buildings

Article

A Methodological Framework to Optimize Data Management Costs and the Hand-Over Phase in Cultural Heritage Projects

Lidia Pinti * **and Serena Bonelli**

Department of Architecture, Built Environment and Construction Engineering, Polytechnic of Milan, Via Ponzio 31, 20133 Milan, Italy
* Correspondence: lidia.pinti@polimi.it

Abstract: This paper illustrates a methodological approach to optimize the data management process and to reduce costs related to information loss, from the preliminary phases to the Facility Management (FM) one. The growing concern about sustainability issues has steadily increased attention to cultural heritage's key role. Concurrently, Europe promotes the application of digital methods for managing interventions both for new and existing buildings. The data issue, especially in heritage projects, represents a crucial aspect; data-recovering activities or shortages of information contribute to relevant expenses and discourage stakeholders. The research focuses on how procedures involving digitalization, applied to heritage projects, can improve the information workflow, supporting the hand-over stage. Although the application of digital techniques has recognized advantages, enhancements for optimizing time and cost savings are required. The research result is a methodological framework to obtain complete heritage as-built deliverables for the management phase. The defined structure is applied through a case study approach to the restoration of a historical lyric theater. Thus, the as-built model represents a database for controlling costs and maintenance procedures. In the end, the work provides a tangible contribution to the Heritage BIM (HBIM) delivery and can be a starting point for future improvements.

Keywords: Building Information Modelling (BIM); cost control; cultural heritage; data loss; Facility Management (FM); Heritage Building Information Modelling (HBIM); information management; project hand-over

check for updates

Citation: Pinti, L.; Bonelli, S. A Methodological Framework to Optimize Data Management Costs and the Hand-Over Phase in Cultural Heritage Projects. *Buildings* **2022**, *12*, 1360. https://doi.org/10.3390/buildings12091360

Academic Editors: Heap-Yih Chong, Hong Zhang and Paulo Santos

Received: 23 June 2022
Accepted: 22 August 2022
Published: 1 September 2022

1. Introduction

In recent years, the growing concern about sustainability issues has focused attention on the definition of new strategies and on the identification of new economic engines of value production in the built environment. These needs, together with the awareness of property heritage's role in sustainable development, point out the urgency to support decisions in the field through proper methodologies. According to the goals of the United Nations Agenda 2030 for Sustainable Development [1] and the European debate, the built environment and, in particular, heritage assets are recognized as the drivers of economic growth in sustainable terms, since the investments, the decisions and management practices in the field stand for "preservation" and "reuse" and may be a solution to the exploitation of resources and land consumption [2,3]. To realize the need to preserve properties and their fundamental function, the high degree of complexity, which characterizes the heritage field, the complex relationships among the challenges of preserving a heritage system of values, the legislation constraints and the high renovation, maintenance or management costs must be overcome, as they often discourage both private and public investments [3]. In detail, in this last case, complexity increases due to the strict budget boundaries that the public administrator must meet [3,4]. Moreover, changes in the regulatory framework in Europe promote the application of innovative tools and digital approaches for improving the processes when managing interventions both on new and, in particular, existing buildings [5]. To this end, the Architecture, Engineering and Construction (AEC) industry has been constantly looking for new methods to increase efficiency and productivity, starting from design and construction (on which the industry and stakeholders concentrated most in the past years) and then to the last stages related to the management of the built environment. Recently, increasing attention has moved to life cycle management, intending to establish a valuable connection from the first phases to those linked to the end of a building's life [5] to provide benefits for actors and stakeholders when approaching the built environment [4–6]. In this process, the quality of the deliverables has a key role, and the data issue, especially in heritage projects, represents a crucial aspect [6–8].

The Data Loss Issue and the Related Costs

In general, the most important key for successful management is in the detailed and complete knowledge of the assets that are being dealt with. This step can appear more critical in the case of interventions on existing buildings, when the level of knowledge of the built environment can be scarce [6,7]. In fact, this context requires an intense checking activity on two different sides: on the available documentation and on the survey, since the acquisition of the related as-built or as-is documentation is the essential point to develop the next management operations [6]. The data created in the design and construction phase are of vital importance for a safe and effective operational strategy during the Maintenance Management (MM) stage [9], but the availability of those data is scarce for what concerns the existing portfolio [6,10]. Indeed, data recovering activities or shortages of information contribute to relevant expenses and discourage stakeholders (both private and public).

The data loss theme, typical of the building life cycle process, is a largely discussed matter. In the literature, very little research provides measurements of the data loss weight in economic terms. Among them, the study performed in the US by the National Institute of Standards and Technology (NIST) [11] still represents a timeless model and an accredited source of reliable data for accounting for the costs of the inadequate interoperability (data flow) in the capital facility industry.

In detail, the study illustrates that owners/Facility Management (FM) players account for approximately 10.6 billion USD of the 15.8 billion USD total inadequate interoperability costs of U.S. capital facility projects in 2002 [11]. Figure 1 illustrates the data loss of the traditional process, arising among the phases of the building life cycle (red line). This is representative of the inadequate interoperability costs documented in the NIST report. Figure 1 compares the data to the curve of the efficient workflow (blue line). A proper methodological framework is highly efficient the more it can minimize the gap between the two curves (red to blue) and, at the same time, due to digitalization or more powerful systems, reduce the information gap occurring phase by phase.

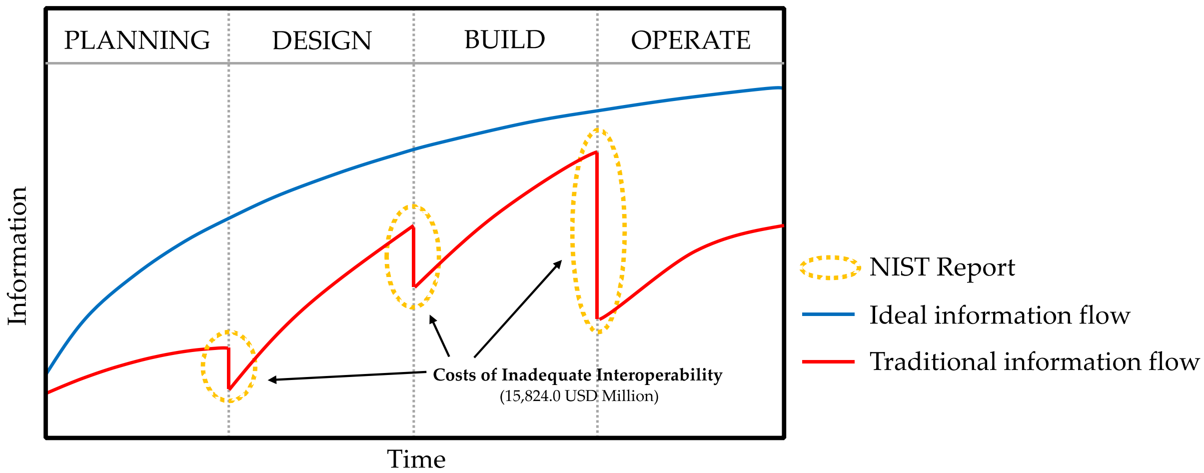


Figure 1. Information loss in the building life cycle and NIST estimated costs (re-elaboration based on Eastman et al. [12] and Gallaher et al. [11]).

In light of that, as reported by Kasprzak and Dubler [13], it becomes vital that data produced during the design and construction phases be transferred into operations effectively. Moreover, according to Kasprzak and Dubler [13] it has been illustrated that the overall impact of Operation and Maintenance (O&M) is two times the amount of time spent on preventive maintenance and four times the amount of time on corrective maintenance over 25 years. Therefore, if appropriate and trustworthy information is not documented at the end of the site phase, it has an exponential adverse effect on the management performance level in the "use" stage [13].

Based on what is claimed above, this work intends to answer the following main question: in view of the recognized gaps, how is it possible to provide a solution to the lack of integrated/structured procedures in information management processes, and how is it possible to optimize the related costs?

To answer the leading interrogative, additional sub-questions have been developed to address the issue. The sub-questions are as follows:

How is it possible to overcome the limitations of the current practice for supporting data flow processes until the hand-over stage?

How can procedures involving digitalization, such as BIM, contribute to this aim?

In fact, in this context, the application of Building Information Modelling (BIM), can represent an opportunity. The Building Information Modelling approach has the main objective of guaranteeing the exchange of information during the whole building life cycle, generating an informative model that is coherent and organized. The BIM strength lies in the capability of defining a real data model of the building that provides not only graphical but also additional information which has been progressively introduced during the development of the process. This kind of information is the baseline to set the adequate framework of efficient management. Therefore, the BIM model can be the tool that enables the transfer of data during the process without losses, and it avoids insufficient or redundant information. In particular, by analyzing the Italian context, it is possible to realize that BIM could become an essential tool to manage existing buildings [14], frequently characterized by historical value in order to plan their maintenance activities [14–17]. Until now, research and applications in the HBIM field concentrate on multiple aspects. There are some approaches linked to BIM for existing buildings for the graphic representation of cultural heritage items, and there are studies regarding the application of BIM in the design or construction of heritage buildings concentrating on the acquisition of 3D survey data from laser scanning and photogrammetry [18]. The recognized gap within the literature was in the lack of integrated procedures and standards to guarantee a continuous information flow and to reduce the related costs occurring along the building cycle.

Moreover, most of the bibliographies mainly deal with new buildings and do not make considerations on construction programming, cost estimation, analyses, simulations, residual management and demolition [19,20].

Indeed, several scientific contributions have provided sector-based works on HBIM implementation and tool application, dealing with investigations falling into specific contexts or specific topic areas. Moreover, several works provide the experimentations to specific building categories, which are too sectoral with no cross-evaluations of applicability in different contexts and different building types. So far, very few reviews have covered the theme of proposing a structured guideline to fit the issue of information in the hand-over phase. Therefore, the literature still lacks research providing methodological frameworks for the integration of Building Information Modelling in the development of an HBIM-as-built that is complete in the data and appropriate for management purposes. Thus, contributions such as roadmaps of implementation are scarce. In light of these issues, this paper aims to illustrate a methodological approach to optimize the data management process and to reduce costs related to information loss in the building life cycle. The proposed process focuses on how Building Information Modelling, applied in the first stages of the building process, can provide value in the deliverables' quality, optimizing the hand-over phase of a project to set a starting point for powerful management. Moreover, the research presents, through a case study approach on a historical lyric theater, a method that can be re-produced as a matrix on other situations in the heritage building field. The as-built model, developed on the lyric theater's ongoing refurbishment site, serves as the main source of information, and it forms a large database for setting management and maintenance procedures. The significance of this study lies in the generation of an HBIM, developed through the application of tools for speeding up the 3D model data update, and in the definition of an integrated data system. The goal is to overcome the limitations of the current practice through the systematic management of integrated information to reduce the waste of data and to optimize time and prevent future expenses. This work, through a step-by-step methodology, provides a contribution to the field of HBIM-as-built delivery and should be a starting point for future improvements in the area.

In summary, the research methodology was developed according to these main milestones:

- Background/Literature analysis (Section 1);
- Problem statement, gap identification (Section 1) and aim and research question definitions (Section 1);
- Methodological framework definition;
- Case study application;
- Discussion;
- Conclusion.

Concerning the structure, this article is organized in the following manner: Section 2 describes the methodological framework structured by phases through which the research is developed; Section 3 presents the application of research methods through the case study approach; and finally, Sections 4 and 5 present and discuss the final results.

2. Methodological Framework

Based on the literature and previous research, this work has identified four stages and related tools to structure a framework to optimize the data flow and to reduce information gaps among the phases. This section introduces a methodological framework developed for managing interventions on heritage buildings and, in detail, for providing appropriate deliverables, the baseline for setting efficient management to reduce costs related to information loss.

