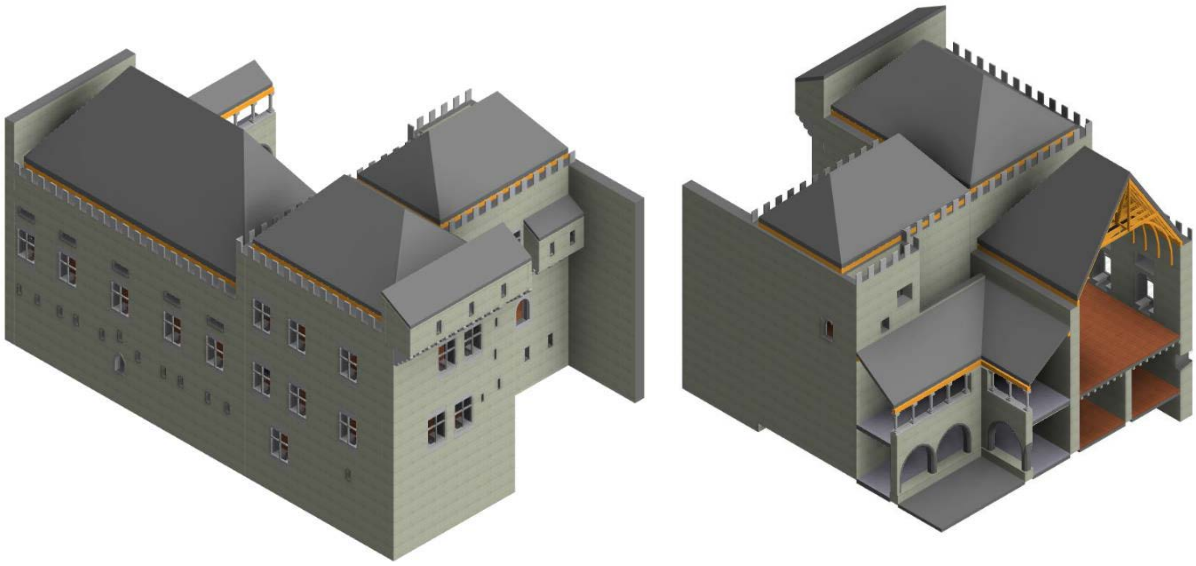
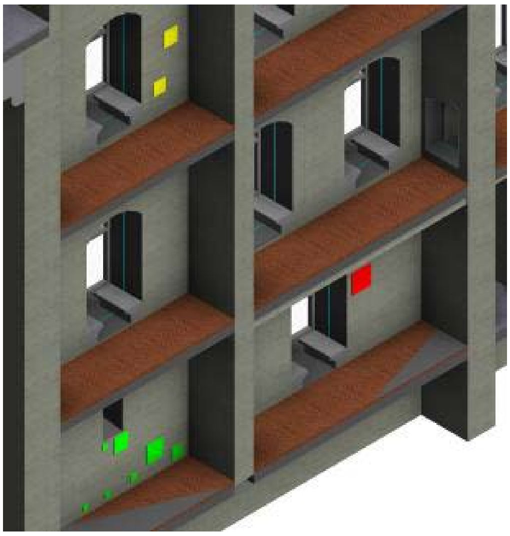


Figure 55: Axonometric views of the proposed model. Source:
Alarcón Bahamondes, 2018.



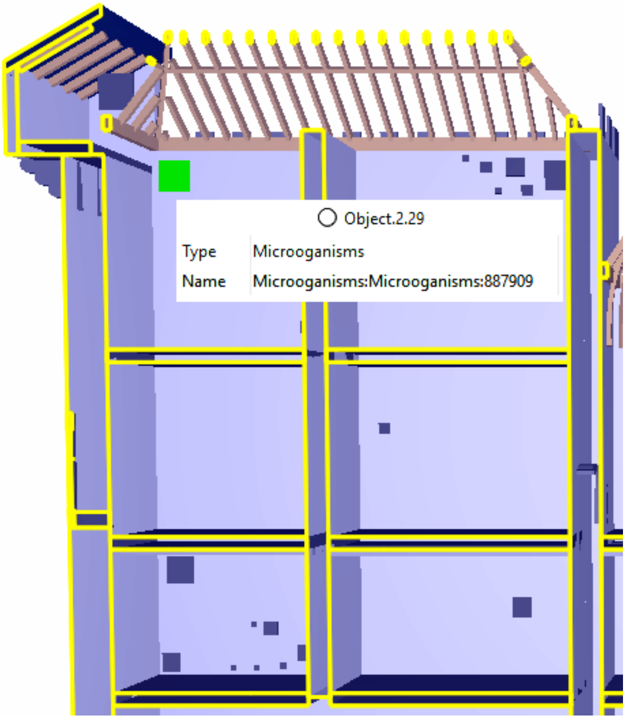


Figure 56: Damage representation in the model.
Source: Alarcón Bahamondes, 2018.

5.2. Demonstration of the proposed framework application

The implemented framework proposed in the Chapter 4 (Figure 38) is demonstrated on the adopted model of Ducal palace, within the defined scope (see Table 29). The demonstration serves as a simulation of the process that is proposed to be done by the design team while applying for the Prerequisite 1 of the Historic value credit category. It involves information management process of creating the documentation for the requested deliverable – Historic Building identity card, with clear focus on interoperability and data preservation.

5.2.1. Filling the Excel template

First step of the process is shown in the BOX E of Figure 38. The team should here create copies of the project information set – up Excel files in their project directory and add the available values of the existing and custom parameters. The project information properties values are, as mentioned, usually known even before the modelling starts. Therefore, the team can enter the values using the Excel spreadsheet, as shown in Table 42. Values for the view and sheet creation, such as sheet naming, numbering and sorting methods, are to be adapted in this step too, since the necessary views and sheets are likewise known at this time.

Table 42: Excel spreadsheet with the project information values.

PARAMETERS	PARAMETER VALUES
Building Address	**R**. Conde Dom Henrique 3, 4800-412 Guimarães, Portugal
Building Name	Paço dos Duques de Bragança
ConstructionMethod	Sustainable renovation
GBC_AUT_IDCResponsible	Jelena Zuric
GBC_AUT_ProjectID	GBC_HB-P01
GBC_PRJ_BuildingCadastralParcel	123456
GBC_PRJ_BuildingCAP	n/a
GBC_PRJ_BuildingClimateZone	D
GBC_PRJ_BuildingCommune	n/a
GBC_PRJ_BuildingCurrentUse	Museum
GBC_PRJ_BuildingIndendedUse	Museum
GBC_PRJ_BuildingLocality	Guimaraes
GBC_PRJ_BuildingPositionType	Free - standing
GBC_PRJ_BuildingProtectionLevel	National Monument
GBC_PRJ_BuildingProvince	n/a
GBC_PRJ_Context	n/a
GBC_PRJ_HistoricFramework	The ground floor contained the kitchen and store rooms and was mainly used by the servants. The first floor held the rooms of the Duke and Duchess and the chapel. The building is structured around a central rectangular courtyard with six tall chimneys. Much of the stone used is granite. The first floor has a covered balcony running along the inside of the building. The second (highest) floor is now used for temporary exhibitions. After the renovations during the Estado Novo period, the house became an official residence of the President of the Republic. The interior contains collections of furniture, carpets and copies of the Pastrana tapestries, attributed to the 15th century painter Nuno Gonçalves, the creator of the panels at São Vincente de Fora in Lisbon. These depict the Portuguese invasion of North Africa.
GBC_PRJ_Other	n/a
GBC_PRJ_PrevInterventionDescription-1	Undoing of the changes done by the military; demolition of surrounding houses; Implementation of reinforced concrete floors and surfacing the reinforced concrete floors with ceramic tiles; Construction of some chimneys according to the existing fireplaces; reconstruction of the roofs according to original ones; coating of reinforced concrete beams and floors with a chestnut cover; The Arragement of kitchen and

	addition of and some services; Installation of sewage networks, sanitary facilities, water distribution, electricity and lightning facilities;
GBC_PRJ_PrevInterventionType-1	Demolition and implementation
PlanningControlStatus	Museum sustainable preservation
Project Name	GBC HB Certification
Project Number	GBC HB Certification
YearOfConstruction	1420-1478
YearOfLastRefurbishment	1936 - 1959

Table 43 shows the example of the filled Excel spreadsheet with the sheet list and the associated parameters. To represent the project in the simplest way, one sheet is created per each credit of every credit category. Additional sheets have been listed for the Prerequisite 1 of Historic value category, according to the requested drawing topics, for demonstration purposes, and since the Historic value Prerequisite 1 deliverables are in the scope of the detailed analysis. It is up to the design team to decide how many sheets are necessary for each credit, and to fill the rest of the columns accordingly.

Table 43: Excel spreadsheet with the sheet list and associated parameters.

Sheet Number	Sheet name	GBC_SRT_CreditCategory	GBC_SRT_PossiblePoints	GBC Historic building	GBC_SRT_PointsToAchieve	Drawn By	Checked By	Approved By
HV_PR 1.1	Construction Phases and Functions	01 - Historic Value	0	Yes	0	BIM Modeller	BIM Coordinator	BIM Manager
HV_PR 1.2	Shell.Walls - Materials & Techniques	01 - Historic Value	0	Yes	0	BIM Modeller	BIM Coordinator	BIM Manager
HV_PR 1.3	Elevation1 - Shell.Walls - Macroscopic forms of degradation	01 - Historic Value	0	Yes	0	BIM Modeller	BIM Coordinator	BIM Manager
HV_C 1.1	Advanced analysis - energy audit	01 - Historic Value	3	Yes	3	BIM Modeller	BIM Coordinator	BIM Manager
HV_C 1.2	Advanced analysis - diagnostic tests on materials and degradation	01 - Historic Value	2	Yes	2	BIM Modeller	BIM Coordinator	BIM Manager
HV_C 1.3	Advanced analysis - diagnostic tests on structures and structural monitoring	01 - Historic Value	3	Yes	3	BIM Modeller	BIM Coordinator	BIM Manager

HV_C 2.0	Project reversibility	01 - Historic Value	2	Yes	2	BIM Modeller	BIM Coordinator	BIM Manager
HV_C 3.2	Chemical and physical compatibility of integrated materials	01 - Historic Value	2	Yes	2	BIM Modeller	BIM Coordinator	BIM Manager
HV_C 3.3	Structural compatibility	01 - Historic Value	2	Yes	2	BIM Modeller	BIM Coordinator	BIM Manager
HV_C 4.0	Sustainable restoration site	01 - Historic Value	1	Yes	1	BIM Modeller	BIM Coordinator	BIM Manager
HV_C 5.0	Scheduled maintenance plan	01 - Historic Value	2	Yes	2	BIM Modeller	BIM Coordinator	BIM Manager
SS_PR 1.0	Construction activity pollution prevention	02 - Sustainable Sites	0	Yes	0	BIM Modeller	BIM Coordinator	BIM Manager
SS_C 1.0	Brownfield redevelopment	02 - Sustainable Sites	2	Yes	2	BIM Modeller	BIM Coordinator	BIM Manager
SS_ C 2.1	Alternative transportation - public transportation access	02 - Sustainable Sites	1	Yes	1	BIM Modeller	BIM Coordinator	BIM Manager
SS_C 2.2	Alternative transportation - bicycle storage and changing rooms	02 - Sustainable Sites	1	Yes	1	BIM Modeller	BIM Coordinator	BIM Manager
SS_C 2.3	Alternative transportation - low-emitting and fuel-efficient vehicles	02 - Sustainable Sites	1	Yes	1	BIM Modeller	BIM Coordinator	BIM Manager
SS_C 2.4	Alternative transportation - parking capacity	02 - Sustainable Sites	1	Yes	1	BIM Modeller	BIM Coordinator	BIM Manager
SS_C 3.0	Site development - open spaces recovery	02 - Sustainable Sites	2	Yes	2	BIM Modeller	BIM Coordinator	BIM Manager
SS_C 4.0	Stormwater design - quantity and quality control	02 - Sustainable Sites	2	Yes	2	BIM Modeller	BIM Coordinator	BIM Manager
SS C 5.0	Heat island effect - non-roof and roof	02 - Sustainable Sites	2	Yes	2	BIM Modeller	BIM Coordinator	BIM Manager
SS C 6.0	Light pollution reduction	02 - Sustainable Sites	1	No	1	BIM Modeller	BIM Coordinator	BIM Manager
WE_PR 1.0	Water use reduction	03 - Water Efficiency	0	Yes	0	BIM Modeller	BIM Coordinator	BIM Manager
WE_C 1.0	Water efficient landscaping	03 - Water Efficiency	3	Yes	3	BIM Modeller	BIM Coordinator	BIM Manager
WE_C 2.0	Water use reduction	03 - Water Efficiency	3	Yes	3	BIM Modeller	BIM Coordinator	BIM Manager
WE_C 3.0	Water metering	03 - Water Efficiency	2	Yes	2	BIM Modeller	BIM Coordinator	BIM Manager
EA_PR 1.0	Fundamental commissioning of building energy systems	04 - Energy and atmosphere	0	Yes	0	BIM Modeller	BIM Coordinator	BIM Manager
EA_PR 2.0	Minimum energy performance	04 - Energy and atmosphere	0	Yes	0	BIM Modeller	BIM Coordinator	BIM Manager

MR_PR 1.0	Storage and collection of recyclables	05 - Materials & Resources	0	No	0	BIM Modeller	BIM Coordinator	BIM Manager
MR_PR 2.0	Demolition and construction waste management	05 - Materials & Resources	0	Yes	0	BIM Modeller	BIM Coordinator	BIM Manager
MR_PR 3.0	Building reuse	05 - Materials & Resources	0	Yes	0	BIM Modeller	BIM Coordinator	BIM Manager
MR_C 1.0	Building reuse - maintaining existing technical element and finishing	05 - Materials & Resources	3	Yes	3	BIM Modeller	BIM Coordinator	BIM Manager
MR_C 2.0	Demolition and construction waste management	05 - Materials & Resources	2	Yes	2	BIM Modeller	BIM Coordinator	BIM Manager
MR_C 3.0	Materials reuse	05 - Materials & Resources	2	Yes	2	BIM Modeller	BIM Coordinator	BIM Manager
MR_C 4.0	Building product environmental optimization	05 - Materials & Resources	5	Yes	5	BIM Modeller	BIM Coordinator	BIM Manager
MR_C 5.0	Regional materials	05 - Materials & Resources	2	Yes	2	BIM Modeller	BIM Coordinator	BIM Manager
IEQ_PR 1.0	Minimum indoor air quality performance (IAQ)	06 - Indoor Environmental Quality	0	Yes	0	BIM Modeller	BIM Coordinator	BIM Manager
IEQ_PR 2.0	Environmental Tobacco Smoke (ETS) control	06 - Indoor Environmental Quality	0	Yes	0	BIM Modeller	BIM Coordinator	BIM Manager
IEQ_C 1.0	Air monitoring	06 - Indoor Environmental Quality	2	Yes	2	BIM Modeller	BIM Coordinator	BIM Manager
IEQ_C 2.0	Outdoor air delivery monitoring	06 - Indoor Environmental Quality	2	Yes	2	BIM Modeller	BIM Coordinator	BIM Manager
IEQ_C 4.1	Low-emitting materials - adhesives and sealants	06 - Indoor Environmental Quality	1	Yes	1	BIM Modeller	BIM Coordinator	BIM Manager
IEQ_C 4.2	Low-emitting materials - paints and coatings	06 - Indoor Environmental Quality	1	Yes	1	BIM Modeller	BIM Coordinator	BIM Manager
IEQ_C 4.3	Low-emitting materials - flooring systems	06 - Indoor Environmental Quality	1	Yes	1	BIM Modeller	BIM Coordinator	BIM Manager
IEQ_C 4.4	Low-emitting materials - composite wood and agrifiber products	06 - Indoor Environmental Quality	1	Yes	1	BIM Modeller	BIM Coordinator	BIM Manager
IEQ_C 5.0	Indoor chemical and pollutant source control	06 - Indoor Environmental Quality	1	Yes	1	BIM Modeller	BIM Coordinator	BIM Manager
IEQ_C 6.1	Controllability of systems - lighting	06 - Indoor Environmental Quality	1	Yes	1	BIM Modeller	BIM Coordinator	BIM Manager
IEQ_C 6.2	Controllability of systems - thermal comfort	06 - Indoor Environmental Quality	1	Yes	1	BIM Modeller	BIM Coordinator	BIM Manager
IEQ_C 7.1	Thermal comfort - design	06 - Indoor Environmental Quality	1	Yes	1	BIM Modeller	BIM Coordinator	BIM Manager
IEQ_C 7.2	Thermal comfort - verification	06 - Indoor Environmental Quality	2	Yes	2	BIM Modeller	BIM Coordinator	BIM Manager
ID_C 1.0	Innovation in design - name accordingly	07 - Innovation in design	5	Yes	5	BIM Modeller	BIM Coordinator	BIM Manager

5.2.2. Using the authoring tool template

The data from the Excel files should be then inserted in the authoring tool. The proposed method uses Dynamo graphs set to be used by the design team by opening the Dynamo Player in Revit. The user is to first choose the graph to be run (one of the graphs described in Chapter 3), and then to insert the inputs for the graph. In this case, the first input should be the Excel file and corresponding sheet. Other inputs are the elements (Revit element categories) to which the parameters and values should be applied to. In this demonstration, the properties from the Dynamo graphs are applied to the project information, external elements (walls, roofs, and slabs), as well as the drawing views and sheets. When the defined properties are inserted, the modelling process can start, and the Revit template is used to extend the information quantity, by using the pre – set libraries, views, and Browser organisation.