A correct process can lead to a substantial reduction in the lost data and cost savings for recovering the information. Thus, the following paragraphs illustrate the research methods and the tools that are then applied in the case study section. The purpose of this part is to supply a global view of the steps and of the essential aspects addressed in the research. Therefore, the methodological structure and the main steps are reviewed in the next paragraphs and are summarized below (Figure 2).

2.1. The Survey Phase: Laser Scanning Technology

The application of new technologies to protect and maintain cultural heritage buildings is now a worldwide tendency [21]. Methods for acquiring precise three-dimensional data, such as those of Terrestrial Laser Scanning (TLS) and of image-based techniques, are more efficient than the traditional methods, especially for describing complex sites and buildings with unusual geometries [22]. Three-dimensional laser scanning has been a widely used system within the survey field, since it is a powerful tool used to obtain an accurate survey of a real object/environment for its capacity to identify details and capture complex shapes [23]. The laser scanning survey is, by far, recognized as one of the preferred methods when dealing with static or structural analyses, when investigating geometric anomalies or when requiring descriptive models [22,24–28]. This kind of technique provides concurrently great reliability in terms of accuracy, information density and autonomy from environmental conditions at the time of acquisition. Moreover, this approach speeds up the traditional process of acquiring a massive amount of data to describe the selected environment. It facilitates the survey of hidden spaces, since TLS, with respect to traditional measurement methods, can reach unattainable areas [23].

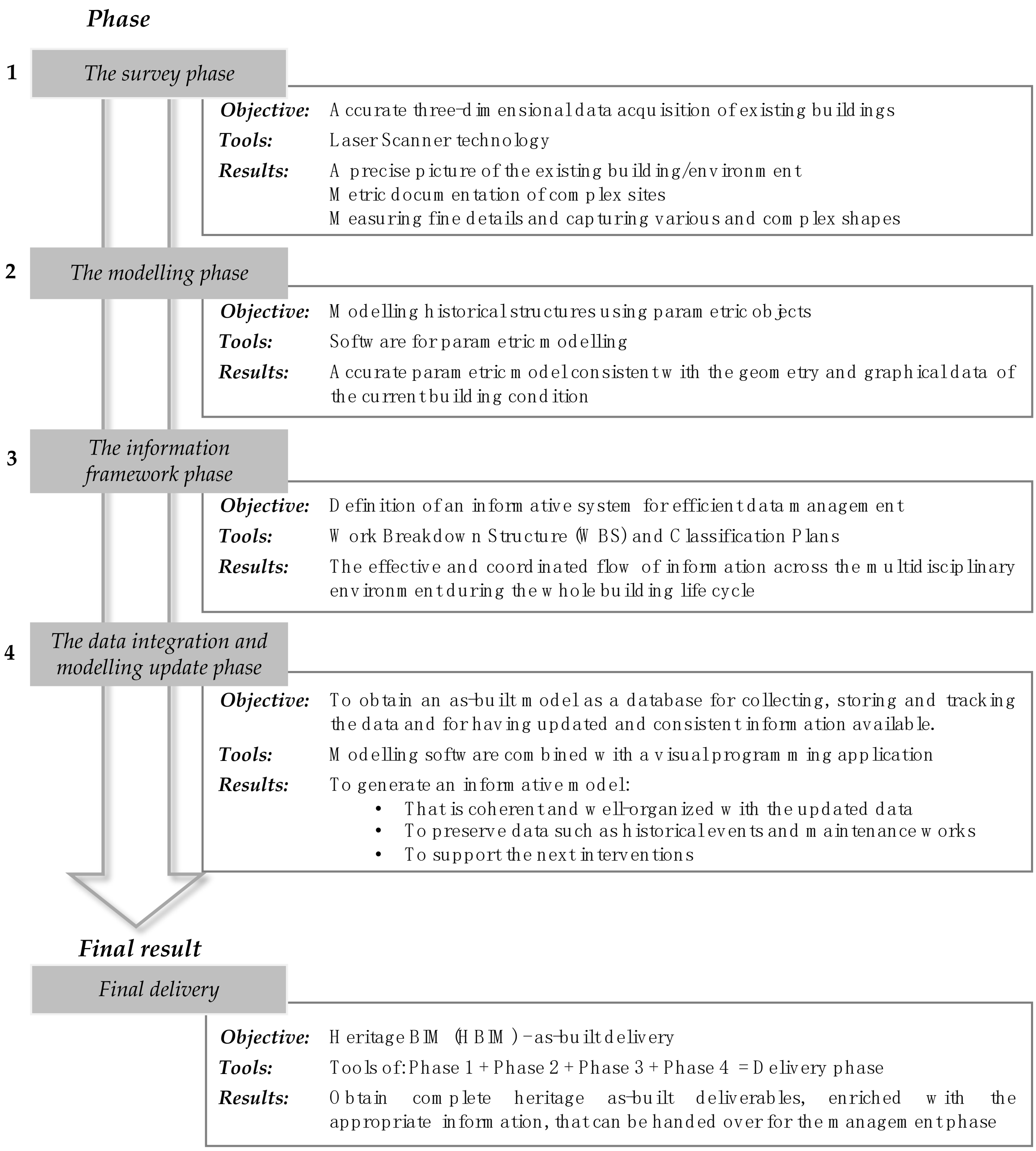


Figure 2. A methodological framework to optimize the information flow of cultural heritage.

The laser scanner tool allows for the remote identification of the morphology of an architectural structure through the laser, which reaches the surface to be detected. For this reason, it is considered a non-destructive system. This aspect is of higher importance in the context of heritage buildings. The three-dimensional laser scanner is directed to the physical element to be scanned, and the laser beam is addressed to the object in a space grid of points. The result is a point cloud made of thousands of points in a three-dimensional space. The point cloud generated can have different densities based on the scanner settings, and, regarding the level of detail requested, it is consistent with the next use.

According to Croce et al. [18], although the acquisition of three-dimensional data is a well-established method, only few studies have investigated the further phase, which implies the processing and elaboration of raw data obtained from the survey. This step requires a well-structured process of treating and segmenting raw data for the next improvements. As reviewed by Utica et al. [23], "point clouds can be often characterized by the presence of interferences, which must be deleted through special techniques before starting with the real data elaboration in specific applications". Therefore, the laser scanning survey provides accurate data for existing buildings and represents an effective tool for the needs of heritage/historical buildings.

The fact that there has been progress with TLS tools in the cultural heritage field, implemented to create three-dimensional models, has been confirmed by Martinez Espejo Zaragoza et al. [29] and Marzouk [30].

Although BIM has been longer associated with design and construction, the birth of these techniques has moved the industry towards new applications, which are effective in the built environment area and even more in heritage buildings [31]. This has been the time in which the Scan-to-BIM process started.

In detail, the approach of converting three-dimensional scanning point cloud data of existing buildings into a BIM model is identified as the Scan-to-BIM process [32]. Indeed, the Scan-to-BIM process is the practice of capturing existing building data based on BIM as the primary technology and the support of the point cloud system.

In this work, laser scanning technology was considered in the context of the methodological framework and was treated as a preliminary source of information for BIM, since it represents the starting point of the data baseline for the next case study developments and for the building model creation (Phase 2).

2.2. The Modelling Phase: Heritage Building Information Modelling (HBIM)

The distinctive area of this project fully contemplates the contributions and research developed under the denomination of Heritage Building Information Modelling (HBIM).

According to Murphy et al. [33], HBIM is based on the concept of modelling historical elements using parametric objects of a database library [22]. As stated by Woodward and Heesom [34], much of the work around HBIM has focused on modelling geometric elements and the related properties of the built asset. Dealing with the cultural–historical built environment consists of facing problems concerning the quality of initial data, survey difficulties and multi-level complexity of the architectural asset. Thus, BIM and related technologies can represent an opportunity.

Looking at the literature, it has been assessed that many restoration projects are not yet taking the benefits of BIM application [35,36], and it has been further underlined that little research has concentrated on this field in comparison to other BIM areas [37]. Works that have introduced the application of HBIM have been very much theoretical in nature until now [34]. As highlighted by Maxwell [38], the application of a value-adding HBIM should encompass information such as material degradation and other details that are fundamental for driving an efficient management strategy and for decision-making processes in the built environment. Thus, the HBIM should be modelled in an appropriate way to host later the data relating to maintenance or to renovation interventions [39].

A well-structured HBIM process represents a chance to manage renovation works in view of providing the premises for the next FM phase. In particular, once site works begin, peculiarities of the construction stages can be followed through a BIM process, and during each phase, data such as safety documents, FM information, etc., can be also stored within the parametric model. This confirms the importance of an HBIM application from the design and the site stage, with the integration of data regarding specific construction elements when "As-Built". Moreover, this allows for the opportunity to use the work for lifecycle management [34] according to the UK approach, which is set on the implementation of the required operational data within an as-built BIM [40].

Previous studies have demonstrated how the identification of a framework for the application of HBIM to encourage conservation projects, both during the design and construction phase and also in the in-use phase of a newly renovated building, represents a critical issue, as recognized by Woodward and Heesom [34], Carbonari [41] and Ciribini, Ventura and Paneroni [42].

According to these considerations, the research provides an HBIM integration from the early stage of a renovation project to optimize the final as-built delivery. The point is to provide a methodology to cover the existing problems and to optimize the related expenses, as extensively reported in the literature, of retrieving the data when dealing with the built environment [14,43–45]. The approach, as described in the case study section, is developed using Autodesk Revit for accurate parametric modelling, consistent with the geometry and graphical data of the current building condition. Then, the work is carried out by applying the specific information framework and the data management techniques explained below.

2.3. The Information Framework Phase: The Informative System for Efficient Data Management

The current way of managing information, due to the early stages of the process and the lack of regulated procedures and standards among the operators involved, negatively influences the exchange and quality of data. Therefore, efficient data management must be based on a systematic collection, analysis and flow of information across the multidisciplinary environment during the whole life cycle [46].

Considering information management, it has been discussed that information is a key field for FM (mainly linked to data and attributes concerning graphics) and that many organizations are not able to take advantage of their data sources efficiently [47]. Thus, the fundamental point for life cycle management is represented by the availability and integration of information [48,49] and thus by the definition of an efficient informative system. The area of information represents the link between the design and the construction and the operational area. Moreover, a correct implementation of an integrated information system for proper management allows for connections among design, construction, technical and economic data, which are useful for defining the most suitable management strategy [49]. Concerning existing buildings, data present a high level of complexity [41], and managing asset information is one of the most problematic aspects for facility managers. It implies gathering data about the asset from the earlier phases of the building's life, processing the information and using it for decision-making processes into the operation and maintenance phase [46,50]. This phase accounts for a high percentage of the global cost spent throughout a building's cycle (more than 50%) [51]. Hence, achieving asset operation efficiency, due to data availability, is important for increasing the total cost of ownership, especially in the case of public buildings, where asset complexity is more relevant with respect to the residential industry [35]. In general, the management of information is poorly performed, and either too much information is produced in silos, or very little is organized from data sets, therefore leading to considerable efforts for information generation [47]. Today, most existing buildings present their attributes in a scattered way, stored and collected in paper documents, in sheets of equipment data or in file folders of maintenance records. On the other hand, the Computerized Maintenance Management System (CMMS) or Computer Aided Facility Management (CAFM) are not inclusive of heritage maintenance. Information on the built environment is often segregated and preserved as a written record for future use; however, with the advent of HBIM, there exist benefits for integrating this essential information into an open-access digital environment. Since historical building records often include a significant amount of layered information, HBIM could present a clear opportunity to maintain data such as historical events, construction data, changes in ownership or transformations in a structured and efficient manner for supporting conservation works [6,34,52]. The data hand-over to the FM phase is often left until the end of the construction phase, and information is typically delivered in manual or non-digital formats [41,44,45,49]. With this late delivery of disrupted data or paper documents, it becomes very awkward for owners and facility managers to evaluate whether the required information is included in the hand-over documents, especially in the case of heritage sites. Therefore, information should be properly organized from the beginning of the process using appropriate data management techniques. The quality of the hand-over process is strictly connected to the way of producing, managing and exchanging information about building objects in their multiple aspects along the whole life cycle from their conception to disposal (UNI 2017) [53].