Project Browser organisation

The documentation set organization is shown in the Revit Project Browser. In order for the workflow to be functional, the team should be enabled to easily navigate throuh the complex documentation set the GBC Certification is demanding. The Excel spreadsheet with the sheet and view list was transferred to Revit, where the views and sheets were named, along with the new parameters and values. Those parameters were used in Project Browser for documentation set sorting. Figure 57 shows the section of the Browser organisation made for the views of Prerequisite 1 of Historic Value. It can be seen here that the views are first sorted by the credit category they belong to, which is Historic Value in this case. Second level of the view grouping is the topic the credit covers, which consists of the views needed for that particular topic. Figure 58 shows the section of the project Browser organisation made for the sheets. They are likewise organized by the credit categroy they belong to, with each credit representing one sheet. The Prerequisite 1 contains four sheets, for the demonstration purposes of this dissertation.

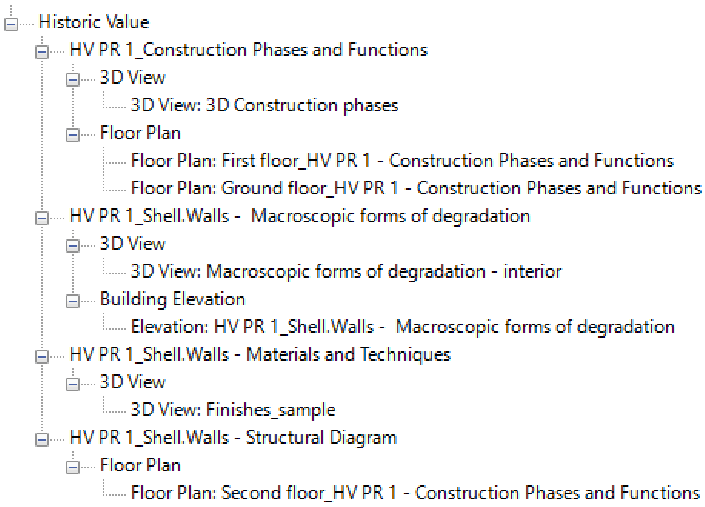


Figure 57: Revit Project Browser organisation: sample of Historic Value views. Source: author.

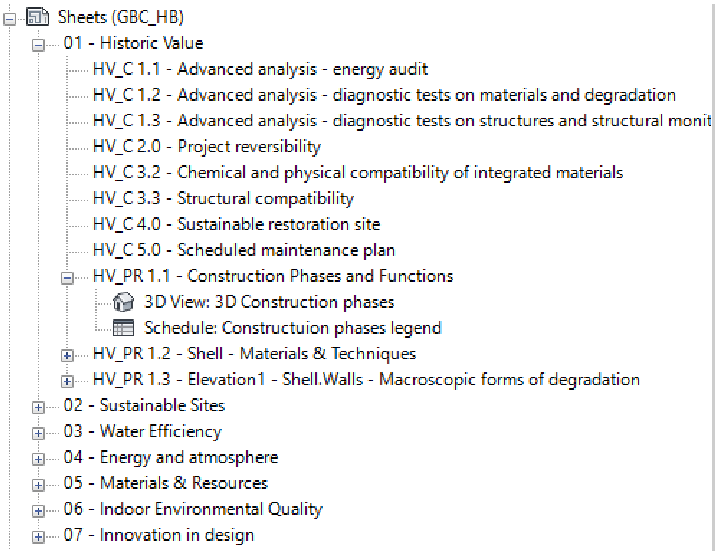


Figure 58: Revit Project Browser organisation: sample for the Sheet organisaition.

Property management

The Excel sheet list (Table 43) is additionaly used to form a Revit schedule, which serves as a checklist for the credit application in order for the team to see which sheets are used to apply for which credit and to control the documentation status. Figure 59 represents the sample of the checklist, showing the information about the sheet: sheet number, the credit category it belongs to, its name: as well as the checking about the Certificaition status: maximum possible points, credit application status points to obtain. The credit application column is based on shared parametrs with the yes / no value, and the points to acheive column is calculated value based on a conditional statement from the credit application column. If the column is checked, it gives the number of points to obtain, and if it is not, it gives zero points, painting the cells in red, so it is clear to the team that they haven't satisfied the credit application yet. The schedule also allows to calculate automatically the total number of points aiming to obtain. Using this principle, schedules can be made and adapted for each of the credit to keep control of the project particularities. Moreover, schedules are commonly used to document data and perform calculations, which is possible to apply in this case too. The constraint is that the data cannot be cross – refferenced between the schedules - calculated values with parameters associated with different schedules, or with associated files. More complex calculations should be performed using more sofisticated tools, such as computational design tools.

<GBC Historic Building Checklist>

A	B	C	D	E	F
Sheet Number	Credit Category	Sheet Name	Possible Points	Credit Application	Points to Obtain
HV_PR 1.1	01 - Historic Value	Construction Phases	0	☑	0
HV_PR 1.2	01 - Historic Value	Shell - Materials & Techniques	0	☑	0
HV_PR 1.3	01 - Historic Value	Elevation1 - Shell.Walls - Macroscopic forms of degradatio	0	☑	0
HV_C 1.1	01 - Historic Value	Advanced analysis - energy audit	3	☑	3
HV_C 1.2	01 - Historic Value	Advanced analysis - diagnostic tests on materials and degr	2	☑	2
HV_C 1.3	01 - Historic Value	Advanced analysis - diagnostic tests on structures and stru	3	☑	3
HV_C 2.0	01 - Historic Value	Project reversibility	2	☑	2
HV_C 3.2	01 - Historic Value	Chemical and physical compatibility of integrated materials	2	☑	2
HV_C 3.3	01 - Historic Value	Structural compatibility	2	☑	2
HV_C 4.0	01 - Historic Value	Sustainable restoration site	1	☑	1
HV_C 5.0	01 - Historic Value	Scheduled maintenance plan	2	☐	0
SS_PR 1.0	02 - Sustainable Sites	Construction activity pollution prevention	0	☑	0
SS_C 1.0	02 - Sustainable Sites	Brownfield redevelopment	2	☑	2
SS_ C 2.1	02 - Sustainable Sites	Alternative transportation - public transportation access	1	☑	1
SS_C 2.2	02 - Sustainable Sites	Alternative transportation - bicycle storage and changing ro	1	☑	1
SS_C 2.3	02 - Sustainable Sites	Alternative transportation - low-emitting and fuel-efficient v	1	☑	1
SS_C 2.4	02 - Sustainable Sites	Alternative transportation - parking capacity	1	☑	1
SS_C 3.0	02 - Sustainable Sites	Site development - open spaces recovery	2	☐	0
SS_C 4.0	02 - Sustainable Sites	Stormwater design - quantity and quality control	2	☑	2
SS C 5.0	02 - Sustainable Sites	Heat island effect - non-roof and roof	2	☐	0
SS C 6.0	02 - Sustainable Sites	Light pollution reduction	1	☑	1
WE_PR 1.0	03 - Water Efficiency	Water use reduction	0	☑	0
WE_C 1.0	03 - Water Efficiency	Water efficient landscaping	3	☑	3
WE_C 2.0	03 - Water Efficiency	Water use reduction	3	☑	3
WE_C 3.0	03 - Water Efficiency	Water metering	2	☑	2
EA_PR 1.0	04 - Energy and atmosphere	Fundamental commissioning of building energy systems	0	☑	0
EA_PR 2.0	04 - Energy and atmosphere	Minimum energy performance	0	☑	0
MR_PR 1.0	05 - Materials & Resources	Storage and collection of recyclables	0	☑	0
MR_PR 2.0	05 - Materials & Resources	Demolition and construction waste management	0	☑	0
MR_PR 3.0	05 - Materials & Resources	Building reuse	0	☑	0
MR_C 1.0	05 - Materials & Resources	Building reuse - maintaining existing technical element and f	3	☑	3
MR_C 2.0	05 - Materials & Resources	Demolition and construction waste management	2	☑	2
MR_C 3.0	05 - Materials & Resources	Materials reuse	2	☑	2
MR_C 4.0	05 - Materials & Resources	Building product environmental optimization	5	☑	5
MR_C 5.0	05 - Materials & Resources	Regional materials	2	☑	2
IEQ_PR 1.0	06 - Indoor Environmental Qua	Minimum indoor air quality performance (IAQ)	0	☑	0
IEQ_PR 2.0	06 - Indoor Environmental Qua	Environmental Tobacco Smoke (ETS) control	0	☑	0
IEQ_C 1.0	06 - Indoor Environmental Qua	Air monitoring	2	☑	2
IEQ_C 2.0	06 - Indoor Environmental Qua	Outdoor air delivery monitoring	2	☑	2
IEQ_C 4.1	06 - Indoor Environmental Qua	Low-emitting materials - adhesives and sealants	1	☑	1
IEQ_C 4.2	06 - Indoor Environmental Qua	Low-emitting materials - paints and coatings	1	☑	1
IEQ_C 4.3	06 - Indoor Environmental Qua	Low-emitting materials - flooring systems	1	☑	1
IEQ_C 4.4	06 - Indoor Environmental Qua	Low-emitting materials - composite wood and agrifiber produ	1	☑	1
IEQ_C 5.0	06 - Indoor Environmental Qua	Indoor chemical and pollutant source control	1	☑	1
IEQ_C 6.1	06 - Indoor Environmental Qua	Controllability of systems - lighting	1	☑	1
IEQ_C 6.2	06 - Indoor Environmental Qua	Controllability of systems - thermal comfort	1	☑	1
IEQ_C 7.1	06 - Indoor Environmental Qua	Thermal comfort - design	1	☑	1
IEQ_C 7.2	06 - Indoor Environmental Qua	Thermal comfort - verification	2	☑	2
ID_C 1.0	07 - Innovation in design	Innovation in design - name accordingly	5	☑	5

Figure 59: Revit schedule as a GBC Historc Building checklist.

Further on, the Excel spreadsheets used for the project information parameters and values were mapped to the Project information sector in Revit. Figure 60 shows the Project information table with the inserted parameters and values. All of the previously listed custom and pre – existing parameters are located here, and can be modified if needed.

Parameter	Value
Identity Data	
Organization Name	Poliecnico di Milano
Organization Description	BIM A+ Master
Building Name	Paço dos Duques de Bragança
Author	Carlo Andrés Alarcón Bahamondes
GBC_AUT_IDCResponsible	Jelena Zuric
GBC_AUT_ProjectID	GBC_HB-P01
GBC_PRJ_BuildingCadastralParcel	123456.000000
GBC_PRJ_BuildingCAP	n/a
GBC_PRJ_BuildingClimateZone	D
GBC_PRJ_BuildingCommune	n/a
GBC_PRJ_BuildingCurrentUse	Museum
GBC_PRJ_BuildingIndendedUse	Museum
GBC_PRJ_BuildingLocality	Guimaraes
GBC_PRJ_BuildingPositionType	Free - standing
GBC_PRJ_BuildingProtectionLevel	National Monument
GBC_PRJ_BuildingProvince	n/a
GBC_PRJ_Context	n/a
GBC_PRJ_HistoricFramework	The ground floor contained the kitchen and store rooms and
GBC_PRJ_Other	n/a
GBC_PRJ_PrevInterventionDescription-1	Undoing of the changes done by the military; demolition of
GBC_PRJ_PrevInterventionType-1	Demolition and implementation
Energy Analysis	
Energy Settings	Edit...
General	
NBSSpecificationPath	
NBLProjectId	46592cb6-d640-4179-9654-be65070c5f4c
Data	
YearOfConstruction	1420-1478
PlanningControlStatus	Museum sustainable preservation
ConstructionMethod	Sustainable renovation
Route Analysis	
Route Analysis Settings	Edit...
Other	
Project Issue Date	21.08.2020.
Project Status	Master thesis project
Client Name	Politecnico di Milano
Project Address	R. Conde Dom Henrique 3
Project Name	GBC HB Certification
Project Number	GBC HB Certification
Address	R. Conde Dom Henrique 3

Figure 60: Project information table with the inserted parameters and values.

Lastly, the custom parameters inserted for the shell are shown here applied to the wall element Revit category. The parameter values were inserted using Revit in this case. The type and instance properties were used. Figure 62 shows the custom type properties with the inserted values. Figure 61 shows the pre – existing and custom instance properties used for the wall element category.

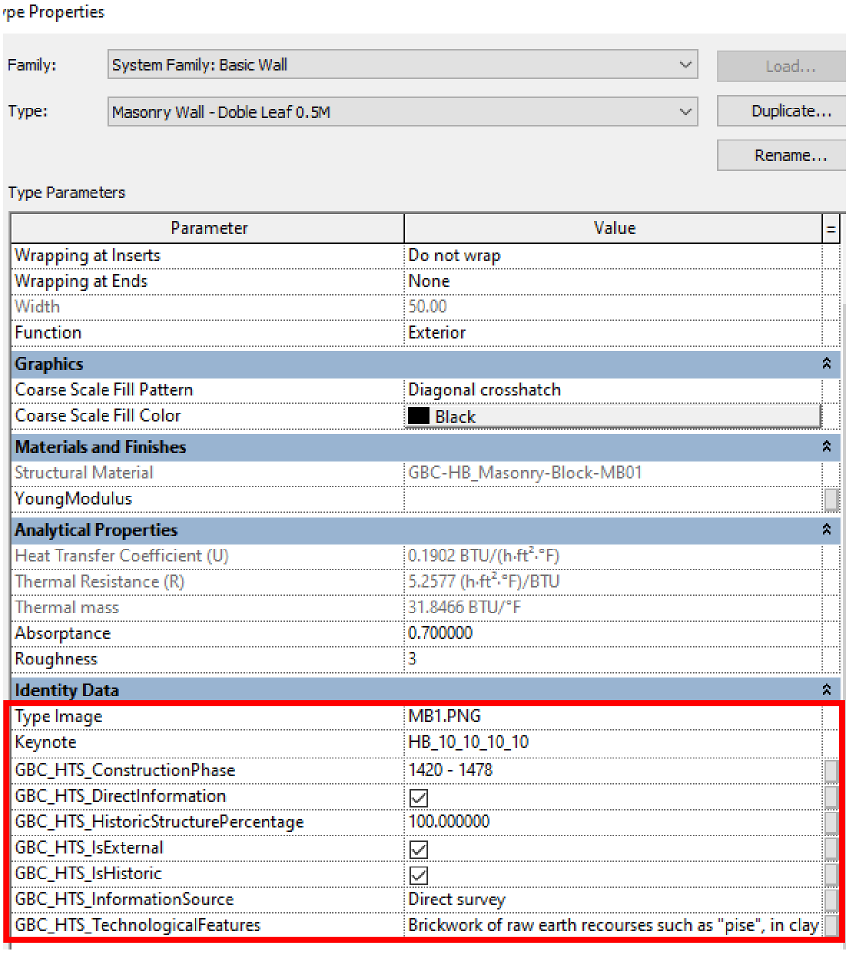


Figure 62: Type properties used for the wall element cageories.