The Work Breakdown Structure (WBS) is a tool capable of linking technical elements, which are the expressions of design choices and the details of interventions/work execution. Therefore, the WBS is a communication tool and a standardized method used to regulate a generic project by applying an analytical structure for the building object, activities and phases (conception, design, construction, maintenance, restoration, demolition).

Through the WBS, the project can be decomposed into simple elements to reach the desired level of detail based on the project's qualities and peculiarities.

Moreover, each stage of the building life cycle can be perceived as a sub-process of the main one. Thus, maintenance is a process manageable through the WBS technique. In support of that, RICS [54], recognizes that maintenance matters, as the maintenance budget distribution among elements, floor areas, etc., should be organized through a WBS or a Cost Breakdown Structure (CBS). These tools help to check and monitor maintenance costs [54–56]. Indeed, a WBS is acknowledged also as a key tool for governing maintenance issues. Apart from these advantages, some weaknesses also exist [57]; significant effort is needed to build and maintain a WBS structure together with its limitations concerning contextual information.

Therefore, in this research work, the WBS represents the starting point of preliminary data organization, which is then fundamental for the next steps. The WBS of the planning phase changes along the overall process, and the final data structure changes along the process, since it is framed for FM purposes. Thus, apart from the WBS limitations, the research concept is that this is a sort of flexible matrix.

In the study, the research develops a framework also using the WBS approach for integrating life cycle information through BIM from the first stages of the project, structuring a management system of the useful data for an as-built delivery for FM.

2.4. Data Integration Phase and Modelling Update

Based on the concepts explained in the previous paragraphs, the following case study was developed through the application of specific tools for managing information in the HBIM environment. A 3D model, developed and updated during an ongoing construction/refurbishment site and then delivered at the end of the execution phase, provides the starting point for implementing specific information on products, components, instructions regarding MEP systems, etc. As has been largely reported from the existing literature, the BIM approach has the main objective of guaranteeing the exchange of information during the whole building life cycle, generating an informative model that is coherent and organized [4–6,12,58–60]. Therefore, the acquisition of the related as-built or as-is documentation is the essential point to start the next management operations.

For the above-mentioned reasons, the definition of new interaction mechanisms between the modeling software and the data management systems is the key to improving the process of creating an as-built model for future FM and O&M objectives.

To reach this kind of goal, this study describes a step-by-step method for connecting different applications, managing digital information and updating the model during an ongoing renovation project to optimize the HBIM-as-built delivery. Among the applications available in the BIM field, this research work uses the Dynamo plug-in to perform an effective data transfer. In detail, Dynamo is a visual programming add-in for Autodesk Revit, provided for implementing information within the model and exchanging data with external applications such as calculation spreadsheets. In particular, Dynamo can connect:

- the parametric model with the database, presenting all the data needed and re-organizing for the hand-over phase (to fill the gap recognized by the NIST Study [11]);

- the parametric model with the site management applications for controlling the site progress and the work schedule.

Thus, the use of the Dynamo application, combined with data management techniques, implies the data processing levels for defining the outputs' delivery. From this documentation, the users and the actors involved are able to extract data, technical reports and additional information such as pictures, external sources, etc. (Figure 3).

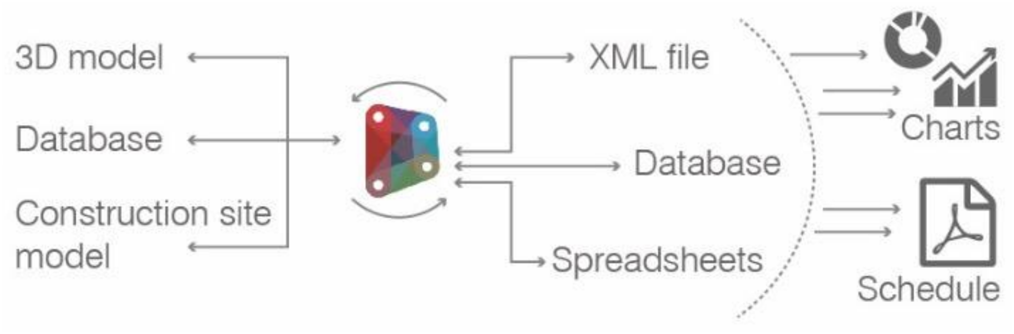


Figure 3. Dynamo dataflow.

The advantages of the Dynamo integration consist of the chance of synchronizing real-time data and updating the model due to the automation of actions usually carried out manually, with a remarkable save of time, and costs and reducing the risks of making mistakes [6,61]. Moreover, the Dynamo plug-in ensures a direct connection with site management software to support the execution phase, and it enables the evaluation of possible interferences at the time and the acceleration of decision-making processes at the construction site and of the data update actions.

Regarding the technical details, Dynamo allows one to work in a visual-programming process based on the Python programming system and thus related to precise algorithms. The user interface presents a panel with a list of software commands, and the workspace is made of a grid where visual programs are developed. Within this type of visualization, it is possible to build a precise structure composed of "Nodes" (Figure 4).

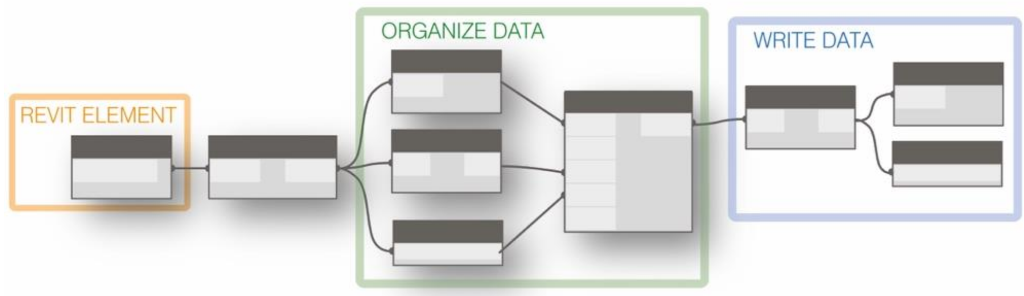


Figure 4. Dynamo structure of nodes.

These enable higher accessibility to the Revit structure, since the nodes are capable of identifying the software hierarchy, and to Revit families, types and instances. Indeed, nodes can be linked with each other with connectors through which the import/export mechanism is defined. The result of this process is strictly related to the way the data framework of the project is combined with the Revit structure. Considering, for example, an element of the digital model, through visual programming systems, it is possible to access, integrate or extract the information contained in the parametric model's descriptive parameters.

The fundamental advantage of this tool is the ability to identify and exchange the specific model properties that cannot be seen through the traditional Abacus tool and that cannot be derived from the model. These features can arise only if the project data are structured and organized; thus, in this context, the application of the Work Breakdown Structure (WBS) and classification plans has become paramount.

For example, due to the integration of information management systems, Dynamo can identify the model categories (walls, floors, doors, windows, etc.) and then select the individual model instances according to the WBS codification. After the first identification, through this process, it is possible to work on data, to update information or to import/export information, filling the model with the required attributes according to the structure that is represented in Figure 5 below and that was implemented in the case study section.

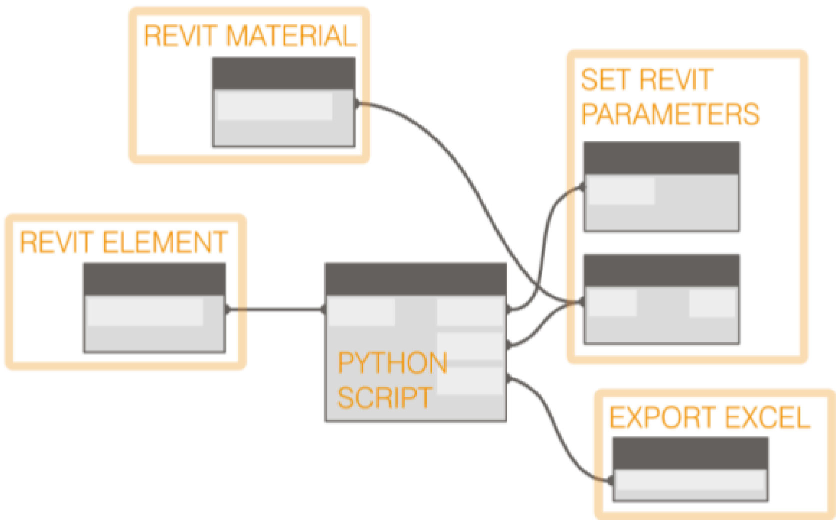


Figure 5. Dynamo framework for accessing the model data.

2.5. The Final Hand-over: Heritage BIM (HBIM)-As-Built Delivery

Considering the theme of the data loss during the building life cycle and the costs linked to information recovery when dealing with existing buildings and, in particular, when operating on the heritage portfolio, it is important to provide structural frameworks aiming at reducing those costs and the recognized building life cycle gaps.

This methodological approach has the objective of obtaining (as the final result) an as-built model that, developed on the ongoing refurbishment site, represents the main data source and a large database for setting management and maintenance procedures.

In the previous paragraph, Figure 1 represents the information loss over the building process, highlighting the data loss on two sides: the first one is the loss of the available data, which are not transferred or exchanged phase-by-phase in the traditional process (in red) from planning to design, construction and FM, and the second is the data lost upstream, since they were not present from the beginning.

As illustrated in Figure 6, the research framework tries to fill the data gap by providing a method, based on the parametric modelling and the interoperability concept, where the data are transferred over the phases and at the same time reducing the gap of the information upstream. Indeed, this approach, based on a systematic structure, tends towards the ideal curve of the information flow (blue curve).

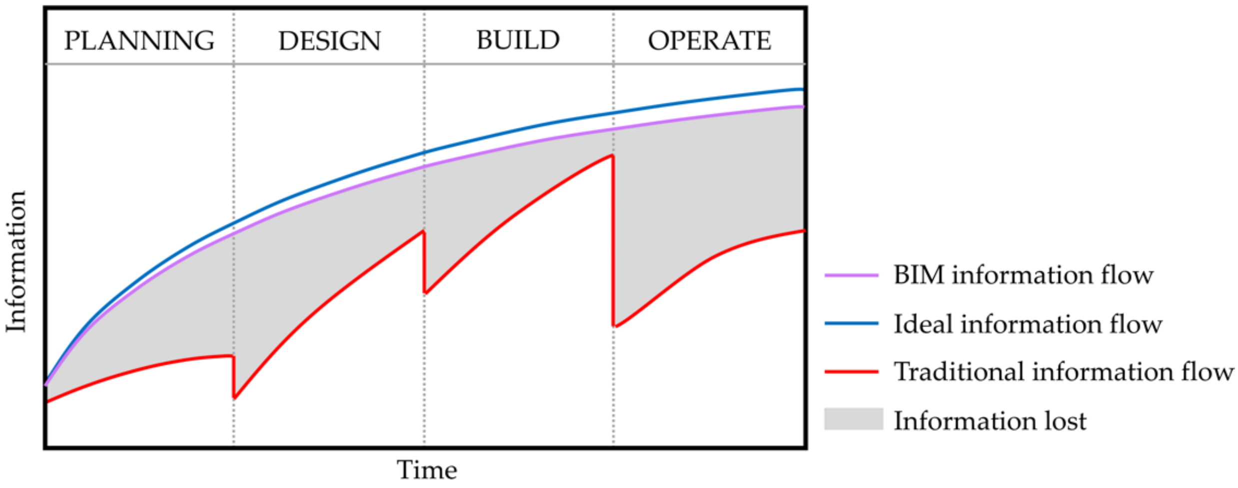


Figure 6. Information loss in the building life cycle and the BIM curve (re-elaboration based on Eastman et al. [12] and Gallaher et al. [11], as in Figure 1).

3. Case Study

3.1. The Lyric Theater Restoration Project

This study concentrates on the case of a historical lyric theater, which is a building dated to the 18th century and which has been affected over the years by different events and transformations. Then, in 2013, the public administration started the conservation plan. After a tender phase, the site work was underway in 2016.

In particular, this kind of project appeared to be suitable for research purposes since:

- it represents a process consisting of restoration works where information management fulfills a key role;
- the preliminary study and the preliminary project, defined by the Public Administration (PA) as the available documentation for the tender stage, were already conducted through parametric modelling and the application of digital technologies; thus, the implication of BIM in the site work phase at that time represented an opportunity of giving continuity and an opportunity for testing the implementation in such a context of public heritage restoration;
- the procurement contract between the PA and the building company contractually demanded the final as-built model for the next maintenance/management operations.

Therefore, the main aspects addressed in the case study application are the followings: the first one is related to the analysis of the available documentation at the time of the site work beginning (including the survey data and the initial parametric model, previously carried out for the procurement phase); the second one is linked to the definition of the information system; the third presents the model development and the data update during the ongoing restoration site; and the fourth shows the final as-built model implemented with FM and O&M data.

3.2. The Survey and the Modelling Phase: Managing the Survey Data and the Preliminary Model

Looking at the diagram above (Figure 2), it should be pointed out that stage 1, represented in the methodology section, is split in two for the case study development (the same for the modelling step). This happens because, in this context, the research began from the analysis of the preliminary documentation of an initial parametric model, created for the tender phase based on a previous laser scanning survey. This way of conducting the survey turned out highly effective, since it made it possible to identify peculiar elements and to define such elements in the spaces which were very difficult to reach. The laser scanning approach also allowed for the faster definition of the project for the tender objectives, and due to this type of survey, based on point clouds, a preliminary theater model was available, since it was built to address the tender scope and was enriched by preliminary material and graphic data.

At this point, after the bidding and the contract stage, the research started with the verification of the available sources (point clouds survey and parametric model) for assessing the data consistency concerning the theater's current condition. After that, when the restoration site started, additional surveys based on the TLS Technology were performed. Indeed, in the case of a heritage/existing building, several aspects can be verified only after on-site investigations, which required drillings or partial demolitions. For example, the laser scanning technique enables access to rooms with structural problems in which it was not safe to enter or the identification of certain spaces which were totally hidden from the sight. Therefore, using a specific TLS tool for detecting internal and small-sized rooms, a step-by-step laser scanning process, following the ongoing site work phases, was elaborated, and thus, the building was regularly checked. Moreover, in the case of unexpected findings, the point cloud data constituted the basis for the model update and for driving the next choices in line with the changing project. Then, the model was edited/implemented, and for example, data on the material or wall layers were integrated. The lyric theater structural system, which was previously supposed based on historical documentation, was precisely incorporated into the model. Moreover, through the TLS, new constructions were accurately located.

In addition to the analysis of existing documentation, the on-site scanning procedure and the geometrical update, the research, after the study of the elementary data in the first model, provided the re-organization and the integration of the informative data and attributes according to the building site. An important objective was to understand the framework of the data and the localization system of the elements. This was the starting point for elaborating a coherent information system that could be combined with the existing information for defining the procedures for updating the model along the renovation site works and then for gathering the data useful for the FM phase.

3.3. Definition of the Information System

After the preliminary analysis, the research work on the lyric theater restoration project went forward to the definition of the WBS for the implementation of the renovation site data. The WBS, integrated to the level suitable for fitting the research aim, is an effective tool for addressing the next operational stages.

Concerning that, the central database was enhanced for holding localization labels (Space Breakdown Structure—SBS) and material attributes and was organized as shown in Figure 7.

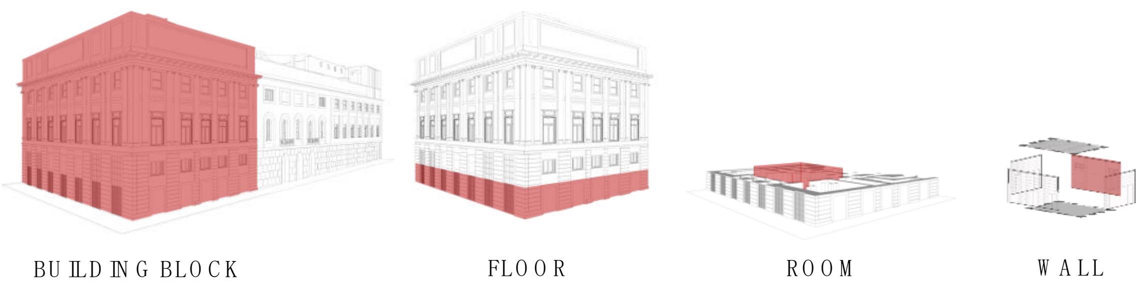


Figure 7. Theater space breakdown structure.

The localization labels and the WBS codes represent the link between the database in the form of calculation sheets and the HBIM model.

Therefore, the WBS as a data management system, combined with the digital model, represents a key element for the next steps of the data update and integration for FM.

The details of data and parameters are summarized in Table 1. In the first column, the table shows the final output/document required, for example, the "Maintenance Plan"; then, the second column gathers the group of data within the related document; the third one presents the specific attributes required; and, in the end, the fourth collects the associated parameter type. The WBS and SBS codes are used as the core data for running the Dynamo application and providing the automatic data input and data update processes.

Table 1. Data and parameter definitions. Blue: Data coming from the related documents.

Document	Section	Parameter Name	Parameter Type
BUILDING ID	Survey	Survey date	Text
		Zone responsible	Text
		Update	Text
		...	...
	General building data	Building picture	Image
		Municipality zone	Text
		Building Type	Text
		Address	Text
		Construction year	Number
		Construction typology	Text
		Square meters of covered surface (m^2)	Number
		Square meters of gross floor area (m^2)	Number
		Volume (m^3)	Number
		...	...
	Cadastral data	Sheet	Text
		Maps	Text
		Sub	Text
		...	...
	Fire safety data	Activity not subject	Yes/No
		NOP obtained	Yes/No
		NOP number	Text
		NOP release date	Text
		CFP obtained	Yes/No
		CFP number	Text
		CFP release date	Text
		CFP activity	Yes/No
		Document link	URL
		...	...
SPACE BREAKDOWN STRUCTURE(SBS)	SBS Code	Building block	Text
		Floor	Text
		Room	Text
		Wall	Text

Table 1. *Cont.*

Document	Section	Parameter Name	Parameter Type
WORK BREAKDOWN STRUCTURE(WBS)	WBS Code	Technical element code	Text
		Technical element name	Text
		Description of consistency	Text
		Interventions to be performed	Text
UNIT PRICE LIST-PRICE ANALYSIS	Classification plan information	WBS code	Text
	Work item	Price list code	Text
		Extended description of the item	Text
		Unit of measure	Text
		Price	Currency
		Percentage of labor	Text
		Percentage of materials	Text
		Percentage of equipment rental fee	Text
		...	...
BILL OF QUANTITIES-QUANTITY TAKEOFF	Classification plan information	SBS code	Text
		WBS code	Text
	Quantity	Price list code	Text
		Extended description of the item	Text
		Unit of measure	Text
		Quantity	Length
	Cost	Price	Currency
		Price of labor	Currency
		Price of materials	Currency
		Price of equipment rental fee	Currency
SAFETY AND COORDINATION PLAN	Classification plan information	SBS code	Text
		WBS code	Text
	Quantity	Extended description of the item	Text
		Unit of measure	Text
		Quantity	Length
	Cost	Price of internal safety burden	Currency
	Risk containment	Potential individual risks	Text
		Potential risk deriving from the activities being performed	Text
		Preventive and protective measures	Text
		Procedures	Text
		...	...
	Time scheduling	Construction site timing	Text

Table 1. *Cont.*

Document	Section	Parameter Name	Parameter Type
TIME SCHEDULE	Quantity	Quantity	Length
	Cost	Price	Currency
		Price of labor	Currency
		Labor cost per hour	Number
	Timeline	ID worksite activity	Text
		Duration	Number
USER MANUAL	Classification plan information	WBS code	Text
		SBS code	Text
	Cost	Price list code	Currency
		Description	Text
	Technical element data	QR code	Image
		Date of last update/modification	Text
		Picture	Image
		Year of realization/installation	Number
		Correct conditions of use	Text
		...	...
MAINTENANCE MANUAL	Classification plan information	WBS code	Text
		SBS code	Text
	User manual information	Date of last update/modification	Text
		Picture	Image
		Year of realization/installation	Number
	Cost	Price list code	Currency
		Description	Text
	Technical element data	Required equipment	Text
		Minimum level of performance	Text
		Possible anomalies	Text
		Maintenance to be performed by user	Text
		Maintenance to be performed by skilled personnel	Text
		...	...
MAINTENANCE PROGRAM	Classification plan information	WBS code	Text
		SBS code	Text
	Technical element data	Intervention typology	Text
		Intervention frequency	Text

Table 1. *Cont.*

Document	Section	Parameter Name	Parameter Type
TENDER SPECIFICATIONS	Classification plan information	WBS code	Text
		SBS code	Text
		Description of consistency	Text
	Cost	Price list code	Text
	Technical element data	Product category	Text
		Work items necessary for the creation of the technical element	Text
		Materials, supply and storage methods	Text
		Reference standards	Text
		Tests, certifications and samples to be carried out	Text
		Execution methods to be followed	Text
		Tests and inspections to guarantee the result	Text
		Equipment needed to carry out the work	Text
		Related technical elements	Text
		References to the Safety and Coordination Plan	Text
		...	...

3.4. On-Site Model Update

In this research work, the data uploading process, linked to the execution phase, was characterized by two aspects: the geometrical update of the building and the data integration into the digital model.

During the construction works, several updates are evident only after on-site demolitions or after the examination of wall layers, thickness and materials, revealed during the construction site. Indeed, the on-site information tracking and analysis becomes fundamental to confirm the choices made previously at the design level and to drive future or alternative decisions in the case of unexpected situations. Regarding the geometrical update, this was mainly performed within the parametric software, which is the most suitable environment for doing this kind of activity. Indeed, the graphical update of the elements was conducted outside of the model through Dynamo, only when complex geometries or systems were present (the generative design approach) (Figure 8).

Then, the second process of data uploading characterizing the theater is linked to the mechanism of integrating, importing/exporting the attribute data (not graphical) through the Dynamo application (Figure 9).

As stated above, the objective of the work was to provide a heritage as-built model as consistent as possible; therefore, the supervision of the overall renovation process and the updating of the model and of the data system at the same time (to reflect the work site progress) are essential. Moreover, the importance of this approach stands in the fact that, usually after the execution phase, some information cannot be retrieved easily.

Then, to overcome the costs and the consequences of recovering the data, the central database, set on the WBS structure, becomes the core point through which information is been managed and organized. This data repository is fueled by the data coming from weekly site visits and managed through the Dynamo nodes. Data directly coming from the BIM model are successively exported using Dynamo and organized within the central database (Figure 10).