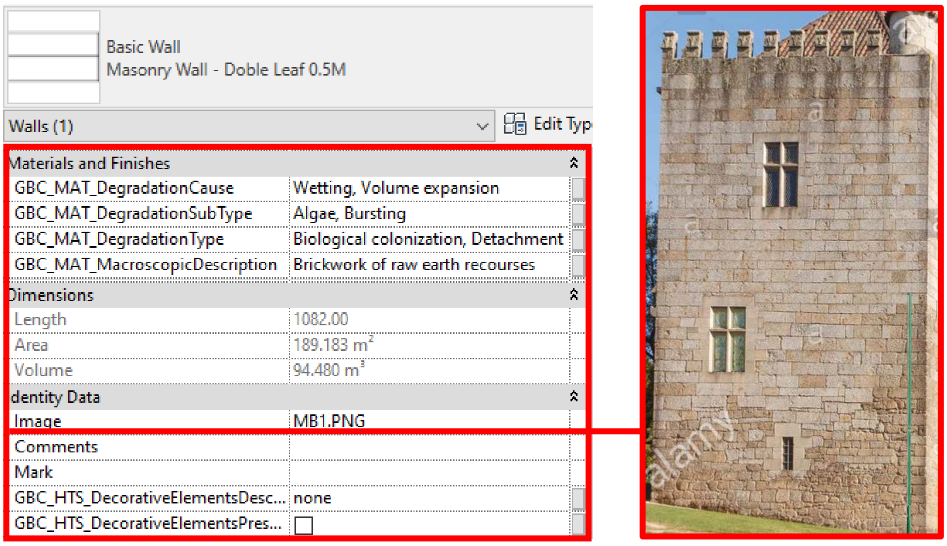


Figure 61: Instance properties used for the wall element categories.

When all the property values are created and inserted within the model, the pre – defined schedule templates are automatically filled. The example of the model elements of the external wall Revit category is made to demonstrate this application. There are a few noticed particularities that should be considered when modelling and defining the properties in this case. Currently, there are numer of ways to create historic element geometry, which also depends on the detail level that is needed. When it comes to the area calculation, the automatically calculated element areas as well as total area of the element in Revit can give more precise results than requested in the HB ID card. There is an option to precisely define the formula for area calculation using computational design tool, giving even more control to the information output. Nevertheless, for this phase this was not seen as necessary. Additional modelling rule for satisfying area calculation results is suppossed to be given to deifning the relationship between different elements. For example, the relationship between the extrernal wall and the floor slabs can be modelled in few different ways, which is also dependant on the existing building facade geometry. When the facade geometry is simple, there is no complex rules needed. If the building has some kind of horizontal divisions, the slab can be modelled to penetrate the walls, which excludes the facade parts that should be taken into account when calculating the external wall area. For that case, the solution can be to add an extra layer to the external walls, which would not be penetrated by the slabs. The layer would be thin, invisible and serve only to connect the external walls in one unity for the calculation. The more complicated the facade geometry is, the modelling rules need to be more strict, especially for the later project stages. Since this dissertation focuses on information management, the goal for the geometry modelling process was to simplify the geometry itself while gathering and transforming all the requested information. Since the walls are modelled as continuous elements, area was extracted automaticlly by Revit. The schedule made for extracting the technological unit information for the HB ID card is shown in Figure 63. The modelling rule proposed for extracting numerical values is to model the historic part of the wall as one wall element, and non – historic as another, and fill the “IsHistoric” parameter accordingly. In this way, all the wall elements will be 100% historic or non – historic. Since only the historic elements are being inserted into the PDF form, and the historic element percentage requested is the personal estimation rather than precise value, the scheduling process can be simplified. Therefore, regarding the Revit schedule, only extrernal and historic walls are shown, by filtering them using the parameters “IsExternal” and “IsHistoric”.

<Pset_Technological unit_Shell - walls>

A	B	C	D	E	F
Direct Information	Technologica lFeatures	Area	Historic Structure Percentage	Decorative Element	Decoration Descrip
Brickwork "adobe" raw clay bricks					
☐	Brickwork "adobe" raw clay bricks	136.5 m²	100	☑	Decorative Fretwo
Brickwork "adobe" raw clay bricks: 1		136.5 m²			
Brickwork of raw earth recourses such as "pise", in clay or in reinforced earth					
☐	Brickwork of raw earth recourses such as "pise", in clay or in reinforced	1333.5 m²	100	☑	Decorative Fretwo
Brickwork of raw earth recourses such as "pise", in clay or in reinforced earth: 5		1333.5 m²			
Brickwork "adobe" raw clay bricks					
☑	Brickwork "adobe" raw clay bricks	235.4 m²	100	☐	None
Brickwork "adobe" raw clay bricks: 1		235.4 m²			
Brickwork of raw earth recourses such as "pise", in clay or in reinforced earth					
☑	Brickwork of raw earth recourses such as "pise", in clay or in reinforced	2250.5 m²	100	☐	None
Brickwork of raw earth recourses such as "pise", in clay or in reinforced earth: 34		2250.5 m²			
Grand total: 41		3955.9 m²			

Figure 63: Revit schedule for the technological units – shell: walls.

When exported to .xml and opened in Excel, the schedule looks like the table shown in Figure 64. The information that needs to be filled into the PDF form of the HB ID card is highlighted.

Pset_Technological unit_Shell - walls					
Direct Information	Technological Features	Area	Historic Structure Percentage	Decorative ElementsPresent	Decoration Descripton
No					
Brickwork "adobe" raw clay bricks					
No	Brickwork "adobe" raw clay bricks	136.5 m²	100	Yes	Decorative Fretworf
		136.5 m²	*Quantity*		
Brickwork of raw earth recourses such as "pise", in clay or in reinforced earth					
No	Brickwork of raw earth recourses such as "pise", in clay or in reinforced earth	1333.5 m²	100	Yes	Decorative Fretworf
		1333.5 m²	*Quantity*		
Yes					
Brickwork "adobe" raw clay bricks					
Yes	Brickwork "adobe" raw clay bricks	235.4 m²	100	No	None
		235.4 m²	*Quantity*		
Brickwork of raw earth recourses such as "pise", in clay or in reinforced earth					
Yes	Brickwork of raw earth recourses such as "pise", in clay or in reinforced earth	2250.5 m²	100	No	None
		2250.5 m²	*Quantity*		
Grand total: 41		3955.9 m²	*TotalStructure Quantity*		

Figure 64: Technological unit – shell: walls information exported to .xml.

Graphical documentation

The View templates are automatically applied to the created views and sheets, as it was defined by the related Excel files. Therefore, when the model is shown on the corresponding view, the pre - set elements to be seen and colors are automatically displayed. Each sheet is set with the Templatte titleblock with the information about the project. Information values are automatically filled in the titleblock when the “Project information” values were inserted from Excel using Dynamo graph. The following paragraphs demonstrate the applied View templates on the created views placed on the pre - set sheets.

Figure 65 represents the view sheet showing the building construction phases. The Filter had been set to apply the defined colors to the external elements (walls, slabs and roofs), corresponding to the construction phase the building elements have been built. The legend on the right side of the drawing explain which color belongs to which construction period.

Figure 66 shows the view sheet representing the building functions on the ground floor plan. The “Room” category was used to apply the functions of the floorplan. The pre - defined room naming and color scheme were used to pick the name of each room, automatically applying its color. The functions legend next to the drawing explains the room naming. The room schedule on the right side of the drawing can easily be created by extracting the needed parameters in the Revit schedule, and putting it on the view sheet. For the demonstration purposes, room number, name and area are shown in the room schedule.

Figure 67 show the view sheet representing historic materials of the building shell. The created shared material library was used to apply the materials to the building elements and to represent them. The created keynote library was used to display the code of each material with a tag. The material legend was inserted in the same way as the room legend – by creating a schedule in Revit. Material name and type image is represented in this example.

Figure 68 shows the view sheet representing wall material degradation forms. The previously created adaptive family of stone degradation types has been used to demonstrate the material degradations. The component size is corresponding to damage area. The applied Filter of the view template was set to show the family colors and keep the rest of the model black and white. The legend on the drawing explains the meaning of each color (the degradation type).

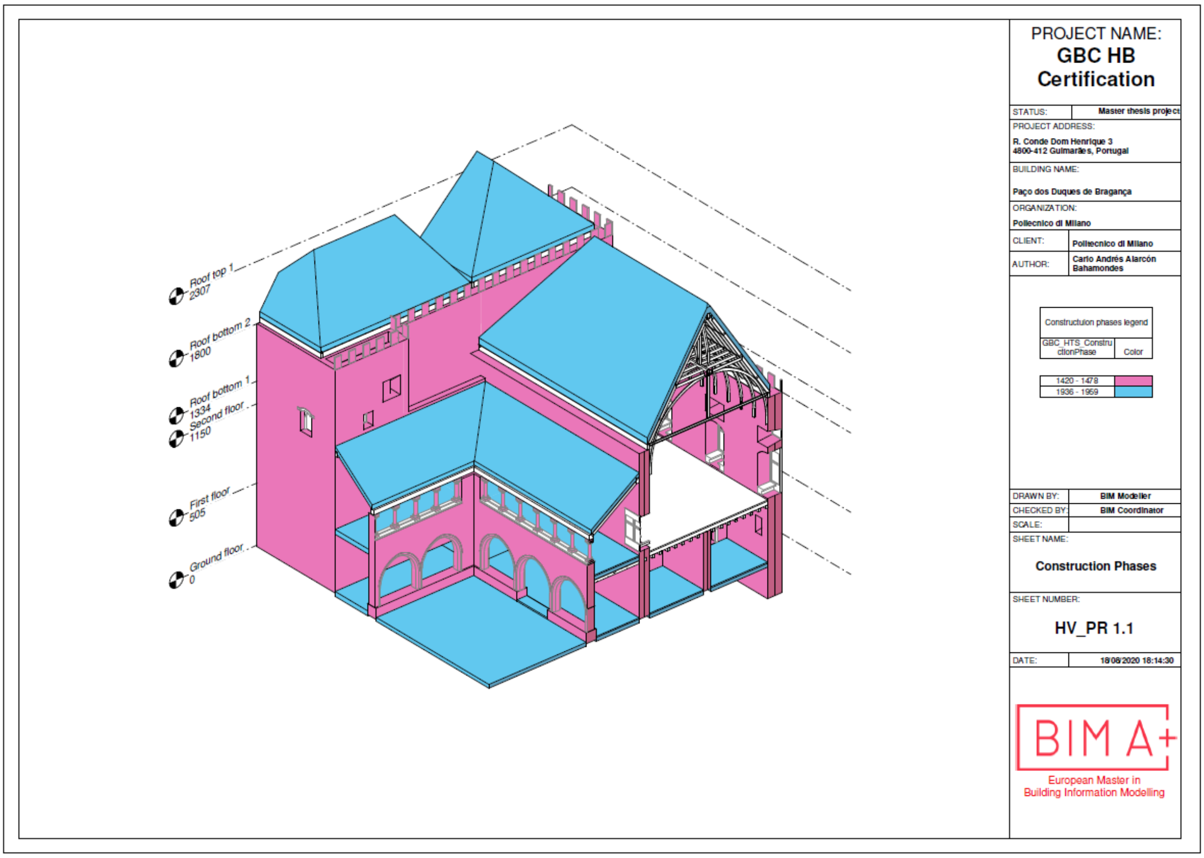


Figure 65: View sheet showing construction phases. Source: author.

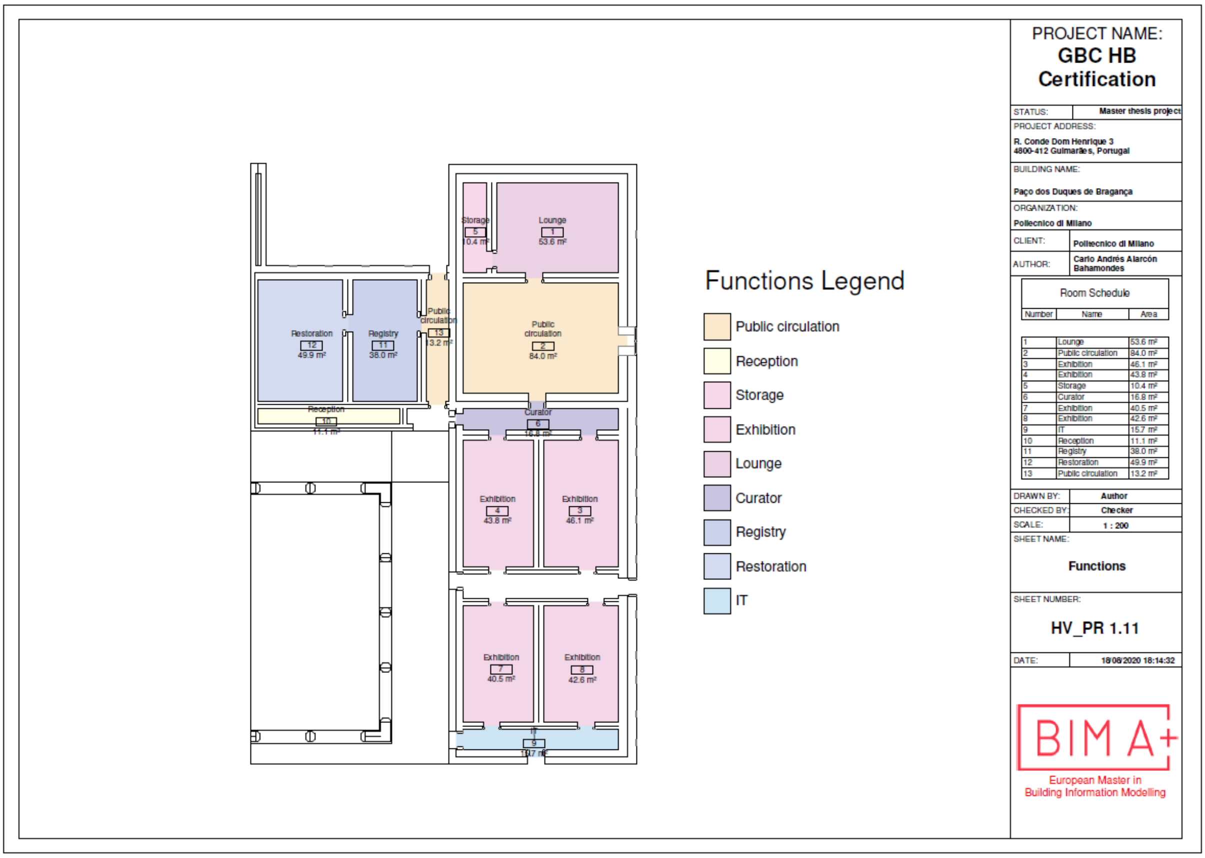


Figure 66: View sheet showing the building functions on the ground floor plan. Source: author.

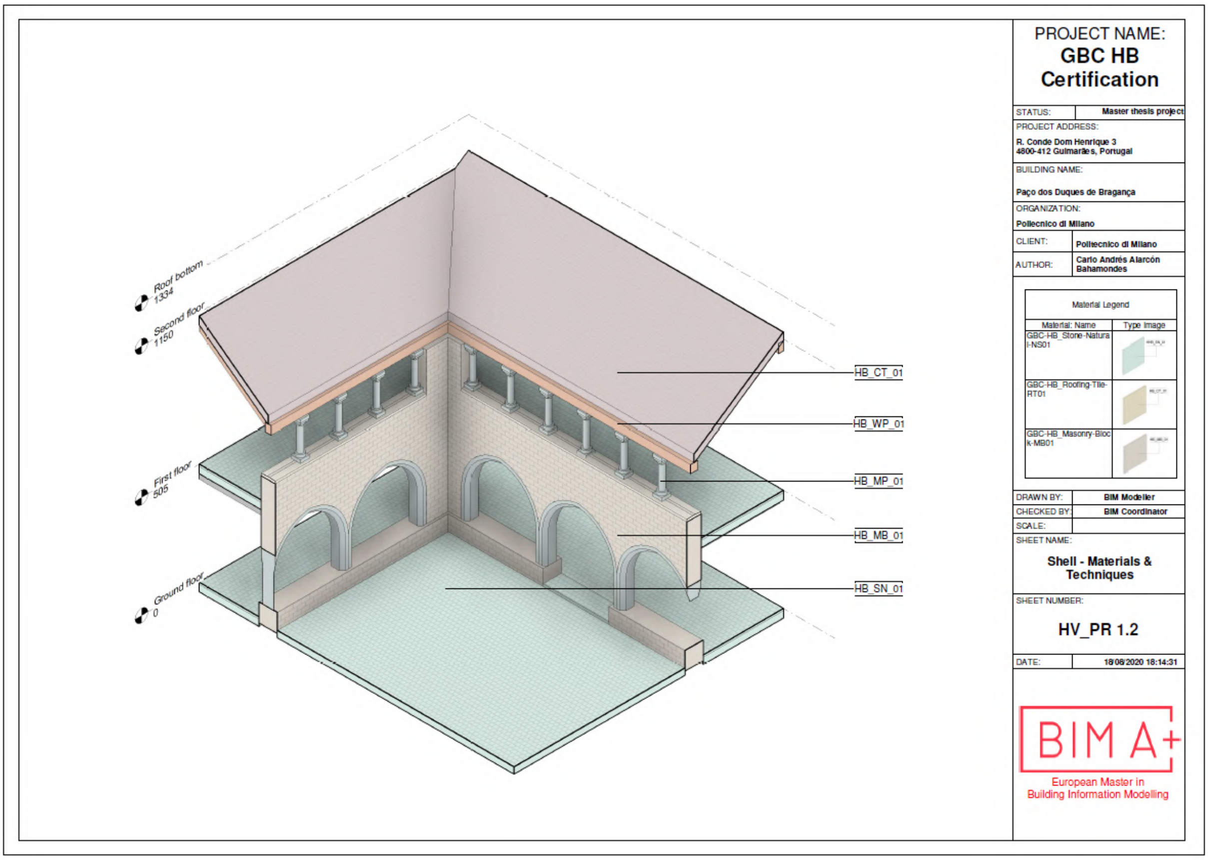


Figure 67: View sheet showing historic materials of the building shell. Source: author.