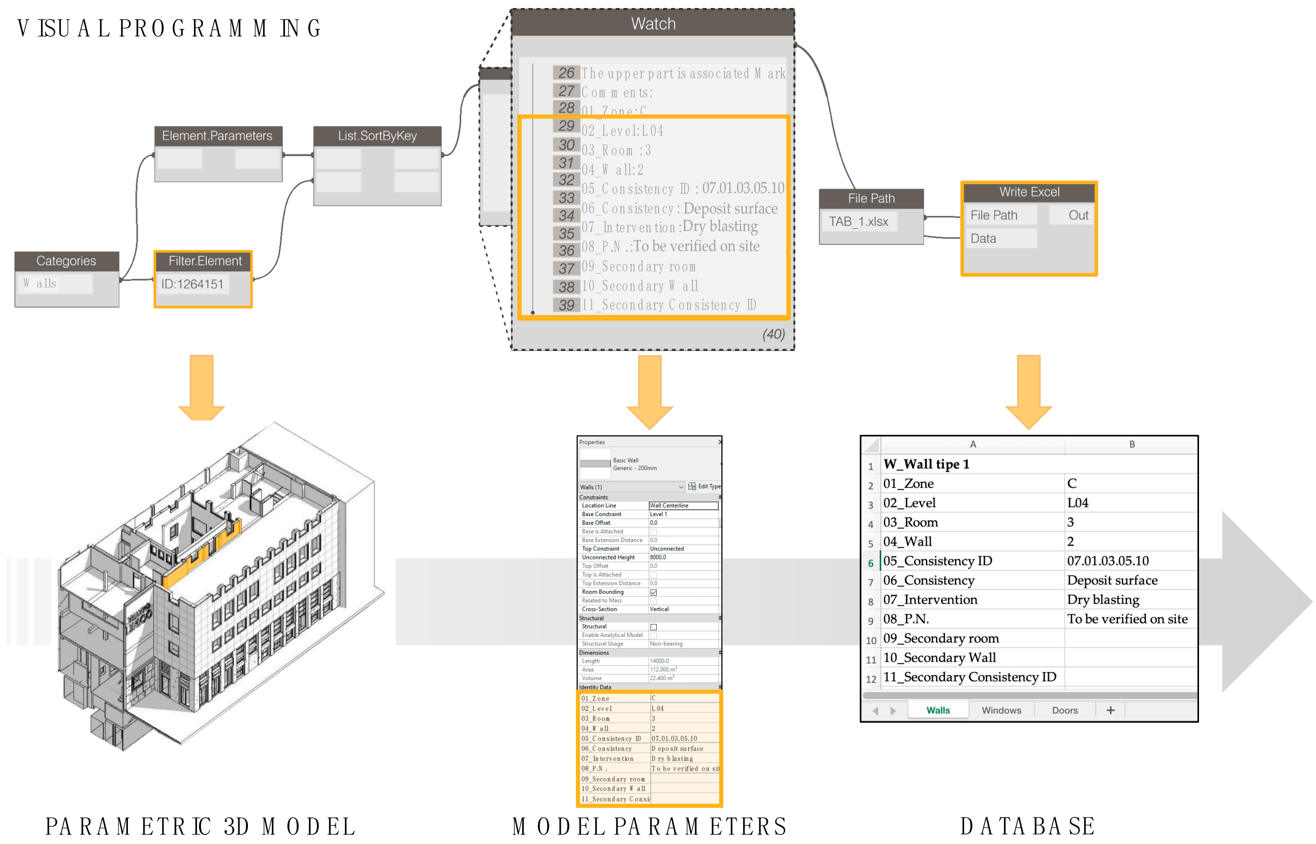


Figure 8. Process of the graphical update applied in the parametric model.

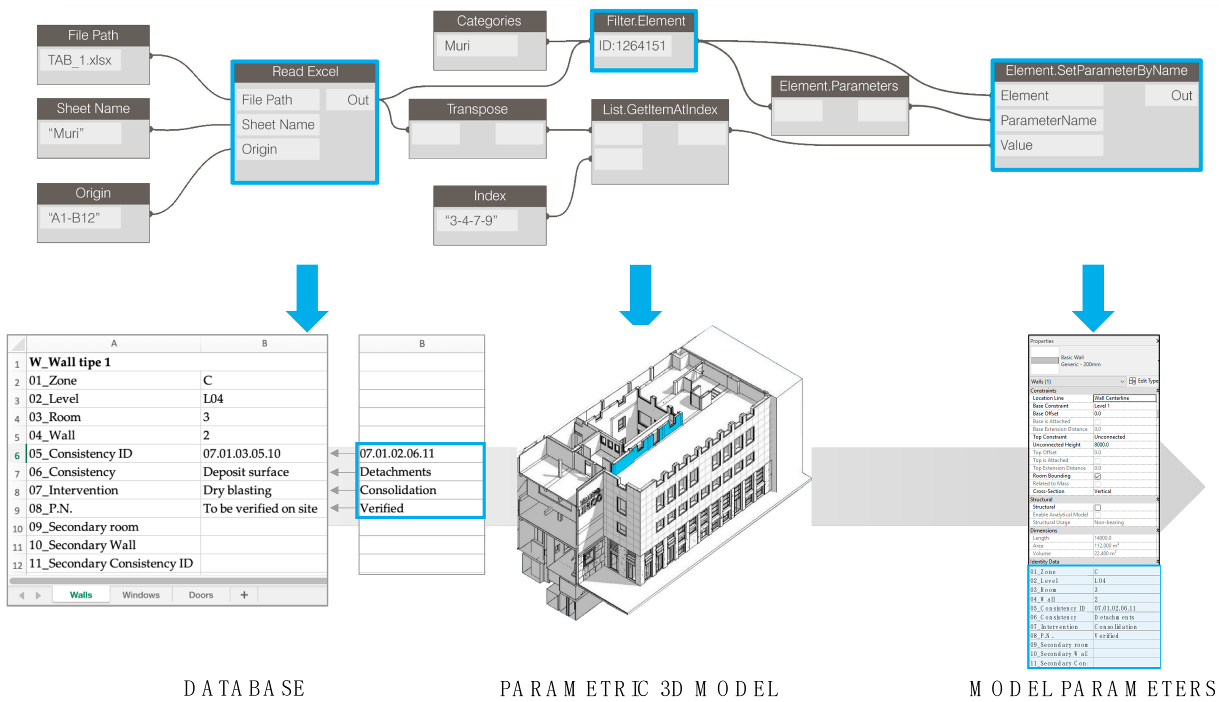


Figure 9. Process of updating the attributes.

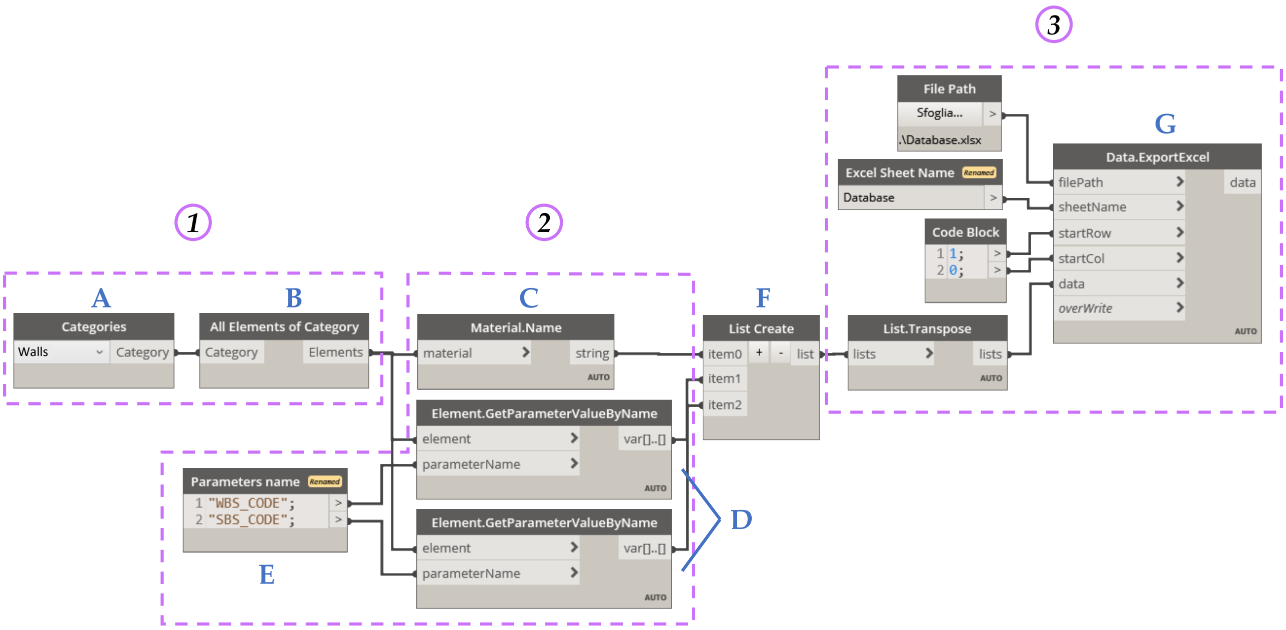


Figure 10. Dynamo structure for linking the parametric model to the database.

Indeed, the information can be extracted from the central database and attached to the corresponding Revit object, such as a technical element, a room, etc. Due to specific Dynamo nodes, it was also possible to obtain automatic compiling of the objects' related fields (Figure 11).

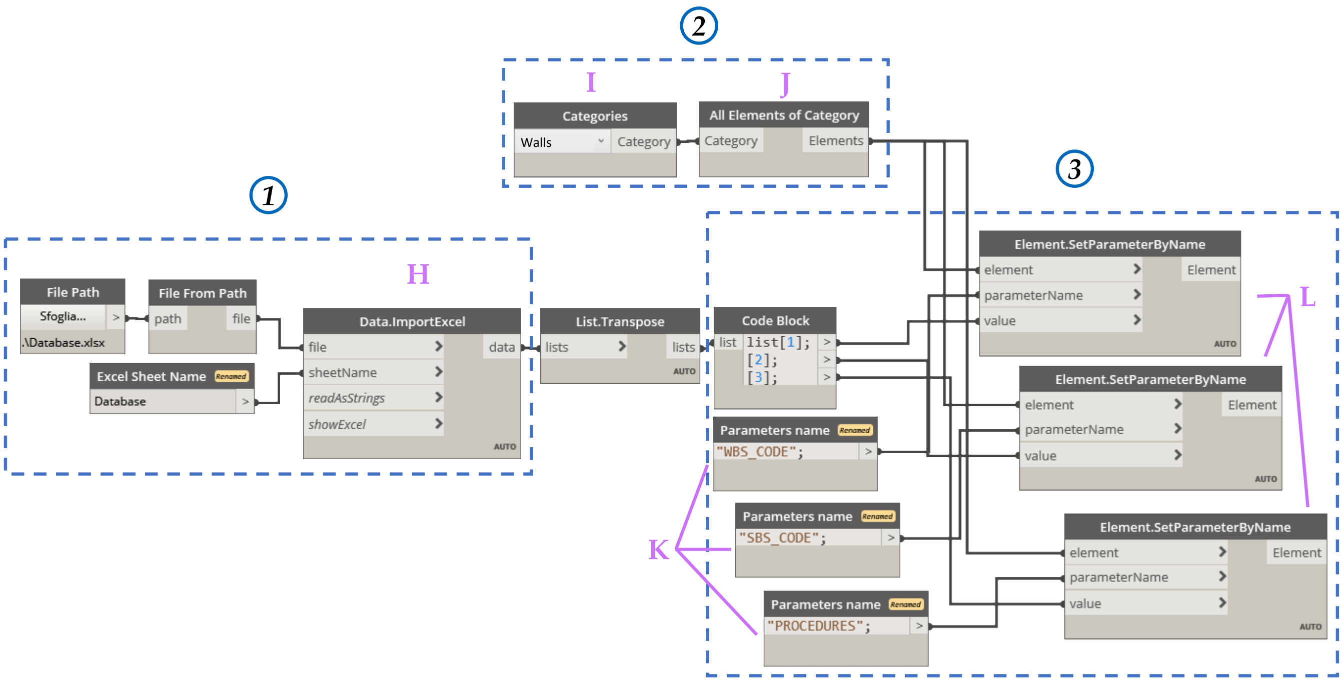


Figure 11. Dynamo structure for linking the database to the parametric model.