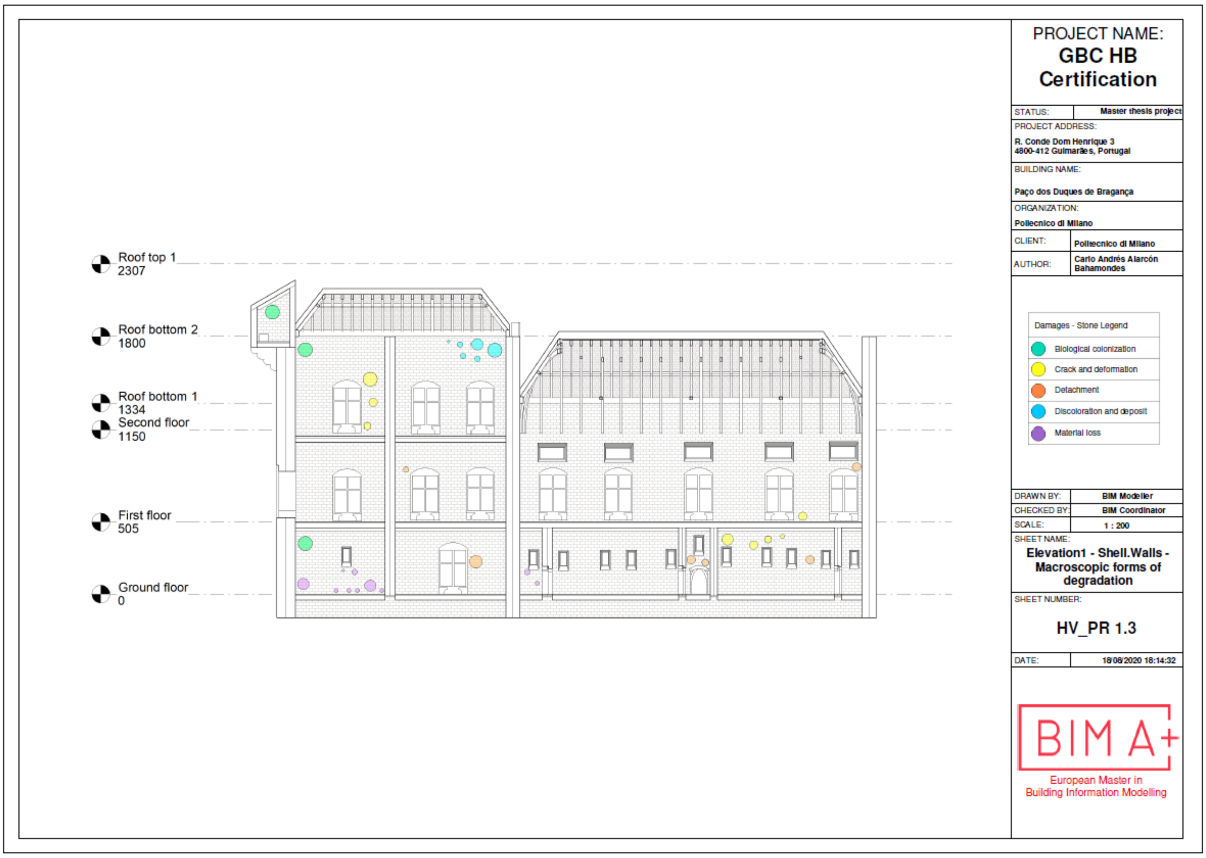


Figure 68: View sheet showing wall material degradation forms. Source: author.

5.2.3. Exporting the results

The final step of the Prerequisite 1 application process requires the team to export the information to the requested deliverables. This demonstation moreover includes the model export to an open file format, IFC, in order to test the created principle for data exchange. The previously shown sheets (Figure 65 - Figure 68) represent the graphical documentation principle application. The sheets can be exported to .pdf or any image – supporting format, and attached to the PDF form of the HB ID Card. When it comes to filling the form tabs, as it had been mentioned, an Excel algorithm, macro, can be set to automatically fill the PDF tabs from the Excel spreadsheets. Figure 69 shows the section of the Historic Building identity card with the filled information about the project and technological unit – external walls. That information was transferred from the Excel files (Table 42 and Figure 64). For filling this particular form, the macro was not used, due to complexity of the requirements the irregular order of the tab in the available PDF document imposed. Regarding the open file format compatibility, the pre – defined custom property sets (Figure 51) have been used to export the properties in the orderly way. The demonstration is represented in Figure 70 and Figure 71, showing the property sets for Project information and technological unit – walls. One improvement that could be useful regarding the model export to the IFC is introducing the possibility to export multiple phases to one IFC model, instead of having to model them as a single phase in Revit, and categorize by using the parameter values.

GBC HISTORIC BUILDING

GBC Historic Building

CARTA D'IDENTITA' DELL'EDIFICIO STORICO

Tutti i campi devono essere compilati se non diversamente specificato.

ID Progetto	GBC_HB-P01	Nome Progetto:	GBC HB Certification
Persona incaricata a compilare il modulo:	Jelena Zuric	Data compilazione:	03.09.2020.

DATI GENERALI DELL'EDIFICIO

Titolare	Paço dos Duques de Bragança								
Provincia	n / a	Comune	n / a	Località	Guimaraes	CAP	n / a	Via	R. Conde Dom Henrique 3,
Particella edificiale/catastale	123456	Coordinate geografiche (1)	41.4465° N - 8.2912° W	Zona climatica (2)	D				
Tipologia edilizia (3)	Edificio isolato	Tipologia intervento	Sustainable renovation	Epoca/Anno di edificazione (4)	1420-1478				
Destinazione d'uso attuale	Museum	Destinazione d'uso progetto	Museum						
Contesto ambientale limitrofo (5)	n / a								
Parametri urbanistici (6)	Museum sustainable preservation	Vincoli normativi vigenti (grado di protezione) (7)	National Monument						
Consistenza fabbricato (8)	15m, 500m2, 7500m3								
Altro	n / a								

QUADRO STORICO

Inserire un breve testo relativo al quadro storio dell'edificio, con particolare attenzione alle trasformazioni che nel tempo hanno interessato la fabbrica. Riportare almeno la destinazione d'uso originaria del fabbricato (al massimo 10.000 caratteri).

The ground floor contained the kitchen and store rooms and was mainly used by the servants. The first floor held the rooms of the Duke and Duchess and the chapel.
The building is structured around a central rectangular courtyard with six tall chimneys. Much of the stone used is granite. The first floor has a covered balcony running along the inside of the building.
The second (highest) floor is now used for temporary exhibitions.
After the renovations during the Estado Novo period, the house became an official residence of the President of the Republic.
The interior contains collections of furniture, carpets and copies of the Pastrana tapestries, attributed to the 15th century painter Nuno Gonçalves, the creator of the panels at São Vincente de Fora in Lisbon.
These depict the Portuguese invasion of North Africa.

ELENCO E SUCCESSIONE TEMPORALE DEGLI INTERVENTI EDILIZI RILEVATI

Inserire un elenco sintetico degli interventi edilizi di cui si possiede documentazione:

Data	Tipologia intervento	Dettagli
1936 - 1959	Demolition and implementatio	Undoing of the changes done by the military; demolition of surrounding b

Classi di unità tecnologiche **CHIUSURA**

Unità tecnologiche	Analisi (9)	Caratteristiche tecniche (10)	Quantità (11)		Struttura storica (12)		Struttura non storica (12)		Elementi architettonici decorativi (cornicioni, stucchi, affreschi, intonaci particolari da preservare, ecc.) (facoltativo) (14)	
Chiusura verticale	Non Rile	Apparecchiature murarie realizzate con paramento costituito da mattoni in t Altro (descrizione):	136.5	m²	100	%	0	%	Si	Descrizione: Decorative fretwork
Chiusura verticale	Non Rile	Apparecchiature murarie costituite da ricorsi in terra cruda tipo "pisè" (allo s Altro (descrizione):	1333.5	m²	100	%	0	%	Si	Descrizione: Decorative fretwork
Chiusura verticale	Rilevata	Apparecchiature murarie realizzate con paramento costituito da mattoni in t Altro (descrizione):	235.4	m²	100	%	0	%	No	Descrizione: None
Chiusura verticale	Rilevata	Apparecchiature murarie costituite da ricorsi in terra cruda tipo "pisè" (allo s Altro (descrizione):	2250.5	m²	100	%	0	%	No	Descrizione: None
		Chiusura verticale totale	3,955.9	m²			100	%		
		Chiusura verticale storica	3,955.9	m²			100	%		
		Chiusura verticale non storica	0	m²			0	%		

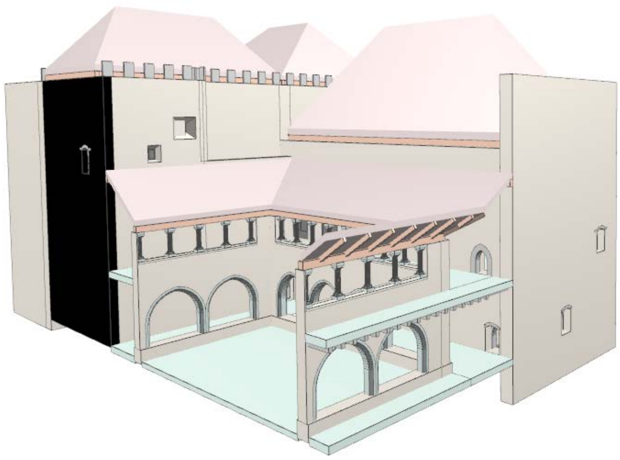
Figure 69: Section of the Historic Building identity card with the filled information.

Building

Summary | Location | Pset_BuildingCo... | Pset_ProductReq... | ProjectInformation

Property	Value
GBC_AUT_ProjectID	GBC_HB-P01
GBC_PRJ_BuildingCAP	n/a
GBC_PRJ_BuildingCadastralParcel	123456
GBC_PRJ_BuildingClimateZone	D
GBC_PRJ_BuildingCommune	n/a
GBC_PRJ_BuildingCurrentUse	Museum
GBC_PRJ_BuildingIndendedUse	Museum
GBC_PRJ_BuildingLocality	Guimaraes
GBC_PRJ_BuildingPositionType	Free - standing
GBC_PRJ_BuildingProtectionLevel	National Monument
GBC_PRJ_BuildingProvince	n/a
GBC_PRJ_Context	n/a
GBC_PRJ_HistoricFramework	The ground floor contained the kitchen and store roo... The building is structured around a central rectangular... The second (highest) floor is now used for temporary... After the renovations during the Estado Novo period,... The interior contains collections of furniture, carpets a...
GBC_PRJ_Other	n/a
GBC_PRJ_PrevInterventionDescription...	Undoing of the changes done by the military; demoliti... surrounding houses; Implementation of reinforced co...
GBC_PRJ_PrevInterventionType- 1	Demolition and implementation

Figure 70: Project information Property set, opened in an IFC viewer (BIMcollab ZOOM).



Wall

Summary | Location | Material | Clashes | Pset_Element... | Pset_Technolo...

Property	Value
Area	189.18 m²
Decorative ElementsPresent	False
Direct Information	True
GBC_HTS_IsExternal	True
GBC_HTS_IsHistoric	True
Historic Structure Percentage	100
Technologica lFeatures	Brickwork of raw earth recourses such as "pise", in clay...

Figure 71: IFC Property set made for the technological unit information of the external wall, opened in an IFC viewer (BIMcollab ZOOM).

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6. CONCLUSIONS

6.1. General conclusions

Overall, BIM implementation workflow requires deep technological skills, precision and discipline from the begining through the whole process of creating the HBIM model. Moreover, economical and time investments need to be made for developing complete custom workflows for the commercial use of the proposed BIM tools. Educating and training the users for the collaboration can present an additional challenge. For the BIM framework to be successfully used, the users should be involved from the beginning, and be willing to follow the newly established protocols.

This dissertation was focused on developing a BIM framework for generating the documentation for Historic Building identity card, with the aim of enabling its extention to the rest of the GBC Historic Building Certification project. The general conclusions are summarized:

- It was possible to relate the information needs of GBC HB Certification to BIM information types and establish a holistic BIM approach as a result. The approach and the systematic analysis of each of the Certification credit are the basis for forming the BIM workflows for Historic Vaule category application.
- It was possible to gather and systematize the data requets fot HB ID Card, and insert them in Revit before the project beginning. Regarding the data structuring, it was possible to use IFC standard as the basis. Requested properties can be generated by combining the use of the pre – existing IFC parameters, and creating the custom properties.
- Demonstration on the case study shows that the generated information can be exported to the requested data format (.pdf) and the open file format (.ifc), including both the pre – existing and custom properties, as well as graphical documentation.
- With the creation of libraries that can be further supplemented, pre – set naming, and formatting rules, the framework is enabled to be extended on the complete GBC HB Certification project, by following the established guidelines.

The methodology of analysing the current practices and workflow needs, as well as the information requests, from the general point of view, and the specific data requests has been followed. This methodology first enabled development of a holistic approach of BIM implementation in the GBC Historic Building Certification process. Then, as each credit category has been systematically assesed, it was shown that multiple information, documentation types and file formats are requested for the GBC Historic building certification process. The tables created for the systematic analysis (see Chapter 3) show which stakeholders have crucial roles for each credit, and in every case, multiple stakeholders are involved, with an often interaction with the external bodies. For the credits within Energy and Atmosphere, Materials and Resources and Indoor Environmental Quality categories, different kind of external bodies are involved. Whether they are suppliers, manufacturers, comissioning managers, these stakeholders rarely have to be included in the modelling itself or have the knowledge of BIM tools. This fact supports the idea of models and information availability in the common, user - friendly environment, and the possibility of exporting the model to formats such as .xml and .ifc file formats. Great number of credits require multiple project stages and multiple software usage as well, and almost all of them imply some sort of external linking (e.g. manufacturer, website historic database). When it comes to BIM uses detected, as it can be seen from the created tables of systematic analysis (see Chapter 3), the certification process would benefit from using the tools at every stage. BIM uses such as quantity take – off and cost analysis are required for the vast majority of credits. Energy and Atmosphere, Water Efficiency, Materials and Resources and Indoor Environmental Quality are the categories most connected to the current widespread BIM uses in the engineering sector. They include analysis series, such as energy analysis, Life – cycle assesment (LCA), lighting analysis and mechanical analysis. Sustainable Sites and Historic Value categories demand deeper research in the context of BIM integration. There are examples of potential solutions for both categories, such as integration of external data – GIS data and Historic element database with authoring software, which is still in the developing stage. Linking and extending series of BIM uses (defined by BIM excellence) can be the most interesting to consider developing for this purpose. The large amount of data from external resources can, in that way, be a part of a single digital database. Lastly, the historic building analysis and integration of new systems without compromising the existing structure requires organized collaboration. The organized collaboration process was established based on a holistic BIM approach, as a BIM workflow for the Historic Value category application.

Furthermore, based on the holistic approach and the developed workflow for obtaining the results for Historic Value category, the specific framework was proposed, implemented and demonstrated. From the framework proposal, it can be seen that the HB ID card information requests have been inserted in the BIM tools so the project team is exempt from having to insert the repetitious information, and they are additionally guided by the pre - set tool. The information has been structured following the open - data exchange (IFC) standard where applicable, or creating systematized libraries and naming rules. The project template has been enriched with the libraries and initial settings that can be supplemented according to the project needs, and guided by their organization and standardization rules. When it comes to data management, exporting project information to IFC was considered to be generally successful, since most of the parameters were either found as pre – existing IFC parameters or have been made as custom ones. Demonstration of the implemented framework on the case study shows its practical application and the feasibility of its realisation. As noticed, the IFC standard currently does not support the historic elements, but the overall work was not inhibited by that fact. With a well - developed authoring tool template and defined exporting options, it is possible to embed the necessary parameters for IFC file with little additional work for parameter mapping. The process of information gathering and transfer was further optimized by using computational design tool. It can be very useful for decreasing manual work by re – using the existing data from the Excel files. User – friendliness is enabled by the Dynamo Player. Dynamo graphs can therefore be used without having to have visual scripting experience, which gives Dynamo player a significant role in this process. Therefore, many more workflows can be optimized by using Dynamo for project files organization. When it comes to the process of making the computational design scripts, they require certain amount of time and experience to master, but result in great number of possibilities. The user experience had been considered by excluding the requirement of additional software skills, and setting the and naming and representation rules in a simple consistent way. Regarding visual representation, the pre – set visualisation rules, reffered to as “View templates” show the application of automatic drawing creation, not having to set up the drawihg style manually on each view. Since one model is used to represent different requests, the drawing process is shortened, and when a mistake needs to be corrected, even when drawings are placed on the sheets, the correction is applied to all the views by changing one model. Lastly, the information inserted in the BIM model during the project can be easily exported to the requested file formats. In the end, the implemented framework can be extended and made applicable to the complete Certification project, with the pre – set rules to enable its consictency. Any pre – existing and custom content inserted in the project template can be kept as a form of a template for any GBC Historic Building Certificaion project. That means that it can be reused and supplemented acccording to specific needs of the project, without having to repeatedly create the information set – up from the beggining.

6.2. Recommendations for the future development

Regarding the suggestions for the future development, it has been noticed that deeper involvement of users in information technology sector for the AEC process is the key for future of HBIM development. Additionally, the AEC industry users need to be willing to change the traditional ways of managing project documentation.

For the future development of the proposed project template in authoring tool, it is suggested to fully complete its creation, for the demonstrated prerequisite as well as the rest of the Certification credits. It could be then be used as a template for any project applying for the HB Certification, and its standardisation would therefore be of a great value. It would include pre - defining: all schedules to fill, calculations to perform, documentation set naming and structuring, visual representation setting, inserting all the remaining parameters, creating the external libraries of the standardized historic materials and degradation, and implementing template instructions inside authoring tool. Then, the computational design tool usage can be extended to perform the requested calculations, which was demonstrated as a possibility in the Chapter 2. The automation of repetitive tasks is its greatest potential in this procedure. Computational design may also be used to perform the control checks of the project (e.g. whether the model elements satisfy the project criteria, if parameters and values correctly inserted, etc.). When it comes to creating the model, the geometry modelling process is complex, and deeper developments need to be directed in establishing standardized rules. Modelling rules should be definitely set for each phase of achieving the certification. Suggestions such as hybrid modelling and schematic libraries can be helpful for simplifying the process while keeping the requested information. External documentation for the lifecycle information of each material can be implemented and potentially standardized for comparison and calculation purposes. As mentioned, the lack of standardised libraries and properties for historic elements entail their official development. The official historic material and degradation types are defined by the local regulations, which opens the possibility of translating them and implementing in the BIM environment. Furthermore, in order to keep the stakeholder collaboration fluent, the open user – friendly platform can be established as a comprehensive database, where the users can communicate without having to use the modelling software. Linking and extending series of BIM uses can be used for this purpose. The online platforms can be linked to the authoring tool, enriching the model with data on the project location (GIS), the assets' historic information, manufacturer information, monitoring analysis results and similar. Moreover, development of the standardized tools integrated in the authoring tool, such as plug – ins for credit calculation and estimation would be beneficial for the whole process of certification, providing that such don't imply great economical investments. Naturally, the project team should estimate at the beginning which tools are feasible to use for the project and which method should be applied. The questions remain on the long – term repository methodologies, updating the file versions, ownership rights, and general maintenance of the information.

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LIST OF ACRONYMS AND ABBREVIATIONS

AEC	Architecture, Engineering, and Construction
BIM	Building Information Modelling
BREAM	Building Research Establishment Environmental Assessment Method
CoSIM	Construction site information modelling
CoSMoS	Confined space monitoring system
GBC	Green building council
GBC HB	Green building council Historic Building
GIS	Geographic information system
HB ID card	Historic building identity card
HBIM	Historic Building Information Modelling
IT	Information Technology
LCA	Life – cycle assesment
LEED	Leadership in Energy and Environmental Design
M&C	Material and Component
US GBC	United States Green building council
WMS	Web map Service
WSN	Wireless sensor network

APPENDICES

APPENDIX 1: SYSTEMATIC ANALYSIS OF GBC HISTORIC BUILDING CREDITS – HISTORIC VALUE

This appendix consists of the spreadsheet table created and used for the systematic analysis of each GBC Historic building credit, for the Historic Value credit category.

APPENDIX 1: SYSTEMATIC ANALYSIS OF GBC HISTORIC BUILDING CREDITS – HISTORIC VALUE

GBC HB Manual requests						Stakeholders								BIM Uses								Example	BIM aspects						BIM elements					Notes	
															Domain model uses by BIM excellence																				
No	Name	Project phase	Purpose	Requested information by GBC HB	Requested information formats = output	ARCHAE.	LAB. SPEC.	RA	Urban planner	SPEC. E.	SE	MEP	External bodies	BIM uses by Penn State	Capturing and Representing	Planning and Designing	Simulating and Quantifying	Constructing and Fabricating	Operating and Maintaining	Monitoring and Controlling	Linking and Extending	Specific solution from the literature	BIM Approach	BIM Information structure	Information managing process	BIM Platforms	Excel calculator, xml	BIM Result	Calculation in BIM Authoring platform	Calculation in external platform	BIM Analysis tool	Multiple BIM software	BIM for Multiple project stages	Comments	BIM - GBC HB credit compatibility
01 Historic Value																																			
HV PR 1	Preliminary analysis	D	Recognize and characterize value of the historical building and its elements.	Construction phases and existing functions; Structural schemes; Material consistency and construction techniques; Matrix of stratigraphic successions; Macroscopic forms of degradation; System schemes;	Dynamic PDF Form with attachments; Schematic (2D) drawings; Photographs;	x		x			x	x	x	Existing Condition modelling; Programming; Record keeping;	Laser Scanning, Photogrammetry, Surveying, 2D Documentation, Record Keeping	n/a	n/a	n/a	n/a	n/a	BIM/Web-services Extension; BIM/ERP Linking	Semantic-web integration in BIM model;	Collect, organize and manage information in a digital database.	Model - based:	Conversion of numerical model to parametric model, insertion and categorization of collected information from multiple databases;	Point cloud software , authoring tool; Model viewer;	x	Digital twin with indications for refurbishment.	x					HBIM model can be the structured information base point for further project development. It can be used as a record of a stage of building's life as well. Requires collaboration between multiple stakeholders.	5
HV C 1.1	Advanced analysis: energy audit	D	Know the energy status of the building in order to guide the design strategies for performance improvement and architectural conservation. Recognize and characterize existing systems to preserve, improve and optimize, contributing to the reduction of energy consumption and increasing occupant comfort.	Building systems typology, classification, degradation state and potential mainenance;	Reports and schematic (2D) drawings;		x					x		Existing Condition Modeling; Programming; Record keeping	2D Documentation; Record Keeping	n/a	Clash Detection	n/a	n/a	Performance Monitoring, Real-time Utilization	BIM/IOT Interfacing	/	Collect, organize and manage information in a digital database.	Element - based:	Inserting parameters in the model elements about summarized analysis results and external links (as parameter values); taging;	Authoring (MEP) tool; Model viewer;		Information linked to model elements as parameters, links and tags.	x					Base for project development. Model elements can be connected to detailed analysis results via links, with only general conclusions / instructions inserted (as parameter values, images or visualisation, depending on the need) for further model development. In the case of the credit, it is only necessary to insert test locations in the 2D drawings.	5
HV C 1.2	Advanced analysis: diagnostic tests on materials and degradation	D	Recognize and characterize the chemical-physical nature of historical material by identifying the main causes of degradation, in order to improve quality occupant comfort and durability	Analysis results; graphical representation of analysis location and the result summary; Materials categorization;	Reports and schematic (2D) drawings;	x	x	x			x	x		Existing Condition Modeling; Programming Record keeping	2D Documentation; Record Keeping	n/a	n/a	n/a	n/a		BIM/IOT Interfacing	Patch-Type Damage/Inspection overlay objects in open format; web - based DOT (Damage Topology Ontology)	Collect, organize and manage information in a digital database.	Element - based; Custom families;	Inserting parameters in the model elements about summarized analysis results and external links (as parameter values); taging;	Authoring tool; Model viewer;	x	Library of historic materials; Information linked to model elements as parameters, links and tags.						Base for treatment of materials for each elements, but detailed schedules / analysis results and the rest of deliverable documentation can interfere with the rest of the model. The suggestion is inserting and using in the model only needed parts of analysis for next project phases, and keeping the whole documentation in a separate model or folder for example.	4
HV C 1.3	Advanced analysis: diagnostic tests on structures and structural monitoring	D	Recognize and evaluate the static-resistant characteristics of the building: materials, static patterns and global behaviour, for further interventions - static consolidation and any strengthening seismic interventions. Minimize replacement of historical elements with new structures or materials (e.g. foundations, load-bearing walls, arches, vaults, wooden structures, metal and reinforced concrete, anchor plates etc.).	Structural elements geometry, classification (types, material properties..), detail and deformation classification	Reports; 2D drawings;		x				x			Existing Condition Modeling; Programming; Record keeping	2D Documentation; Record Keeping	n/a	n/a	n/a	n/a	Performance Monitoring, Real-time Utilization, Structural health monitoring	BIM/IOT Interfacing	Real-time monitoring through wireless sensor network (WSN) technology integrated with BIM;	Collect, organize and manage information in a digital database.	Structural Model - based:	Inserting parameters in the model elements about summarized analysis results and external links (as parameter values); taging;	Authoring (Structure) tool; Model viewer;	x	Information linked to model elements as parameters, links and tags.						The base for further structural develomplent. Useful for keeping large amount of data in one place. The suggestion is inserting and using in the model only needed parts of analysis for next project phases, and keeping the whole documentation in a separate model, for example.	4
HV C 2	Project reversibility	D	Minimize insertions, replacements or additions, and the signs of suture between historical and new structures.	Checklists, Calculation and analysis results, sums of cost;	Reports;			x			x			Design Authoring, Design Review; Programming; Cost Estimation, Construction System Design*	Record Keeping;	Conceptualization, Design Authoring, Selection and Specification, Lean Process Analysis	Clash Detection, Cost Estimation, Quantity Take-Off (QTO),Constructability Analysis	n/a	n/a	Performance Monitoring, Real-time Utilization, Structural health monitoring	n/a	n/a	Design solutions, simulate and compare results	Model - based:	Model design solutions, inserting element parameters; export results	Authoring (Structure) tool; Structural analysis tool*; Model viewer;		Model/s with estimated costs, and reversibility assesments;			x			Quck quantity and cost generation of elements to form early decisions; useful for later 4D schedules too;	3
HV C 3.1	Compatible end-use	D	Identify compatible intended uses with conservation and positive effects on the settlement dynamics from a social, cultural, economic and human health perspective, creating spaces for the community.	Space usage compatibility, Calculation results, Report;	Graphical, Descriptive (Reports);			x	x				x	Site analysis, Programming, Cost Estimation;	2D Documentation; Record Keeping	Space Programming		n/a	n/a		BIM/GIS Overlapping	/	Design solutions, simulate and compare results	Model - based;	Integrated with GIS; Model design solutions, inserting element parameters, classifications, and schedules; perform calculations and cost estimations; export results	Authoring tool; Space analysis tool; Model viewer;		Model/s with analysis of external space usage and assesment						Authoring tool should be connected to GIS to evaluate sites. Local urban plans should be considered during design of solutions.	5
HV C 3.2	Chemical and physical compatibility of integrated materials	C	Evaluate the compatibility of restoration mortars and original materials, considering the aesthetic, chemical-mineralogical and physical-mechanical requirements.	Check list of diagnostic investigations of materials: type of investigation, standard followed, instruments used; Report: results od laboratory and on – site analysis, attaching relevant information Technical sheets of restoration materials, from manufacturer	Reports;		x	x						n/a	2D Documentation; Record Keeping	n/a	n/a	n/a	n/a	n/a	BIM/Spec Linking	/	Collect and organize information in digital database	Element - based:	Insert additional parameters to relevant elements; export results	Authoring tool; Model viewer;		Information enriched model.					x	Detailed material analysis to be performed by specialists in the field, not necessary to be connected with the BIM model; Summary of results such as material classiffication, characterization, durability and treatments can be inserted as element properties in the model, for documenting / visualising purposes.	2
HV C 3.3	Structural compatibility	C	Minimize invasiveness of intervention and resources by making the most of the static characteristics of existing structures – considering loads and maintenance.	State of structure degradation - analysis results; Design solutions and compatibility demonstration; Estimated metric calculation; Cost estimation; Schematic drawings;	Reports; Schematic drawings;						x			Structural analysis, Cost Estimation	2D Documentation; Record Keeping	Design Authoring (Structural)	Structural Analysis, Cost Estimation, Quantity Take-Off (QTO)					/	Design solutions, simulate and compare results	Structural Model - based:	Authoring tool - structural model, analysis and simulations; export results	Authoring (Structure) tool; Structural analysis tool*; Model viewer;		Structural model with relevant parameters			x		x		3*
HV C 4	Sustainable restoration site	C	Reduce the negative environmental effects of activities by adopting strategies for restoration techniques and reducing the use of non - renewable resources during construction.	Construcion site sustainable restoration plan; Techniques;	Graphical, Reports, Instructions;			x			x	x	x	Phase Planning, Site Utilization Planning, Design Authoring,	2D Documentation; Record Keeping	Construction Planning	Constructability Analysis, Cost Estimation (Labor, Equipment), Quantity Take-Off (QTO)	Site Set-out		Field BIM		/	CoSIM development	Model - based:	CoSIM development process;	CoSIM Software; Authoring tool (terrain / landscaping); Model checking software; Scheduling software; 4D		CoSIMmodel with instructions for treating water, vegetaion and energy.			x		x	Collaboration of multiple stakeholders required;	4*
HV C 5	Scheduled maintenance plan	C	Reduce long-term intervention costs (referring to site management) lowering economic impact of small maintenance interventions. Ensure durability of the building by providing the occupants adequate information and maintenance measures.	Risk Assesment, Maintenance Plan;	Descriptive; Reports, Schedules, Manuals;			x			x	x	x	Maintenance Scheduling;		Operations Planning	Clash Detection		Handover and Commissioning, Asset Management,	Building Automation, Field BIM	BIM/FM Integration (BIMFMI)	/	BIM for Facility Management	Model - based:	BIM for Facility Management procedure	Design Review Software, Building Automation System (BAS) linked to Record Model • Computerized Maintenance		Facility Management BIM			x		x	Collaboration of multiple stakeholders required; COBiE specifications are recommended for information structuring.	4*
HV C 6	Specialist in architectural	D	Include a specialist in architectural and landscape heritage for the process.	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a		n/a	n/a	n/a	n/a	n/a	n/a	n/a	0

APPENDIX 2: SYSTEMATIC ANALYSIS OF GBC HISTORIC BUILDING CREDITS – SITE SUSTAINABILITY

This appendix consists of the spreadsheet table created and used for the systematic analysis of each GBC Historic building credit, for the Site Sustainability credit category.