As highlighted before, Dynamo is based on a structure of "functional nodes", through which it is possible to run specific features. This information string involves input and output data. Each individual node performs a specific action. This action can be a simple activity, such as extrapolating a single value, or, on the other hand, it can be a complex process, such as that linked to generative design trials. The visual programming procedure defined for the research case study is made of several nodes which play multiple operations to structure the data and exchange information in a framed manner.

As reported in Figure 10, the logical scheme, which is implied to export the data from the model and organize the specific information in the database, is composed of the stages below:

- The first step (number 1 in the Figure 10 above) of the sequence allows for the identification of all the "Building elements", which are all the model elements that need to include the relevant information. This action is realized due to a particular node: the Categories node, identified by the letter "A" in Figure 10. This node can extract a list of the overall model categories that constitute the parametric model (for example, the wall category). The node "Category" is combined with the node "All elements category" (identified by the letter "B" in Figure 10 above) to obtain an export of all the elements associated with a specific category built into the model.
- The second stage (number 2 in the Figure 10 above) is made of several phases for selecting the parameters to export. The node "Material name" (identified by the letter "C" in the Figure 10) returns a list of the materials that compose an individual element, such as a list of the wall layers. Then, due to the node "Element.GetParameterValueByName" (letter "D" in the Figure 10), it is possible to deduce each value connected to a specific parameter within the model. For example, Figure 10 presents the data outcome of the values linked to the WBS and SBS parameters listed in the node "Parameters name" (the "code block node", letter "E" in Figure 10). In the end, all the results obtained through these actions are merged into a single inventory by means of the node "List Create" (Letter "F" in the Figure 10);
- Then, the final stage (number 3 in the Figure 10 above) leads to the extrapolation of the model data to implement the derived information into the central database. In detail, this happens through the node "Data.ExportExcel" (letter "G" in the Figure 10). This node is composed of the data of the central repository: "the file name", "the excel name" and the "sheet name", in which the data need to be implemented.

As described in Figure 10, the logic sequence of the second figure (Figure 11) is made of three main stages. The overall mechanism is summarized in the above schema. In this way, it is possible to read the attributes coming from the central database and associate them with the parametric model. Therefore, this system allows one to:

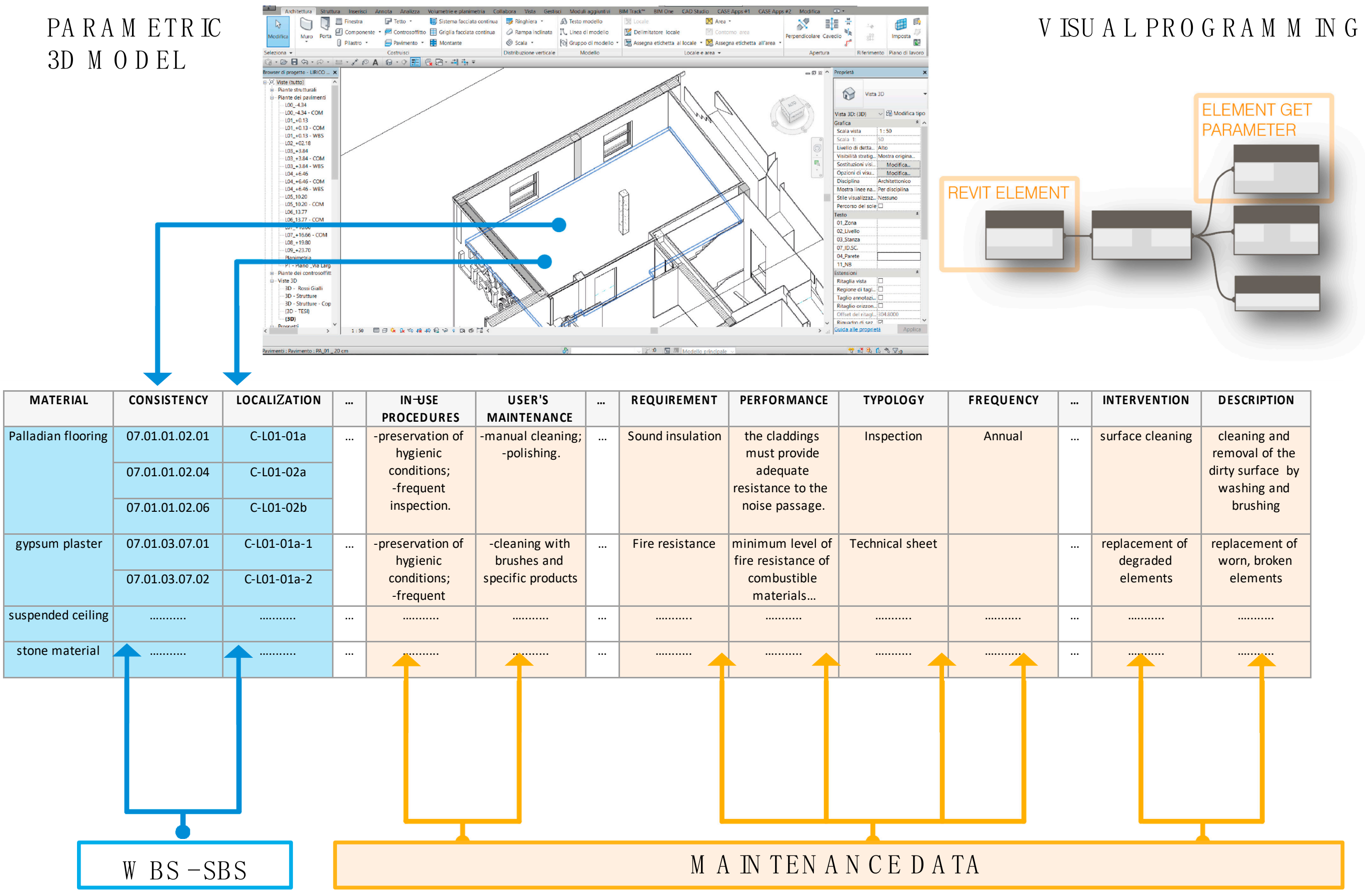
- fill the data within an empty parameter of the model;
- update the information into the model;
- create new parameters with new attributes or values.

Below, the main steps of the logic sequence are outlined:

- In the first step (number 1 in the Figure 11 above), the node "data.ImportExcel" (identified with the letter "H" in the Figure 11) enables one to read the data of the spreadsheet file (the database).
- In the second stage (number 2 in the Figure 11 above), the combination of the node "Categories" (letter "I" in the Figure 11) and the other node "All Elements of Category" (letter "J" in the Figure 11) allows the identification of the elements that need to be enriched with the related information.
- In the last stage (number 3 in the Figure 11 above), the node "Parameters name" (the so-called "code block" node which is identified by the letter "K" in the Figure 11) can select the corresponding data, which are required for a specific model's parameter. Then, due to the integration of the node "Element.SetParameterByName" (letter "L" in the Figure 11), this information can be physically written and associated with the proper field. In this way, new or updated data can be easily included in the model. Moreover, the implementation of new parameters is allowed.

3.5. Heritage-As-Built for FM

As mentioned in the previous sections, the research focuses on how digitalization can improve the information workflow, supporting the hand-over stage for the next FM goals. Therefore, in addition to the data recovered during the lyric theater renovation site, the second type of data, which is fundamental to define the suitability of HBIM for FM purposes, is collected from external sources. In particular, specific data concerning maintenance, inspections and preventive activities to contrast material degradations are integrated through Dynamo from external links. Indeed, documents such as the maintenance plan, the maintenance manual, the user handbook, and the maintenance schedule (required by law in Italian legislation) can be produced and updated automatically with Dynamo. Therefore, due to this approach, it is possible to draft different outputs and documents (Figure 12).



MATERIAL	CONSISTENCY	LOCALIZATION	...	IN-USE PROCEDURES	USER'S MAINTENANCE	...	REQUIREMENT	PERFORMANCE	TYPOLOGY	FREQUENCY	...	INTERVENTION	DESCRIPTION
Palladian flooring	07.01.01.02.01	C-L01-01a	...	-preservation of hygienic conditions; -frequent inspection.	-manual cleaning; -polishing.	...	Sound insulation	the claddings must provide adequate resistance to the noise passage.	Inspection	Annual	...	surface cleaning	cleaning and removal of the dirty surface by washing and brushing
	07.01.01.02.04	C-L01-02a											
	07.01.01.02.06	C-L01-02b											
gypsum plaster	07.01.03.07.01	C-L01-01a-1	...	-preservation of hygienic conditions; -frequent	-cleaning with brushes and specific products	...	Fire resistance	minimum level of fire resistance of combustible materials...	Technical sheet		...	replacement of degraded elements	replacement of worn, broken elements
	07.01.03.07.02	C-L01-01a-2											
suspended ceiling	....	....	...	....	....	...	....	....	....	....	...	....	....
stone material	....	....	...	....	....	...	....	....	....	....	...	....	....

Figure 12. Integration of maintenance data.

Another important aspect is given by the possibility to attach the O&M documents to the HBIM. Thus, through specific parameters, as explained below, the .pdf version of the maintenance plan or the .pdf file of some technical cards can be integrated into the model and can be made available at any time.

The data input process can be performed directly into the Dynamo's interface with the use of specific parameters. In the Revit software, different types of parameters are available. In this case, the URL parameters are introduced to host external links and to attach multi-media files and web sources. In this way, the whole as-built documentation required for the management phase is accessible.

In Revit, it is possible to associate attributes structured by name, typology, etc., to the shared parameters (within the families, within instances or material properties). The shared parameters are connected to an external file, usually with a ".txt" size, which is set according to the users' needs and that can be applied also in other projects according to the intervention type. For the case of the lyric theater, the shared parameters are structured in the form of an additional breakdown system for data in the model, and these are tailored based on the project objectives. The documents related to the maintenance plan (maintenance manual, user handbook, maintenance schedule) can be directly linked to individual materials (ex: plaster layer). The history of interventions or the list of the project materials can be connected to the Revit Type (for example, brick-walls). Moreover, single interventions can be associated to Revit instances (for example, wall structural stabilization). For the lyric theater, a URL parameter is associated with specific views, such as floor or section views, connected to comparative status drawings (displaying demolitions and new construction elements) to make the transformations visible.

4. Discussion of Results

The implemented methodological structure has been defined to meet municipality needs in documentation, in planning conservation interventions and in managing the next operation stage. The automatization of the whole mechanism of data exchange gives a remarkable contribution to reducing typing errors, duplications, redundant data, etc., usually linked to data transfer processes. Thus, the project acquires a higher quality, and on the other hand, the automatization provides time savings.

Regarding the cost issue, it should be said that, in the research, the specific detail of a cost-saving value is not yet available, since the framework is right now implemented, and the management phase has just started. The research set a first baseline in identifying a roadmap and a matrix of implementation. Looking at the results related to the costs field, effective options offered by this methodology are linked to the possibility of also obtaining the economic evaluation derived from the maintenance activities performed during the management practice, as well as obtaining the history of the maintenance costs throughout the useful life of the heritage building. These are of valuable importance in supporting decision-making processes.

Regarding the case study, at least 3 years of running management are required for extracting and quantifying the benefits of this method, which should be evaluated on the building use phase and on facility manager data and feedback.

Considering that recovering information after a construction/renovation delivery has been largely documented in the literature, it is assumed that the structured methodological framework proposed can provide an optimization; on the other hand, the limit of the research until now consists of the fact that a measure of the avoided expenses is not ready now but will be for a future investigation. Moreover, the same approach can be implied in another building type case study (different from that of the theater) with the same logic by following the project from design to the renovation site until the hand-over phase for measuring the cost savings after a minimum running period.