APPENDIX 2: SYSTEMATIC ANALYSIS OF GBC HISTORIC BUILDING CREDITS – SITE SUSTAINABILITY

No	Name	Project phase	Purpose	Requested information by GBC HB	Requested information formats = output	ARCHAE.	LAB. SPEC.	RA	Urban planner	SPEC. E.	SE	MEP	External bodies	BIM uses by Penn State	Domain model uses by BIM excellence							Specific solution from the literature	BIM Approach	BIM Information structure	Information managing process	BIM Platforms	Excel calculator, xml	BIM Result	Calculation in BIM Authoring platform	Calculation in external platform	BIM Analysis tool	Multiple BIM software	BIM for Multiple project stages	Comments	BIM - GBC HB credit compatibility
															Capturing and Representing	Planning and Designing	Simulating and Quantifying	Constructing and Fabricating	Operating and Maintaining	Monitoring and Controlling	Linking and Extending														
02 Sustainable Sites																																			
SS PR 1	Construction activity pollution prevention	C	Reduce pollution from construction activities by controlling soil erosion, waterway sedimentation, outflow of pollutants into the sewer or on the ground, airborne dust, protection of acoustic comfort and the health of the users during the processing phases.	Erosion and Sediment Control Plan; Photographic and inspection Report; Report on work progress and implemented measures of ESC plan;	Project drawings (ESC Plan); Reports; Construction saff manuals;			x		x	x		x	Phase Planning , Code Validation, 3D Coordination, Site Utilization Planning	2D Documentation, Record Keeping;	Design Authoring; Construction Planning; Lean Process Analysis;	Acoustic Analysis, Constructability Analysis, Cost Estimation, Quantity Take-Off (QTO), Clash Detection, Risk and Hazard Assessment, Safety Analysis, Spatial Analysis, Code Checking & Validation	Construction Logistics, Site Set-out, Construction Waste Management	Handover and Commissioning; Building Inspection	Field BIM	BIM / GIS Overlapping, BIM/IOT Interfacing	/	Erosion and Sediment Control Plan design, realization, monitoring and documentation;	Model - based: multidisciplinary models;	BIM Process for multiple stages - collect and sort data, model design solutions, insert element parameters, classifications, and schedules; perform analysis, calculations and cost estimations; monitor the realization;	Authoring tool (terrain / landscaping); Model checking software; Scheduling software; 4D model integration software; Model viewer;	x	BIM model with complete information on Erosion and Sediment Control Plan and execution monitoring;	x	x	x	x	x	Collaboration of multiple stakeholders required and external resources involvement;	5
SS C 1	Brownfield redevelopment	D	Correct the causes of degradation or pollution and restore the health and safety of the site.	Official environmental specification on site liabilities; Technical report on identified materials; Complete pollutant management plan documentation; Reports on performed measures;	Project; Reports;		x		x		x		x	Phase Planning , Code Validation, 3D Coordination, Site Utilization Planning	2D Documentation, Record Keeping;	Design Authoring, Construction Planning, Lean Process Analysis;	Cost Estimation, Quantity Take-Off (QTO), Clash Detection, Constructability Analysis; Risk and Hazard Assessment, Safety Analysis, Spatial Analysis, Code Checking & Validation;	Construction Logistics; Site Set-out;	Handover and Commissioning; Building Inspection	Field BIM, Performance Monitoring, Real-time Utilization;	BIM / GIS Overlapping, BIM/IOT Interfacing;	/	Collect and sort information from external resources (construction site analysis), plan and monitor the intervention process;	Model - based: multidisciplinary models;	BIM Process for multiple stages - collect and sort data, model design solutions, insert element parameters, classifications, and schedules; perform analysis, calculations and cost estimations; monitor the realization;	Authoring tool (terrain / landscaping); Model checking software; Scheduling software; 4D model integration software; Model viewer;	x	BIM model for site redevelomplent planning and management;	x	x	x	x	x	Collaboration of multiple stakeholders required and external resources involvement	5
SS C 2.1	Alternative transportation: public transportation access	D	Reduce pollution caused by car traffic.	Official documentation on public transportation project; Documentation on parking area of car sharing service; Site plan indicating public transport station / car sharing service parking distance from the buildings' entrances; Neighborhood plan indicating pedestrian relevant paths;	Legal documents; Graphical;			x	x				x	Design Authoring, Design Review,	2D Documentation	Conceptualization, Design Authoring, Urban Planning,	Accessibility Analysis; Code Checking & Validation	n/a	n/a	n/a	BIM/GIS Overlapping, BIM/Web-services Extension	Plug - in for location analysis connecting authoring tool, GIS and credit calculations;	GIS information transfer to BIM authoring tool, demonstration of results;	Element - base	Location identification and distance caluclation;	Authoring tool interacting with GIS;	x	Information enriched BIM model; Design solution;	x					Information on public transportation stations / schedules can be retrieved quickly with online websites such as google maps / bus company websites. GIS software can be useful for sidewalk information retrieval, for example.	4
SS C 2.2	Alternative transport: bicycle racks and changing rooms	D	Promote the use of environmentally sustainable transportation.	Plan indicating the location and quantity of bicycle and locker rooms; Graphical presetation of bycicle storage; Number of storage rooms according to occupant number; Documentation of agreement with the bike sharing service (optional);	Legal documents; Graphical; Calculation report;			x					x	Design Authoring, Design Review, Cost Estimation	2D Documentation	Conceptualization, Design Authoring; Value Analysis	Cost Estimation; Code Checking & Validation	n/a	n/a	n/a	BIM/GIS Overlapping, BIM/Web-services Extension	Plug - in for location analysis connecting authoring tool, GIS and credit calculations;	solution in authori	Model - based	Design solution, calculations, and result simulation;	Authoring tool interacting with GIS;	x	Information enriched BIM model; Design solution;	x		x			Information such as occupancy, space usage analysis and historical building limitaitons can be retrieved from the existing model which can make the design and evaluation of solution faster.	4
SS C 2.3	Alternative transport: low - emitting and fuel - efficient vehicles	D	Reduce environmental impact generated by car traffic.	Floor plan of designed parking space; Number of designed parking spaces / alternative fuel vehicles / filling stations, occupancy number (FTE); Documentation of usage procedures (equipment use, discounts..); Equipment information;	Graphical; Reports; Specificaitons;			x	x				x*	Design Authoring, Design Review, Cost Estimation	2D Documentation	Conceptualization, Design Authoring; Value Analysis	Cost Estimation; Code Checking & Validation	n/a	Handover and Commissioning * (training the staff on equipment usage)	n/a	BIM/GIS Overlapping; BIM/Spec Linking	Plug - in for location analysis connecting authoring tool, GIS and credit calculations;	Design solution in authoring tool; simulate possible solutions; connect BIM model elements with external resources; Perform cost estimations; choose and export best solution;	Model - based	Design solution, calculations, and result simulation;	Authoring tool interacting with GIS; Model viewer;	x	Information enriched BIM model; Design solution;	x	x				Information such as occupancy, space usage analysis and historical building limitaitons can be retrieved from the existing model which can make the design and evaluation ofsolution faster.	4
SS C 2.4	Alternative transportation: parking capacity	D	Reduce environmental impact generated by car traffic.	Amount and type of existing and project parking places; Type of infrastructure and / or support programs for carpooling and vanpooling; Information on the planned parking capacity, number of preferential parking spaces, number of FTEs, zoning requirements of the local regulations or copies of brochures that provide support structures for the carpooling and vanpooling;	Graphical; Reports;			x	x				x	Design Authoring, Design Review;	2D Documentation	Conceptualization, Design Authoring; Value Analysis	Code Checking & Validation	n/a	n/a	n/a	BIM/GIS Overlapping;	Plug - in for location analysis connecting authoring tool, GIS and credit calculations;	Design solution in authoring tool; simulate possible solutions; connect BIM model elements with external resources; Perform cost estimations; choose and export best solution;	Element - based; multi - category parameter calculation, comparison; *	Retrieve information from local urban zoning; provide, simulate solutions and choose best fit option;	Authoring tool; Model viewer;	x	Information enriched BIM model; Design solution;	x	x				Information such as occupancy, space usage analysis and historical building limitaitons can be retrieved from the existing model which can make the design and evaluation ofsolution faster.	4
SS C 3	Site development: open spaces recovery	D	Recover historical parks and gardens by restoring the original conditions for native plants, natural habitats, wetlands and surface water bodies altered by human action.	Amount of open space expected / required; Calculation results; Intervention plan;	Graphical; Reports;			x	x	x	x	x	x	Programming, Site Analysis. Design Authoring, Design Review; Sustainability Analysis; Code Validation	2D Documentation	Conceptualization, Design Authoring; Selection and Specification; Space Programming	Clash Detection, Code Checking & Validation; Cost Estimation; Sustainability Analysis; Light, Reflectivity and Solar Analysis;	n/a	n/a	n/a	BIM/GIS Overlapping; BIM/Spec Linking	/	tailed design proje	Model - based: multidisciplinary models;	Multi - disciplinary project information management;	Programming software; Authoring tool; Analysis software; Model viewer;	x	Information enriched BIM model; Design solution;	x	x	x	x		Collaboration of multiple stakeholders required and external resources involvement.	5
SS C 4	Stormwater design: quantity and quality control	D	Llimit disruption of natural cycle by managing the outflow of rainwater, reducing waterproof covering surfaces, increasing of infiltrations on site, reducing pollution from the stormwater outflow and the elimination of contaminants. Enhance the recovery of existing historical management systems.	Rainwater Management Plan, Best Management Practices (BMPs); Volume of the surface runoff; Rainwater assessment report; List of rainwater management strategies in relation to weather events; List of the structural control systems; Description of the pollutants removed; Percentage of annual precipitation treated and how it does not compromise the historical value; Optional narrative description of	Graphical; Reports;			x	x	x	x		x	Site Analysis. Design Authoring, Design Review; Sustainability Analysis; Code Validation; Record Modeling;	2D Documentation; Record Keeping;	Conceptualization, Design Authoring; Selection and Specification;	Clash Detection, Code Checking & Validation; Cost Estimation; Sustainability Analysis;	n/a	n/a	Field BIM	BIM/GIS Overlapping; BIM/Spec Linking	/	Detailed design and realization project;	Model - based: multidisciplinary models;	Multi - disciplinary project information management;	Authoring tool; Analysis software; Mpdel checker; Model viewer;	x	Information enriched BIM model; Design solution;	x	x	x	x		Project design using BIM; Collaboration of multiple stakeholders required and external resources involvement	5
SS C 5	Heat island effect: non-roof and roof	C	Reduce the effects of the local heat island with adequate design respecting the existing typological-morphological balance.	Plan highlighting shaded paved surfaces; Quantities of paved surfaces contributing to credit; Information of compliant surfaces (e.g. SRI values for reflective flooring materials); Elaborate roof graphics highlighting all surfaces covered with reflective materials or with green roof systems; List of covering materials the project and their coefficient of solar reflection, emittance, the solar reflection index (SRI) and the inclination in which they are arranged with respect to a horizontal surface; Documentation	Graphical; Reports;			x			x			Design Authoring, Design Review; 3D Coordination	2D Documentation;	Conceptualization, Design Authoring; Selection and Specification;	Solar Analysis, Reflectivity Analysis;	n/a	n/a	n/a	BIM/GIS Overlapping; BIM/Spec Linking	/	tailed design proje	Model - based: multidisciplinary models;	Multi - disciplinary project information management;	Authoring tool; Analysis software; Model viewer;	x	Information enriched BIM model; Design solution;	x	x	x	x		Project design using BIM; Collaboration of multiple stakeholders required and external resources involvement	5
SS C 6	Light pollution reduction	D	Retain architectural character of the building, minimize the light scatters generated by the building and the site, reduce sky-glow to increase night sky access, improve nighttime visibility through glare reduction and reduce development impact from lighting on environment.	Demonstrate the achievement of the expected lighting parameters, within the area and at the boundary of the project site and beyond. Calculate the vertical illuminance levels at the site boundary up to a height equal to the highest lighting fixture on the site;	Graphical; Reports;			x		x				Design Authoring, Design Review; Lighting Analysis; Maintenance Scheduling; Asset Management;	2D Documentation;	Conceptualization, Design Authoring; Selection and Specification;	Lighting Analysis;	n/a	Asset Maintenance;	Real-time Utilization;	BIM/Spec Linking; BIM/IOT Interfacing;	/	tailed design proje	Element - based;	Multi - disciplinary project information management;	Authoring tool; Analysis software; Asset management tools; Model viewer;	x	Information enriched BIM model; Design solution;	x	x	x	x	x	Collaboration of multiple stakeholders required and external resources involvement.	5

APPENDIX 3: SYSTEMATIC ANALYSIS OF GBC HISTORIC BUILDING CREDITS – WATER EFFICIENCY, ENERGY & ATMOSPHERE AND MATERIALS & RESOURCES

This appendix consists of the spreadsheet table created and used for the systematic analysis of each GBC Historic building credit, for the Water Efficiency, Energy & Atmosphere and Materials & Resources credit categories.

APPENDIX 3: SYSTEMATIC ANALYSIS OF GBC HISTORIC BUILDING CREDITS – WATER EFFICIENCY, ENERGY ATMOSPHERE AND MATERIALS RESOURCES

No	Name	Project phase	Purpose	Requested information by GBC HB	Requested information formats = output	ARCHAE.	LAB. SPEC.	RA	Urban planner	SPEC. E.	SE	MEP	External bodies	BIM uses by Penn State	Domain model uses by BIM excellence: Capturing and Representing	Planning and Designing	Simulating and Quantifying	Constructing and Fabricating	Operating and Maintaining	Monitoring and Controlling	Linking and Extending	Specific solution from the literature	BIM Approach	BIM Information structure	Information managing process	BIM Platforms	Excel calculator, xml	BIM Result	Calculation in BIM Authoring platform	Calculation in external platform	BIM Analysis tool	Multiple BIM software	BIM for Multiple project stages	Comments	BIM - GBC HB credit compatibility
Water efficiency																																			
WE PR 1	Water use reduction	D	Increase water efficiency in buildings to reduce the burden on municipal water supply and wastewater systems.	Manufacturer data showing the water consumption indexes, the manufacturer and model of each equipment and accessory; List of plumbing fixtures by usage groups, if applicable. Each usage group defined; Flow rates calculations results.	Calculations; Reports;			x			x*	x	x	Design Authoring, Design Review; Building System Analysis; Asset Management;	n/a	Conceptualization, Design Authoring; Selection and Specification;	Clash Detection, Code Checking & Validation;	Site Set-out;	Asset Maintenance; Asset Procurement;	n/a	BIM/Spec Linking;	Using computational design for calculation and credit validation assessment;	Detailed Mechanical design project;	Element - based;	Modeling / importing elements, inserting shared parameter values, performing calculations and additional analysis; simulate design solutions and choose best fit option.	Authoring tool; Analysis software; Asset management tools;	x	Information enriched BIM model; Design solution;	x	x	x	x	x	Mechanical fixture design project with multiple stakeholders involved;	5
WE C 1	Water efficient landscaping	D	Limit the use of drinking water, surface or subsoil water near the building, for irrigation / ornamental purposes. Restore the original rainwater collection systems (cisterns, tracing of channels and drains, etc).	Soil analysis (soil and climate) - plant species and landscape design that uses native and adaptable plants capable of reducing or eliminating the need for irrigation; Water consumption levels calculations; Calculations (percentage of water use reduction); irrigation management plan; Rain water collection plan; Manufacturer data and maintenance information;	Graphical; Reports;		x	x	x	x		x	x	Design Authoring, Design Review; Building System Analysis; Asset Management;	2D Documentation	Conceptualization, Design Authoring; Selection and Specification;	Solar Analysis;	n/a	Asset Maintenance; Asset Procurement	Real-time Utilization;	BIM/Spec Linking; BIM/IOT Interfacing	/	Design, construction and maintenance process;	Model - based; multidisciplinary models;	disciplinary project information manag	Authoring tool; Analysis software; Asset management tools;	x	Information enriched BIM model; Design solution; Element specifications;*	x	x	x	x	x	Project design; Collaboration of multiple stakeholders required and external resources involvement	5
WE C 2	Water use reduction	D	Further increase water efficiency within buildings to reduce the burden on municipal water supply and wastewater systems.	Manufacturer data showing the water consumption indexes and the model of each equipment and accessory; List of plumbing fixtures by usage groups; Each usage group defined; Flow rates calculations results.	Calculations; Reports;			x			x*	x	x	Design Authoring, Design Review; Building System Analysis; Asset Management;	n/a	Conceptualization, Design Authoring; Selection and Specification;	Clash Detection; Code Checking & Validation;	Site Set-out;	Asset Maintenance; Asset Procurement;	n/a	BIM/Spec Linking;	Using computational design for calculation and credit validation assessment;	Detailed Mechanical design project;	Element - based;	Modeling / importing elements, inserting shared parameter values, performing calculations and additional analysis; simulate design solutions and choose best fit option.	Authoring tool; Analysis software; Asset management tools;	x	Information enriched BIM model; Design solution;	x	x	x	x	x	Mechanical fixture design project with multiple stakeholders involved;	5
WE C 3	Water metering	D	Support the management of water resources, monitor losses and identify additional water saving opportunities thanks to the accounting of the volumes of water consumed	Summarized water consumption for each system; Protocol for data collection procedures and schedules; Manufacturer data; Calculations results;	Reports; Specifications;			x				x		Building System Analysis, Maintenance Scheduling;	n/a	Selection and Specification	n/a	n/a	n/a	Performance Monitoring;	BIM/Spec Linking; BIM/FM Integration (BIMFMI)	/	Estimation calculations and parameter value insertion. Scheduling maintenance. *	Element - based;	Calculating needs for water consumption / metering and inserting parameter values for meter positions, linking manufacturer data and metering schedules;	Authoring tool; Analysis software; Asset management tools;	x	Information enriched BIM model - information on meter types and use as parameter values;	x					There is no design process for this credit. BIM can be useful for retreiving data on system types, buildings' dimensions, occupancy loads, needs for meter positioning, calculations, and similar; Data such as schedules and manufacturer information can be linked to particular elements, keeping it in the common repository.	2
No	Name	Project phase	Purpose	Requested information by GBC HB	Requested information formats = output	ARCHAE.	LAB. SPEC.	RA	Urban planner	SPEC. E.	SE	MEP	External bodies	BIM uses by Penn State	Domain model uses by BIM excellence: Capturing and Representing	Planning and Designing	Simulating and Quantifying	Constructing and Fabricating	Operating and Maintaining	Monitoring and Controlling	Linking and Extending	Specific solution from the literature	BIM Approach	BIM Information structure	Information managing process	BIM Platforms	Excel calculator, xml	BIM Result	Calculation in BIM Authoring platform	Calculation in external platform	BIM Analysis tool	Multiple BIM software	BIM for Multiple project stages	Comments	BIM - GBC HB credit compatibility
04 Energy & Atmosphere																																			
EA PR 1	Fundamental commissioning of building energy systems	C	Verify that the energy-related systems are installed, calibrated and perform according to the OPR, BOD and construction documents.	OPR; List od systems to be commissioned; BOD; Specific Requests for Commissioning activities; Commissioning plan; Final report on Commissioning activities; Systems manuals;	Reports; Graphical;			x		x	x	x	x	Design Authoring, Design Review; Lighting, Energy, Mechanical analysis; Sustainability Analysis; Maintenance Scheduling; Asset Management	2D Documentation; 3D Detailing	Design Authoring; Selection and Specification	QTO; Energy Utilisation*; Lighting Analysis; Thermal Analysis; Energy Utilisation; Sustainability Analysis; Clash	Site Set-out;	Asset Procurement; Handover and Commissioning; Building Inspection	Building Automation, Performance Monitoring	(BIMFMI)	/	Detailed design, construction and maintenance process;	Model - based; multidisciplinary models;	Multi - disciplinary project information management;	Authoring tool; Analysis software; Asset management tools;	x	Information enriched BIM model/s; Simulation and analysis results; Design solution; Element specifications;	x	x	x	x	x	Multi - stage project process process using BIM; Collaboration of multiple stakeholders required and external bodies involvement;	5
EA PR 2	Minimum energy performance	D	Establish a minimum level of improvement of energy efficiency r to reduce the economic and environmental impacts of energy consumption, respecting the cultural value.	ASHRAE reference forms; Project climate zone; Calculated energy consumption by type of building (project and reference); Compliance with current legislation; Final report of annual energy consumption;	Reports; Graphical;			x		x	x	x	x	Design Authoring, Design Review; Lighting, Energy, Mechanical analysis; Building System Analysis; Sustainability Analysis; Code Validation	2D Documentation	Design Authoring; Selection and Specification	Code Checking & Validation; Cost Estimation;; QTO; Energy Utilisation*; Lighting Analysis; Thermal Analysis; Energy Utilisation	n/a	n/a	Performance Monitoring	n/a	/	Energy model and simulation in BIM; Monitoring and collecting data;	Model - based; multidisciplinary models;	Multi - disciplinary project information management;	Authoring tool; Analysis software; Asset management tools;	x	Information enriched BIM model/s; Simulation and analysis results; Design solutions; Monitoring;	x	x	x	x	x	Multi - stage project process process using BIM; Collaboration of multiple stakeholders required and external bodies involvement;	5
EA PR 3	Fundamental refrigerant management	D	Reduce the destruction of stratospheric ozone.	Where applicable - plan for the elimination of CFC and HCFC based refrigerants; Manufacturers documentation for HVAC & R systems;	Reports;					x		x	x	n/a	n/a	n/a	n/a	n/a	n/a	n/a	BIM/Spec Linking;	/	Element parameter values insertion;	Element - based;	Insertion of parameter values for HVAC & R elements;	Authoring tool;		Information enriched BIM model;						There is no model or element design, simulation or calculation process needed for this credit; BIM tools in this case can be used for information retrieval (on HVAC & R system types) and record keeping, by inserting values and linking	1
EA C 1	Optimize energy performance	D	Establish a minimum level of improvement of energy efficiency r to reduce the economic and environmental impacts of energy consumption, respecting the cultural value.	ASHRAE reference forms; Project climate zone; Calculated energy consumption by type of building (project and reference); Compliance with current legislation; final report of annual energy consumption;	Reports;			x		x	x	x	x	Design Authoring, Design Review; Lighting, Energy, Mechanical analysis; Building System Analysis; Sustainability Analysis; Code Validation;	umentation; 3D D	Design Authoring; Selection and Specification	Code Checking & Validation; QTO; Energy Utilisation*; Lighting Analysis; Thermal Analysis; Energy Utilisation;	n/a	n/a	Performance Monitoring	n/a	/	Energy model and simulation in BIM;	Model - based; multidisciplinary models;	Multi - disciplinary project information management;	Authoring tool; Analysis software;	x	Information enriched BIM model/s; Simulation and analysis results; Design solutions;	x	x	x	x	x	Complex project design using BIM; Collaboration of multiple stakeholders required and external bodies involvement;	5
EA C 2	Renewable energies	C	Promote production of renewable energy sources, in order to reduce the environmental and economic impact.	Types of renewable energy on and off - site; Calculated produced energy of each renewable energy source on site; Documentation of any incentive that was provided to support the installation of renewable energy systems in place. Contract	Reports;			x		x	x	x	x	Design Authoring, Design Review; Lighting, Energy, Mechanical analysis; Building System Analysis; Sustainability Analysis; 3D Coordination Code Validation; Site Utilization Planning;	n/a	Design Authoring; Selection and Specification	Code Checking & Validation; QTO; Energy Utilisation*; Lighting Analysis; Thermal Analysis; Energy Utilisation;	Construction Logistics	Asset Procurement; Handover and Commissioning	n/a	BIM/Spec Linking;	/	Detailed design, construction and maintenance project in BIM;	Model - based; multidisciplinary models;	Multi - disciplinary project information management;	Authoring tool; Analysis software;	x	Information enriched BIM model/s; Simulation and analysis results; Design solutions;	x	x	x	x	x	Complex project design using BIM; Collaboration of multiple stakeholders required and external bodies involvement;	5
EA C 3	Enhanced commissioning	C	Start the Commissioning process in the early design stages and carry out additional activities after the performance checks of the systems.	OPR; List od systems to be commissioned; BOD; Specific Requests for Commissioning activities; Commissioning plan; Final report on Commissioning activities; Systems manuals;	Reports; Graphical;			x		x	x	x	x	Design Authoring, Design Review; Lighting, Energy, Mechanical analysis; Sustainability Analysis; Maintenance Scheduling; Asset Management	2D Documentation; 3D Detailing	Design Authoring; Selection and Specification	QTO; Energy Utilisation*; Lighting Analysis; Thermal Analysis; Energy Utilisation; Sustainability Analysis; Clash	Site Set-out;	Asset Procurement; Handover and Commissioning; Building Inspection;	Building Automation, Performance Monitoring	(BIMFMI)	/	Detailed design, construction and maintenance process;	Model - based; multidisciplinary models;	Multi - disciplinary project information management;	Authoring tool; Analysis software; Asset management tools;	x	Information enriched BIM model/s; Simulation and analysis results; Design solution; Element specifications;	x	x	x	x	x	Multi - stage project process process using BIM; Collaboration of multiple stakeholders required and external bodies involvement;	5
EA C 4	Enhanced refrigerant management	D	Minimize direct contributions to global warming.	Where applicable - a plan for the leimination of CFC and HCFC based refrigerants; Manufacturers documentation used for HVAC & R	Reports;					x		x	x	n/a	n/a	n/a	n/a	n/a	n/a	n/a	BIM/Spec Linking;	/	Element parameter values insertion;	Element - based;	Insertion of parameter values for HVAC & R elements;	Authoring tool;		Information enriched BIM model;						There is no model or element design, simulation or calculation process needed for this credit; BIM tools in this case can be used for information retrieval (on HVAC & R system types) and	1
EA C 5	Measurement and verification	C	Provide monitoring of the building's energy consumption during operation.	Measurement and verification plan; Indications of meters positions;	Reports; Graphical;			x		x		x	x	Design Authoring, Design Review;Sustainability Analysis; Code Validation;	2D Documentation;	Design Authoring; Selection and Specification;	Code Checking & Validation; QTO; Sustainability Analysis;	n/a	Asset Procurement; Handover and Commissioning	Field BIM; Performance Monitoring;	BIM/Spec Linking; BIM/IOT Interfacing;	/	Element parameter values insertion;	lement - based;	Insertion of parameter values for HVAC & R elements;	Authoring tool; Analysis software; Asset	x	formation enriched BIM mode	x	x	x	x	x	Since information on HVAC & R system can be used from previous credit acheivement, the same information can be used to obtain this credit, by retreiving data and inserting additional relevant	3
No	Name	Project phase	Purpose	Requested information by GBC HB	Requested information formats = output	ARCHAE.	LAB. SPEC.	RA	Urban planner	SPEC. E.	SE	MEP	External bodies	BIM uses by Penn State	Domain model uses by BIM excellence: Capturing and Representing	Planning and Designing	Simulating and Quantifying	Constructing and Fabricating	Operating and Maintaining	Monitoring and Controlling	Linking and Extending	Specific solution from the literature	BIM Approach	BIM Information structure	Information managing process	BIM Platforms	Excel calculator, xml	BIM Result	Calculation in BIM Authoring platform	Calculation in external platform	BIM Analysis tool	Multiple BIM software	BIM for Multiple project stages	Comments	BIM - GBC HB credit compatibilit
05 Materials & Resources																																			
MR PR 1	Storage and collection of recyclables	D	Reduce the amount of waste produced by occupants, which are transported and disposed in landfills.	Floor plan highlighting areas for the collection and storage of recyclables, containers with the related capacities, routes for the collection of waste; Calculations according to the tables provided by the local authorities (where possible); Alternatively	Reports; Graphical;			x					x	Coceptualization; Design Authoring, Design Review; Site Utilizaton Planning;	2D Documentation;	Design Authoring;	Clash Detection; Risk and Hazard Assessment; Spatial Analysis;	Construction Logistics;	Space Management; Handover and Commissioning;	Field BIM;	BIM/Spec Linking;	Plug - in for material and waste estimation connected with proprietary software	Design and simulate the solutions, choose best fit option; Insert parameter values and link manufacturer data;	Model - based;	Multi - disciplinary project information management;	Authoring tool; Analysis software; Asset management tools;	x	Design, construction and operation project of storage areas;	x	x			x	Design project using BIM software, which results can be exported as credit application documentaton; Multiple stakeholders required and external bodies involvement (such as local tansportation companies for collection of waste);	5
MR PR 2	Demolition and construction waste management	C	Divert demolition and construction waste from landfilling or incineration facilities. Redirect recyclable resources back to the manufacturing process and reusable materials to appropriate sites.	Demolition and Construction Waste Management Plan; Waste schedule - types, quantities sent to landfills or diverted; Percentage of diverted waste;	Reports;			x		x			x	Design Authoring, Design Review; Site Utilizaton Planning;	2D Documentation;	Design Authoring;	QTO;	Construction Logistics; Constructio waste management	Building Inspection;	Field BIM	BIM/IOT Interfacing	M&C (Material and Component) bank tool for waste waste calculation and deconstruction management, to calculate waste disposal charging fee and pickup truck requirements, with BIM model as a source.	Construction site design and optimization;	Model - based;	Multi - disciplinary project information management; Insertion of information about elements quantity to demolish, material type and quantity, road hauliers; performing calculations, analysis; Monitoring and documenting;	Authoring tool; Analysis software;	x	Design and construction project; Colllecting and storing monitored results;	x	x	x	x	x	Collaboration of multiple stakeholders required and external bodies involvement; using BIM the information on elements volume, material type and construction logistics can be created and retrieved; Information such as costs, and similar data from external bodies can be inserted to perform calculations;	4
MR PR 3	Building reuse	C	Extend the life cycle of the existing building stock, in relation to the production and transport of materials.	Identity card of the historic building (HV PR 1); Structural elements scheduling and categorization;	Graphical; Reports;						x			Structural Analysis; Asses management;	2D Documentation;	Design Authoring;	QTO; Structural Analysis;	n/a	Asset Management;	n/a	n/a	Plug - in for material and waste estimation connected with proprietary software	BIM for structural analysis;	Model - based;		Authoring tool (structural); Analysis software;			x		x			Being closely related to HV C 1.2, this credit can be applied for using BIM software accordingly.	5
MR C 1	Building reuse: maintaining existing technical element and fi nishing	C	Extend the life cycle of the existing building stock, in relation to the production and transport of materials.	Identity card of the historic building (HV PR 1); Structural elements scheduling and categorization;	Graphical; Reports;						x			Structural Analysis; Asses management;	2D Documentation;	Design Authoring;	QTO; Structural Analysis;	n/a	Asset Management;	n/a	n/a	Plug - in for material and waste estimation connected with proprietary software	BIM for structural analysis;	Model - based;		Authoring tool (structural); Analysis software;			x		x			Being closely related to HV C 1.2, this credit can be applied for using BIM software accordingly.	5
MR C 2	Demolition and construction waste management	C	Divert demolition and construction waste from landfilling or incineration facilities. Redirect recyclable resources back to the manufacturing process and reusable materials to appropriate sites.	Demolition and Construction Waste Management Plan; Waste schedule - types, quantities sent to landfills or diverted; Percentage of diverted waste;	Reports;			x		x			x	Design Authoring, Design Review; Site Utilizaton Planning;	2D Documentation;	Design Authoring;	QTO;	Construction Logistics; Constructio waste management	Building Inspection;	Field BIM	BIM/IOT Interfacing	M&C (Material and Component) bank tool for waste waste calculation and deconstruction management, to calculate waste disposal charging fee and pickup truck requirements, with BIM model as a source.	Construction site design and optimization;	Model - based;	Multi - disciplinary project information management; Insertion of information about elements quantity to demolish, material type and quantity, road hauliers; performing calculations, analysis; Monitoring and documenting;	Authoring tool; Analysis software;	x	Design and construction project; Colllecting and storing monitored results;	x	x	x	x	x	Collaboration of multiple stakeholders required and external bodies involvement; using BIM the information on elements volume, material type and construction logistics can be created and retrieved; Information such as costs, and similar data from external bodies can be inserted to perform calculations;	4
MR C 3	Materials reuse	C	Reuse building materials and products to reduce the demand for virgin materials and the production of waste, limiting the impacts associated with the extraction and processing of raw materials.	List of reused or recovered materials used in the project and the related costs; Construction costs for the materials or of actual material costs, excluding labor and equipment costs;	Reports;			x					x	Cost Estimation;	n/a	Selection and Specification;	QTO; Cost estimation;	n/a	Relocation Management; Asset Procurement;	n/a	BIM/Spec Linking;	Plug - in for material and waste estimation connected with proprietary software	Information enriching elements, performing QTO and cost estimation;	Element - based;	Linking iexternal data, parameter values insertion, scheduling and calculation;	Authoring tool connected with external information sources;		Information enriched BIM model; QTO and Cost estimation calculations;	x					Information on material types, quantities can be retrieved from existing model; Manufactureer specification can be linked in the model as an external source of data;	3
MR C 4	Building product environmental optimization	C	Encourage the use of products and materials with known information of impacts on the life cycle and virtuous impacts from an environmental, economic and social point of view.	EPD or LCA with third - party verification or manufacturer declaration; Multi-criteria certifications (FSC, PEFC, etc.);	Reports;			x		x			x	Design Authoring, Design Review;	2D Documentation;	Selection and Specification;	Life Cycle Assessment (LCA)	n/a	n/a	n/a	BIM/Spec Linking; BIM/PLM Overlapping	Plug - in for material and waste estimation connected with proprietary software	BIM for LCA;	Element - based;	LCA Analysis in BIM;	Authoring tool; Analysis software;	x	LCA results and assesment;	x	x				/	4
MR C 5	Regional materials	C	Support the use of indigenous resources and reduce the environmental impacts of transportation. Encourage the use of transport with limited environmental impact such as rail or ship transport.	List of purchased products that are extracted, processed, produced or recovered at a limited distance; Product specification (manufacturer names, costs, distances between the site and the production site, distances between the site and the extraction site); Where appropriate, material certificates documenting that the origin and processing of the material occurred within the adeguate radius; Where appropriate,	Reports;			x		x			x	Design Authoring, Design Review; Site Utilizaton Planning; Digital Fabrication;	n/a	n/a	QTO; Cost estimation;	n/a	Asset Procurement;	n/a	BIM/Spec Linking;	Plug - in for material and waste estimation connected with proprietary software	Information enriching elements, performing QTO and cost estimation;	Element - based;	Linking iexternal data, parameter values insertion, scheduling and calculation;	Authoring tool connected with external information sources;	x	Information enriched BIM model; QTO and Cost estimation calculations;	x	x				External information such as material / product sources location, transportation mode to the construction site is required; BIM can be helptul assisting in QTO and cost estimation, by retreiving data from design model;	3

APPENDIX 4: SYSTEMATIC ANALYSIS OF GBC HISTORIC BUILDING CREDITS INDOOR ENVIRONMENTAL QUALITY

This appendix consists of the spreadsheet table created and used for the systematic analysis of each GBC Historic building credit, for the Indoor Environmental Quality credit category.