Considering the case study application, apart from the recognizable benefits, the primary weakness is related to the time taken by the stage of data selection. The possibility of introducing useless information can lead to inefficiencies in the whole procedure. Therefore, all of the time and work dedicated to structure the proper information management framework are paramount. For this reason, it is fundamental to start the process with the "end in mind", with the awareness of the future perspective and the end objectives of the HBIM model. Thus, from the beginning, it is vital to set the appropriate structure of the model and the documentation according to the final uses and aim. This step can be perceived as expensive in terms of time and effort, accounting for a relevant part of the process, but it is the key to a successful result in a broader and long-term viewpoint. In our case, the quality and the detail of the different documentation's outputs were driven by a constant dialogue, with the client and a precise reference to the legislative context's requirements.

Moreover, the use of Dynamo enables a significant advantage in accelerating the data exchange process and in increasing the quality of the overall heritage building renovation project. On the other hand, the complexity of applying this kind of digital tool, such as for managing the data, requires firstly the technical ability of coordinating several activities from multiple perspectives and secondly a skilled qualification. In recent years, considering the implementation status of Building Information Modelling in general and that of the heritage BIM, this aspect can represent a constraint for many public and also private actors.

The last consideration, in the light of this research work, lies in the cost field. In particular, the value of implementing HBIM in conservation renovation projects lies in the ability to better coordinate data and, subsequently, for designing and construction [62]; however, as stated by [62], this may mean that the upfront cost is increased. On the other hand, to appropriately estimate the HBIM value or weight, this kind of expense should be balanced with the impact of the related project risks [62].

5. Conclusions

The aging and degradation of the built environment represent a relevant issue that implies an important economic commitment, given the enormous heritage that some countries manage [63]. Considering this context, systems for improving the current management practice are required. Indeed, this demand should concern the management of heritage building projects, from the renovation site to the delivery and then to the FM stage.

Moreover, HBIM work is predominantly focused on the pre-construction state [62], and few improvements in implementing technologies, such as identification systems or real-time data, have been carried out in the previous years [31].

This research work presents a methodology to approach a renovation intervention on a public heritage building, looking at the next operation phases. The application of the BIM methodology constitutes a critical matter, especially in the case of complex assets and even more so in the heritage of public works [63].

The creation of an HBIM model, properly modelled in its characteristics, enriched with parameters and defined by all the data for the management phase, can represent an efficient tool for managing the building portfolio in a life cycle view.

The research methodology describes how it is possible to collect several attributes and specifications when dealing with a heritage building project with the use of BIM.

The developed methodology represents an integrated procedure that takes advantage of different applications which can be connected. It enables a rapid update and an automatic data exchange during the building life cycle.

The application of a BIM approach to a restoration project and to a historical lyric theater site highlights that the use of new technologies and tools usually implied in new construction interventions can also offer positive effects on existing buildings and heritage buildings.

Looking at the final research result, an informative model, enriched and updated with information, perfectly describes the current condition of the built asset and provides crucial and consistent information for the FM and the O&M practice. Regarding the research, it is significant to highlight that this study is based on the constant recording activity of both the geometric and informative data, which are logged and updated during the renovation work phase, which is not used for heritage projects. Furthermore, the recording should also be used to maintain a log of ongoing work, methods employed during construction and conservation knowledge to ensure that it is maintained in a digital repository [62]. This provides value to the overall heritage as-built process.

Therefore, this research work represents a tangible contribution, since it provides a solution to the lack of integrated/structured procedures in information management processes in order to optimize the related costs. This work also sets a structured framework that can be reproduced as a matrix in other contexts and adapted to the related projects ‘peculiarities. Thus, future improvements will concern its large-scale applicability.

The presented contribution also highlights the chances that BIM can provide to conservation activities. The aim is that its implementation in private and public cases progressively increases. In general, the issue of conservation management is recognized as an area in need of future direction [62]. Therefore, future developments of the system could be linked to the following matters:

- One point is that the literature lacks guides concerning HBIM management specialized for building typology such as churches, theaters, etc. Each type of heritage building presents some features, so guidelines in a BIM context should be provided as a future research path. Today, it has been necessary to adapt their application to the few working guidelines that are available [63].
- Then, as recognized by [62], a significant work in this field, including guidelines by national bodies, has focused heavily on capturing and modelling heritage buildings and special individual components with less regard to the issues surrounding conservation work or management. This is another area that needs improvement.
- As a future research investigation, quantitative analysis in practical cases is required. In-detail data should be tested in multiple buildings, looking at the system performance in the O&M practice.

Author Contributions: Conceptualization, L.P. and S.B.; methodology, L.P. and S.B.; software, L.P. and S.B.; validation, L.P. and S.B.; formal analysis, L.P. and S.B.; investigation, L.P. and S.B.; resources, L.P. and S.B.; data curation, L.P. and S.B.; writing—original draft preparation, L.P. and S.B.; writing—review and editing, L.P. and S.B.; visualization, L.P. and S.B.; supervision, L.P. and S.B.; project administration, L.P. and S.B.; funding acquisition, L.P. and S.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. United Nations. Transforming Our World: The 2030 Agenda for Sustainable Development. 2015. Available online: https://sdgs.un.org/sites/default/files/publications/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf (accessed on 10 May 2022).
2. Dell'Ovo, M.; Dell'Anna, F.; Simonelli, R.; Sdino, L. Enhancing the Cultural Heritage through Adaptive Reuse. A Multicriteria Approach to Evaluate the Castello Visconteo in Cusago (Italy). *Sustainability* **2021**, *13*, 4440. [CrossRef]
3. Rossitti, M.; Oppio, A.; Torrieri, F. The Financial Sustainability of Cultural Heritage Reuse Projects: An Integrated Approach for the Historical Rural Landscape. *Sustainability* **2021**, *13*, 13130. [CrossRef]
4. Pinti, L.; Bonelli, S.; Brizzolari, A.; Mirarchi, C.; Dejaco, M.C.; Kiviniemi, A. Integrated Information Management for the Fm: Building Information Modelling and Database Integration for the Italian Public Administration; eWork and eBusiness in Architecture, Engineering and Construction. In Proceedings of the 12th European Conference on Product and Process Modelling, (ECPPM 2018), Denmark, Copenhagen, 12–14 September 2018; Taylor & Franccis Group: London, UK, 2018; pp. 21–28. [CrossRef]
5. Pinti, L.; Codinhoto, R.; Bonelli, S. A Review of Building Information Modelling (BIM) for Facility Management (FM): Implementation in Public Organisations. *Appl. Sci.* **2022**, *12*, 1540. [CrossRef]
6. Barazzetti, L.; Banfi, F.; Brumana, R.; Gusmeroli, G.; Previtali, M.; Schiantarelli, G. Cloud-to-BIM-to-FEM: Structural Simulation with Accurate Historic BIM from Laser Scans. *Simul. Model. Pract. Theory* **2015**, *57*, 71–87. [CrossRef]
7. Fai, S.; Graham, K.; Duckworth, T.; Wood, N.; Attar, R. Building Information Modelling and Heritage Documentation. In Proceedings of the 23rd International Symposium, International Scientific Committee for Documentation of Cultural Heritage (CIPA), Prague, Czech Republic, 12–16 September 2011; pp. 12–16.
8. Fai, S.; Filippi, M.; Paliaga, S. Parametric Modelling (BIM) for the Documentation of Vernacular Construction Methods: A BIM Model for the Commissariat Building, Ottawa, Canada. In *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Proceedings of the XXIV International CIPA Symposium, Strasbourg, France, 2–6 September 2013*; Copernicus GmbH: Göttingen, Germany, 2013; Volume II-5-W1, pp. 115–120.
9. Ashworth, S.; Tucker, M. FM Awareness of Building Information Modelling (BIM): August 2017. 2017. Available online: https://www.researchgate.net/publication/319159345 (accessed on 10 May 2022).
10. Bruno, N.; Roncella, R. HBIM for Conservation: A New Proposal for Information Modeling. *Remote Sens.* **2019**, *11*, 1751. [CrossRef]
11. Gallaher, M.P.; O'Connor, A.C.; Dettbarn, J.L., Jr.; Gilday, L.T. *Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry*; National Institute of Standards and Technology: Gaithersburg, MD, USA, 2004; p. NIST GCR 04-867. [CrossRef]
12. Eastman, C.; Teicholz, P.; Sacks, R.; Liston, K. *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors*; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2008; ISBN 978-0-470-18528-5.

13. Kasprzak, C.; Dubler, C. Aligning BIM with FM: Streamlining the Process for Future Projects. *Australas. J. Constr. Econ. Build.* **2012**, *12*, 68. [CrossRef]
14. D'Urso, C. Information Integration for Facility Management. *IT Prof.* **2011**, *13*, 48–53. [CrossRef]
15. Biagini, C.; Capone, P.; Donato, V.; Facchini, N. IT Procedures for Simulation of Historical Building Restoration Site. In Proceedings of the International Symposium on Automation and Robotics in Construction and Mining (ISARC 2015), Oulu, Finland, 15–18 June 2015; IAARC: Oulu, Finland, 2015; pp. 1–8.
16. Bruno, N.; Roncella, R. A Restoration Oriented HBIM System for Cultural Heritage Documentation: The Case Study of Parma Cathedral. In *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Proceedings of the ISPRS TC II Mid-term Symposium "Towards Photogrammetry 2020", Riva del Garda, Italy, 4–7 June 2018*; Copernicus GmbH: Göttingen, Germany, 2018; Volume XLII–2, pp. 171–178.
17. Palestini, C.; Basso, A.; Graziani, L. Integrated Photogrammetric Survey and BIM Modelling for the Protection of School Heritage, Applications on a Case Study. In *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Proceedings of the ISPRS TC II Mid-term Symposium "Towards Photogrammetry 2020", Riva del Garda, Italy, 4–7 June 2018*; Copernicus GmbH: Göttingen, Germany, 2018; Volume XLII–2, pp. 821–828.
18. Croce, V.; Caroti, G.; Piemonte, A.; Bevilacqua, M. From Survey to Semantic Representation for Cultural Heritage: The 3D Modeling of Recurring Architectural Elements. *Acta IMEKO* **2021**, *10*, 98–108. [CrossRef]
19. Akcamete, A.; Akinci, B.; Garrett, J.H. Potential Utilization of Building Information Models for Planning Maintenance Activities. In Proceedings of the International Conference on Computing in Civil and Building Engineering, Nottingham, UK, 30 June–2 July 2010.
20. Cheng, J.C.P.; Ma, L.Y.H. A BIM-Based System for Demolition and Renovation Waste Estimation and Planning. *Waste Manag.* **2013**, *33*, 1539–1551. [CrossRef] [PubMed]
21. Youn, H.-C.; Yoon, J.-S.; Ryoo, S.-L. HBIM for the Characteristics of Korean Traditional Wooden Architecture: Bracket Set Modelling Based on 3D Scanning. *Buildings* **2021**, *11*, 506. [CrossRef]
22. Abbate, E.; Invernizzi, S.; Spanò, A. HBIM Parametric Modelling from Clouds to Perform Structural Analyses Based on Finite Elements: A Case Study on a Parabolic Concrete Vault. *Appl. Geomat.* **2022**, *14*, 79–96. [CrossRef]
23. Utica, G.; Pinti, L.; Guzzoni, L.; Bonelli, S.; Brizzolari, A. Integrating Laser Scanner and BIM for Conservation and Reuse: "The Lyric Theatre of Milan". In Proceedings of the ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Kyiv, Ukraine, 4–6 December 2017; Volume IV-5/W1, pp. 77–82. [CrossRef]
24. Lubowiecka, I.; Armesto, J.; Arias, P.; Lorenzo, H. Historic Bridge Modelling Using Laser Scanning, Ground Penetrating Radar and Finite Element Methods in the Context of Structural Dynamics. *Eng. Struct.* **2009**, *31*, 2667–2676. [CrossRef]
25. Castellazzi, G.; D'Altri, A.M.; Bitelli, G.; Selvaggi, I.; Lambertini, A. From Laser Scanning to Finite Element Analysis of Complex Buildings by Using a Semi-Automatic Procedure. *Sensors* **2015**, *15*, 18360–18380. [CrossRef]
26. Georgopoulos, A.; Lambrou, E.; Pantazis, G.; Agrafiotis, P.; Papadaki, A.; Kotoula, L.; Lampropoulos, K.; Delegou, E.; Apostolopoulou, M.; Alexakis, M.; et al. Merging Geometric Documentation with Materials Characterization and Analysis of the History of the Holy Aedicule in the Church of the Holy Sepulchre in Jerusalem. In *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Proceedings of the GEOMATICS & RESTORATION—Conservation of Cultural Heritage in the Digital Era, Florence, Italy, 22–24 May 2017*; Copernicus GmbH: Göttingen, Germany, 2017; Volume XLII-5-W1, pp. 487–494.
27. Korumaz, M.; Betti, M.; Conti, A.; Tucci, G.; Bartoli, G.; Bonora, V.; Korumaz, A.G.; Fiorini, L. An Integrated Terrestrial Laser Scanner (TLS), Deviation Analysis (DA) and Finite Element (FE) Approach for Health Assessment of Historical Structures. A Minaret Case Study. *Eng. Struct.* **2017**, *153*, 224–238. [CrossRef]
28. Radicioni, F.; Matracchi, P.; Brigante, R.; Brozzi, A.; Cecconi, M.; Stoppini, A.; Tosi, G. The Tempio Della Consolazione in Todi: Integrated Geomatic Techniques for a Monument Description Including Structural Damage Evolution in Time. In Proceedings of the ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Florence, Italy, 16 May 2017; Volume XLII-5/W1, pp. 433–440.
29. Martinez Espejo Zaragoza, I.; Caroti, G.; Piemonte, A. The Use of Image and Laser Scanner Survey Archives for Cultural Heritage 3D Modelling and Change Analysis. *ACTA IMEKO* **2021**, *10*, 114. [CrossRef]
30. Marzouk, M. Using 3D Laser Scanning to Analyze Heritage Structures: The Case Study of Egyptian Palace. *J. Civ. Eng. Manag.* **2020**, *26*, 53–65. [CrossRef]
31. Pavón, R.M.; Arcos Alvarez, A.A.; Alberti, M.G. BIM-Based Educational and Facility Management of Large University Venues. *Appl. Sci.* **2020**, *10*, 7976. [CrossRef]
32. Usmani, A.R.A.; Elshafey, A.; Gheisari, M.; Chai, C.; Aminudin, E.B.; Tan, C.S. A Scan to As-Built Building Information Modeling Workflow: A Case Study in Malaysia. *J. Eng. Des. Technol.* **2019**, *18*, 923–940. [CrossRef]
33. Murphy, M.; McGovern, E.; Pavia, S. Historic Building Information Modelling (HBIM). *Struct. Surv.* **2009**, *27*, 311–327. [CrossRef]
34. Woodward, A.; Heesom, D. Implementing HBIM on Conservation Heritage Projects: Lessons from Renovation Case Studies. *Int. J. Build. Pathol. Adapt.* **2020**, *39*, 96–114. [CrossRef]
35. Volk, R.; Stengel, J.; Schultmann, F. Building Information Modeling (BIM) for Existing Buildings—Literature Review and Future Needs. *Autom. Constr.* **2014**, *38*, 109–127. [CrossRef]
36. Kassem, M. BIM to Shape the Future of the Buildings of the Past. Available online: https://www.bdonline.co.uk/intelligence-for-architects/bim-to-shape-the-future-of-the-buildings-of-the-past/5069413.article (accessed on 6 May 2022).

37. Okakpu, A.; Ghaffarianhoseini, A.; Tookey, J.; Haar, J.; Ghaffarianhoseini, A.; Rehman, A.U. A Proposed Framework to Investigate Effective BIM Adoption for Refurbishment of Building Projects. *Archit. Sci. Rev.* **2018**, *61*, 467–479. [CrossRef]
38. Maxwell, I. Integrating Digital Technologies in Support of Historic Building Information Modelling: BIM4Conservation (HBIM)—A COTAC Report. 2014. Available online: https://cotac.global/resources/COTAC-HBIM-Report-Final-A-21-April-2014-2-small.pdf (accessed on 10 May 2022).
39. Oreni, D.; Brumana, R.; Georgopoulos, A.; Cuca, B. HBIM for Conservation and Management of Built Heritage: Towards a Library of Vaults and Wooden Bean Floors. In Proceedings of the ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Strasbourg, France, 2–6 September 2013; Volume II-5/W1, pp. 215–221. Available online: https://www.isprs-ann-photogramm-remote-sens-spatial-inf-sci.net/II-5-W1/215/2013/isprsannals-II-5-W1-215-2013.pdf (accessed on 10 May 2022).
40. Jensen, C. Overview of the Main PAS 1192 Documents Useful for BIM Implementation. Available online: https://www.ice.org.uk/engineering-resources/information-sheets/overview-of-the-main-pas-1192-documents-useful-for-bim-implementation/ (accessed on 6 May 2022).
41. Carbonari, G.; Stravoravdis, S.; Gausden, C. Building Information Model Implementation for Existing Buildings for Facilities Management: A Framework and Two Case Studies. In *Building Information Modelling (BIM) in Design, Construction and Operations*; WIT Press: Southampton, UK, 2015; Volume 149, pp. 395–406. Available online: https://www.witpress.com/elibrary/wit-transactions-on-the-built-environment/149 (accessed on 10 May 2022).
42. Ciribini, A.; Ventura, S.M.; Paneroni, M. BIM Methodology as an Integrated Approach to Heritage Conservation Management. In *Building Information Modelling (BIM) in Design, Construction and Operations*; WIT Press: Southampton, UK, 2015; Volume 149. Available online: https://www.witpress.com/elibrary/wit-transactions-on-the-built-environment/149 (accessed on 10 May 2022).
43. Chen, H.-M.; Hou, C.-C.; Wang, Y.-H. A 3D Visualized Expert System for Maintenance and Management of Existing Building Facilities Using Reliability-Based Method. *Expert Syst. Appl.* **2013**, *40*, 287–299. [CrossRef]
44. Kassem, M.; Kelly, G.; Dawood, N.; Serginson, M.; Lockley, S. BIM in Facilities Management Applications: A Case Study of a Large University Complex. *Built Environ. Proj. Asset Manag.* **2015**, *5*, 261–277. [CrossRef]
45. Alnaggar, A.; Pitt, M. Towards a Conceptual Framework to Manage BIM/COBie Asset Data Using a Standard Project Management Methodology. *J. Facil. Manag.* **2018**, *17*, 175–187. [CrossRef]
46. Wong, J.K.W.; Ge, J.; He, S.X. Digitisation in Facilities Management: A Literature Review and Future Research Directions. *Autom. Constr.* **2018**, *92*, 312–326. [CrossRef]
47. Codinhoto, R.; Kiviniemi, A.; Kemmer, S.; Essiet, M.; Donato, V.; Tonso, L. BIM-FM: Manchester Town Hall Complex. 2013. Available online: https://www.researchgate.net/publication/260190387_BIM-FM_Manchester_Town_Hall_Complex (accessed on 10 May 2022).
48. Brandt, E.; Wittchen, K.B. EPIQR—A New Surveying Tool for Maintenance and Refurbishment. In *CIB W078 Workshop*; Available online: https://www.irbnet.de/daten/iconda/CIB2139.pdf (accessed on 10 May 2022).
49. Omar, N.S.; Hatem, W.A.; Najy, H.I. Developing of Building Maintenance Management by Using BIM. *IJCIET* **2018**, *9*, 13.
50. Araszkiewicz, K. Digital Technologies in Facility Management–The State of Practice and Research Challenges. In Proceedings of the Procedia Engineering, Primosten, Croatia, 19–22 June 2017; Volume 196, pp. 1034–1042. [CrossRef]
51. Thabet, W.; Lucas, J. Asset Data Handover for a Large Educational Institution: Case-Study Approach. *J. Constr. Eng. Manag.* **2017**, *143*, 05017017. [CrossRef]
52. Della Torre, S. How the Concept of Preventive Conservation Implemented on Built Cultural Heritage Can Work as a Factor for Regional Economic Developemnt. In Proceedings of the PRECOAH 2011 International Conference on Preventive Conservation of Architectural Heritage, Nanjing, China, 29–30 October 2011; pp. 14–22.
53. Ente Nazionale Italiano di Unificazione, Building and Civil Engineering Works-Digital Management of the Informative Processes-Part 4: Evolution and Development of Information within Models, Documents and Objects 2017 (UNI 11337-4:2017). Available online: https://store.uni.com/en/uni-11337-4-2017 (accessed on 27 January 2022).
54. Royal Institution of Chartered Surveyors (RICS) ICMS Explained-A User Guide for the International Construction Measurement Standards 2017. Available online: https://www.rics.org/globalassets/rics-website/media/upholding-professional-standards/sector-standards/construction/rics-icms-explained-user-guide-rics.pdf (accessed on 10 May 2022).
55. *Royal Institution of Chartered Surveyors (RICS) New Rules of Measurement-Nrm 3: Order of Cost Estimating and Cost Planning for Building Maintenance Works*; Royal Institution of Chartered Surveyors (RICS): London, UK, 2014; ISBN 978-1-78321-024-4. Available online: www.rics.org (accessed on 10 May 2022).
56. Le, A.T.H.; Domingo, N.; Rasheed, E.; Park, K.S. Building Maintenance Cost Planning and Estimating: A Literature Review. In Proceedings of the 34th Annual ARCOM Conference, ARCOM 2018, Belfast, UK, 3–5 September 2018; pp. 697–706.
57. Salvendy, G. (Ed.) *Handbook of Industrial Engineering: Technology and Operations Management*, 3rd ed.; John Wiley & Sons: Hoboken, NJ, USA, 2001; ISBN 978-0-471-33057-8. [CrossRef]
58. Vanlande, R.; Nicolle, C.; Cruz, C. IFC and Building Lifecycle Management. *Autom. Constr.* **2008**, *18*, 70–78. [CrossRef]
59. Succar, B.; Sher, W.; Aranda-Mena, G. A Proposed Framework to Investigate Building Information Modelling through Knowledge Elicitation and Visual Models. In Proceedings of the 2007 Conference of the Australasian Universities Building Education Association, Melbourne, Australia, 4–5 July 2007; pp. 308–325.

60. Gu, N.; London, K. Understanding and Facilitating BIM Adoption in the AEC Industry. *Autom. Constr.* **2010**, *19*, 988–999. [CrossRef]
61. Lee, G.; Sacks, R.; Eastman, C.M. Specifying Parametric Building Object Behavior (BOB) for a Building Information Modeling System. *Autom. Constr.* **2006**, *15*, 758–776. [CrossRef]
62. Ji, S.Y.; Kim, M.K.; Jun, H.J. *Campus Space Management Using a Mobile Bim-Based Augmented Reality System*; CAADRIA: Hong Kong, China, 2017; pp. 105–114.
63. Bazán, Á.M.; Alberti, M.G.; Álvarez, A.A.A.; Pavón, R.M.; González Barbado, A. BIM-Based Methodology for the Management of Public Heritage. CASE Study: Algeciras Market Hall. *Appl. Sci.* **2021**, *11*, 11899. [CrossRef]