APPENDIX 4: SYSTEMATIC ANALYSIS OF GBC HISTORIC BUILDING CREDITS – INDOOR ENVIRONMENTAL QUALITY

No	Name	Project phase	Purpose	Requested information by GBC HB	Requested information formats = output	ARCHAE.	LAB. SPEC.	RA	Urban planner	SPEC. E.	SE	MEP	External bodies	BIM uses by Penn State	Domain model uses by BIM excellence: Capturing and Representing	Planning and Designing	Simulating and Quantifying	Constructing and Fabricating	Operating and Maintaining	Monitoring and Controlling	Linking and Extending	Specific solution from the literature	BIM Approach	BIM Information structure	Information managing process	BIM Platforms	Excel calculator, xml	BIM Result	Calculation in BIM Authoring platform	Calculation in external platform	BIM Analysis tool	Multiple BIM software	BIM for Multiple project stages	Comments	BIM - GBC HB credit compatibility
06 Indoor Environmental Quality																																			
IEQ PR 1	Minimum indoor air quality performance (IAQ)	D	Achieve air quality in confined spaces to protect the health of the occupants, the conservation of the building, satisfy the comfort and cultural value.	Demonstration of compliance with the applicable sections of UNI EN 15251:2008;	Reports;*			x		x		x		Design Authoring, Design Review; Code Validation; 3D Coordination; Mechanical Analysis;	2D Documentation;	Design Authoring; Selection and Specification;	Code Checking & Validation; Clash detection;	n/a	Handover and Commissioning; Asset Management; Building Inspection	Performance Monitoring; Real-time Utilization;	BIM/Spec Linking; BIM/IOT Interfacing;	/	Ventilation system design, with elements, parameter values, simulations and calculations;	Model - based;	Project design in authoring tool (MEP), calculations, simulations and analysis;	Authoring tool; Model checker; Analysis tool;	x	Information enriched BIM model/s; Simulation and analysis results; Design solutions;	x	x	x	x	x	/	
IEQ PR 2	Environmental Tobacco Smoke (ETS) control	D	Prevent / minimize exposure of building occupants, indoor surfaces and ventilation air distribution systems to environmental tobacco smoke (ETS).	Anti-smoking policy, identifying areas where smoking is prohibited; Documentation (e.g. floor plans and renderings) visually indicating areas where the smoking policy is active; Monitor and record data for each smoking area;	Graphical; Reports;			x		x		x	x	O2: Design Authoring, Design Review; Mechanical Analysis;	2D Documentation;	O2: Design Authoring; Selection and Specification;	Clash detection;	n/a	Handover and Commissioning; Asset Management;	Performance Monitoring; Real-time Utilization;	BIM/Spec Linking; BIM/IOT Interfacing;	/	O2: Project design, simulation and monitoring;	Element / Model - based;	O2: Project design in authoring tool; simulations and analysis;	Authoring tool; Model checker; O2: Analysis tool; Monitoring tool;	x	Information enriched BIM model/s; Simulation and analysis results; Design solutions;	x	x	x	x	x	If there are to be areas dedicated for smoking, BIM can be an useful tool for project design, simulaiton and monitoring - results requested by the credit description;	5
IQ C 1	Air monitoring	D	Provide capacity for ventilation system monitoring to help sustain building conservation and occupant well-being.	CO2 monitoring sensors in plans, with diagrams, elevations (if necessary), and data sheets; Ventilation systems specifications, with monitoring; Alarm system according to UNI 10339 for mechanical ventilation systems; Manufacturer's guidelines for system calibration;	Graphical; Reports;					x		x		Asset Management; Building System Analysis	2D Documentation;	Selection and Specification;	Code Checking & Validation; Clash detection;	n/a	Handover and Commissioning; Asset Management;	Performance Monitoring; Real-time Utilization;	BIM/Spec Linking; BIM/IOT Interfacing;	/	Element and result representation and documentation;	Element - based;	Element insertion and representation; Monitor, collect and sort data; Parameter values insertion; linking manufacturer information;	Authoring tool; Monitoring tool;	x	Information enriched BIM model/s; Design solution; Data monitoring and sorting tool;	x					/	4
IQ C 2	Outdoor air delivery monitoring	D	Evaluate minimum external air flow rate according to a contaminant or reference parameter, conserving the building or quality of indoor air.	*Follow the chapter 8.3 of UNI 10339;* Mechanical equipment scheme / ventilation design project;	Graphical; Reports;			x				x		Design Authoring, Design Review; Mechanical Analysis; Code Validation;	2D Documentation;	Design Authoring; Selection and Specification;	Code Checking & Validation; Clash detection; Thermal Analysis; Acoustic Analysis; Sustainability Analysis;	n/a	Handover and Commissioning; Asset Management;	Performance Monitoring;	BIM/Spec Linking;	/	Ventilation system design, with appropriate elements, parameter values, simulations and	Model - based;	Project design in authoring tool (MEP), calculations, simulations and analysis;	Authoring tool; Model checker; Analysis tool;	x	Information enriched BIM model/s; Simulation and analysis results; Design solutions;	x	x	x	x	x	Collaboration of multiple stakeholders required and external resources involvement.	5
C IQ 3.1	Construction IAQ management plan: during construction	C	Reduce problems of IAQ deriving from restoration process; guarantee conservation / comfort and well-being of construction workers and occupants.	Indoor Air Quality Management Plan (IAQ) for demolition and construction phase; Photographic documentation of the practices of IAQ followed and implemented;	Graphical; Reports;			x		x		x	x	Mechanical Analysis; Code Validation; 3D Coordination; Site Utilization Planning; Construction System Design;	2D Documentation; Record Keeping;	Design Authoring; Selection and Specification; Demolition Planning;	Code Checking & Validation; Clash detection; Risk and Hazard Assessment; Safety Analysis	Construction Logistics; Site Set-out;	Building Inspection;	Field BIM;	BIM/Spec Linking;	/	Construction site project with multiple stakeholders involved;	Model - based;	Design modelling, simulating and analysing data; inserting parameters and linking external information (eg. Manufacturer data on material specifications)	Authoring tool; Model checker; Analysis tool; Monitoring tool;	x	Information enriched BIM model/s with external data linking; Simulation and analysis results; Design solutions; Results from monitoring;	x	x	x	x	x	Extensive information about equipment specification, such as detailed analysis of contaminant levels and similar, along with collaboration with IEQ specialits, is requested for this credit. BIM can therefore be linked with this information during the construction site planning.	4
IQ C 3.2	Construction IAQ management plan: before occupancy	C	Reduce problems of IAQ deriving from restoration process; guarantee conservation / comfort and well-being of construction workers and occupants.	Indoor Air Quality Management Plan (IAQ), the replacement of all air filtration systems; Indoor air quality test results and HVAC systems control; For projects that complete a flush-out procedure, record dates, occupancy, air flow rates, internal temperature and humidity and other special considerations; For projects that complete the Indoor Air Quality Test, a copy of the test report and verification that	Reports;					x		x	x	Code Validation;	Record Keeping;	n/a	n/a	n/a	Building Inspection;	Field BIM;	BIM/Spec Linking; BIM/IOT Interfacing;	/	Collect and store data;	Element - based;	Collect and store data as parameter values;	Authoring tool; *	x	Information enriched BIM model/s with external data linking;	x	x	x	x	x	On - site analysis result can be linked, although reports on measuring can be done seperately from BIM;	1
C IQ 4.1	Low-emitting materials: adhesives and sealants	C	Reduce contaminants in the building that are odorous, irritating and / or harmful to comfort and well-being of installers and occupants.	List of each interior adhesive, sealant, cement product, parquet paint and primer used in the project, manufacturer's name, product name, specific VOC data for each product (in g / m3), and the corresponding VOC value allowed by the reference standard; If the VOC budget approach is used, indicate the quantity of product used; Material	Reports;					x			x	Code Validation;			Code Checking & Validation; QTO;		Asset Procurement;		BIM/Spec Linking;	/	Collect and store data;	Element - based;	Collect and store data as parameter values;	Authoring tool; *	x	Information enriched BIM model/s with external data linking;		x	x	x	x	Information on general material type and quantity can be retrieved from the BIM model; Summarized information on materials can be inserted as parameter values in BIM model, to check code compliance;	1
C IQ 4.2	Low emissive materials: paints and coatings	C	Reduce contaminants in the building that are odorous, irritating and / or harmful to comfort and well-being of installers and occupants.	List of each interior adhesive, sealant, cement product, parquet paint and primer used in the project, manufacturer's name, product name, specific VOC data for each product (in g / m3), and the corresponding VOC value allowed by the reference standard; If the VOC budget approach is used, indicate the quantity of product used; Material safety data sheets (MSD cards),	Reports;					x			x	Code Validation;			Code Checking & Validation; QTO;		Asset Procurement;		BIM/Spec Linking;	/	Collect and store data;	Element - based;	Collect and store data as parameter values;	Authoring tool; *	x	Information enriched BIM model/s with external data linking;		x	x	x	x	Information on general material type and quantity can be retrieved from the BIM model; Summarized information on materials can be inserted as parameter values in BIM model, to check code compliance;	1
IQ C 4.3	Low emissivity materials: flooring	C	Reduce contaminants in the building that are odorous, irritating and / or harmful to comfort and well-being of installers and occupants.	List of each interior adhesive, sealant, cement product, parquet paint and primer used in the project, manufacturer's name, product name, specific VOC data for each product (in g / m3), and the corresponding VOC value allowed by the reference standard; If the VOC budget approach is used, indicate the quantity of product used; Material safety data sheets (MSD cards), certificates and test results;	Reports;					x			x	Code Validation;			Code Checking & Validation; QTO;		Asset Procurement;		BIM/Spec Linking;	/	Collect and store data;	Element - based;	Collect and store data as parameter values;	Authoring tool; *	x	Information enriched BIM model/s with external data linking;		x	x	x	x	Information on general material type and quantity can be retrieved from the BIM model; Summarized information on materials can be inserted as parameter values in BIM model, to check code compliance;	1
IQ C 4.4	Low emission materials: composite wood products and vegetable fibers	C	Reduce contaminants in the building that are odorous, irritating and / or harmful to comfort and well-being of installers and occupants.	List of each interior adhesive, sealant, cement product, parquet paint and primer used in the project, manufacturer's name, product name, specific VOC data for each product (in g / m3), and the corresponding VOC value allowed by the reference standard; If the VOC budget approach is used, indicate the quantity of product used; Material	Reports;					x			x	Code Validation;			Code Checking & Validation; QTO;		Asset Procurement;		BIM/Spec Linking;	/	Collect and store data;	Element - based;	Collect and store data as parameter values;	Authoring tool; *	x	Information enriched BIM model/s with external data linking;		x	x	x	x	Information on general material type and quantity can be retrieved from the BIM model; Summarized information on materials can be inserted as parameter values in BIM model, to check code compliance;	1
IEQ C 5	Indoor chemical and pollutant source control	D	Minimize the contaminants identified as problematic for building conservation or for occupant comfort and IAQ.	Documentation on the location, dimensions of permanent dirt barriers and doormats; Tabular list of dirt barriers; Building maintenance plan that indicates the cleaning and maintenance of the permanent dirt barriers and doormats, necessary to intercept the contaminants brought inside the building; List that identifies areas or premises that need to be partitioned; Detail the partitions from the floor	Graphical; Reports;			x		x		x		Programming; Design Authoring, Design Review; Maintenance Scheduling;	2D Documentation;	Conceptualization; Design Authoring; Space Programming; Selection and Specification;			Asset Procurement; Asset Maintenance		BIM/Spec Linking;	/	Project design with element specification;	Element / Model - based;	Design and simulate solutions in authoring tool; perform analysis and choose best fit option;	Authoring tool; Model checker; Analysis tool;	x	Information enriched BIM model/s; Simulation and analysis results; Design solutions;	x		x	x	x	/	4
IEQ C 6.1	Controllability of systems - lighting	D	Provide users the possibility of adjusting the lighting system compatible with their needs, compatible with the protection of the building.	Floor plan indicating the location, zoning, and the type of lighting control provided; Include furniture layouts, individual and / or shared work areas; Information of the lighting design, of sensors and lighting controls;	Graphical; Reports;			x		x		x		Design Authoring, Design Review; Code Validation; Maintenance Scheduling;	2D Documentation;	Design Authoring; Selection and Specification;	Code Checking & Validation; Lighting Analysis;	n/a	Asset Maintenance	Building Automation; Real-time Utilization	BIM/Spec Linking; BIM/IOT Interfacing;	/	Lighting contrtol design in BIM with specific attention to artifficial light equipment;	Element / Model - based;	Design and simulate solutions in authoring tool; perform analysis and choose best fit option;	Authoring tool; Model checker; Analysis tool; Monitoring tool;	x	Information enriched BIM model/s; Simulation and analysis results; Design solutions;	x	x	x	x	x	/	
IEQ C 6.2	Controllability of systems: thermal comfort	D	Provide a high level of thermal comfort system control, by individuals or groups in multi-occupant spaces, compatible with the protection of the building.	For the controls of the individual workstations - list of the total number of single workstations and the devices for regulating thermal comfort; For spaces shared by multiple occupants - list of the total number of spaces shared by multiple occupants and a description of the	Graphical; Reports;			x				x		Design Authoring, Design Review; Code Validation; Maintenance Scheduling;	2D Documentation;	Design Authoring; Selection and Specification;	Code Checking & Validation; Thermal Analysis ;	n/a	Asset Maintenance	Building Automation; Real-time Utilization	BIM/Spec Linking; BIM/IOT Interfacing;	/	Thermal optimization in BIM;	Model - based;	Design and simulate solutions in authoring tool; perform analysis and choose best fit option;	Authoring tool; Model checker; Analysis tool; Monitoring tool;	x	Information enriched BIM model/s; Simulation and analysis results; Design solutions;	x	x	x	x	x	/	
IEQ C 7.1	Thermal comfort: design	D	Provide a thermally suitable environment for the building conservation / occupants well-being.	Client requests regarding thermal comfort; Level of metabolic activity; Criteria adopted for the maintenance of environmental conditions aimed at the conservation of the building; Summarized operational procedures for construction systems; General information, replacement plans, maintenance, operating instructions and a maintenance and control program; Mechanical design	Graphical; Reports;			x		x		x		Design Authoring, Design Review; Code Validation; Maintenance Scheduling;	2D Documentation;	Design Authoring; Selection and Specification;	Code Checking & Validation; Thermal Analysis ;	n/a	Asset Maintenance		BIM/Spec Linking; BIM/IOT Interfacing;	/	HVAC system design;	Model - based;	Design and simulate solutions in authoring tool; perform analysis and choose best fit option;	Authoring tool; Model checker; Analysis tool;	x	Information enriched BIM model/s; Simulation and analysis results; Design solutions;	x	x	x	x	x	/	5
IEQ C 7.2	Thermal comfort: verification	D	Provide monitoring of the environmental parameters of the building.	If 20% of the occupants of the building express dissatisfaction with the conditions of thermal comfort, a written plan containing the corrective action; Survey on thermal comfort to be administered to the occupants of the building.	Reports;							x		Maintenance Scheduling; Building System Analysis;	Record Keeping	n/a	n/a	n/a	Asset Maintenance	Building Automation; Real-time Utilization	BIM/Spec Linking; BIM/IOT Interfacing;	/	HVAC system monitoring;	Model - based;	Collect and store data as parameter values;	Authoring tool; Model checker; Analysis tool;	x	Information enriched BIM model/s;	x	x	x	x	x	/	2

APPENDIX 5: BIM WORKFLOWS FOR HISTORIC VALUE CREDITS

This appendix consists of the proposed BIM workflows for the Historic Value credit category, according to the request of each credit.

APPENDIX 5: BIM WORKFLOWS FOR THE CREDITS OF HISTORIC VALUE CREDIT CATEGORY