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Old buildings need new ideas: Holistic integration of conservation-restoration process data using Heritage Building Information Modelling

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ABSTRACT

The preservation of cultural heritage and the renovation, restoration and remodelling processes could benefit greatly from Building Information Modelling (BIM) workflows being established. Currently, experts are involved with fractionated workflows, where a lot of data are missing, become lost or are duplicated by different stakeholders. All the resulting confusion severely impacts on the preservation of heritage as well as the efficiency of its restoring/remodelling/revitalizing from the point of view of current needs. Heritage information is usually conveyed through conservation-restoration plans and guidelines In this research, a new methodology for managing the information holistically integrated into the BIM is proposed. The workflow is showcased on a demo-case building that is protected as cultural heritage. Consequently, the conservation plan becomes more accessible, not only for stakeholders in heritage, but also stakeholders responsible for the renovation, such as architects and contractors. This can result in an improved understanding of the heritage and a better revitalization.

1. Introduction

1.1. Digitization of the cultural heritage process

The preservation of cultural heritage is a complex process involving a variety of methods and many different professions. An owner who wishes to preserve heritage objects or change their function must obtain the appropriate planning permission, which must be made in accordance with the guidelines of a competent heritage-preservation office. The office prescribes the development of a conservation plan, which, after an evaluation, provides precise guidelines for the conservation, and represents the starting point for the final architectural renovation plan.

Recent developments in the field of Architecture, Engineering and Construction (AEC) have provided incentives to digitalise the processes associated with cultural heritage. In particular, Building Information Modelling (BIM) can be seen as an opportunity to review the current methods used in this field and find alternatives that are more effective and efficient. BIM is a digital tool and a way of communicating information within the construction industry. Its disruptive approach aims to integrate the design, modelling, asset planning and facility management. It provides a digital representation of a building's characteristics throughout the building's life cycle and thus helps to streamline the processes and make them more efficient. The main characteristic of BIM is the integration of a three-dimensional digital model with quantitative and qualitative information that makes it possible to establish relationships between elements and links to external documents [1]. It is a communication tool that has the ability to bring together actors from different fields in industry and is valuable during the entire life cycle of a heritage-relevant object. This characteristic offers great potential as a heritage-information system [2–4].

1.2. Heritage Building Information Modelling (HBIM)

Heritage BIM (HBIM), also Historic BIM, is a sub-field of Building Information Modelling that is meant to capture more accurately the geometry and information that relate to historical buildings [5]. Its raison d'etre originates in the lack of functionality in 'standard' BIM, which is mainly used in the design of modern buildings. When dealing with the digitisation of historical buildings, there is a requirement for advanced tools, which are typically not found in most BIM use cases. An example of such a tool

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is enhanced geometry generation, which aims to capture the often nonplanar and complex geometries of heritage objects. There are a few directions of research into HBIM: (1) scan-to-BIM; (2) historical BIM elements; (3) integration of HBIM/GIS; and (4) heritage data models, briefly explained hereafter. (1) Vital parts of the whole heritage BIM process are the data-acquisition and digitising processes, also referred to as scan-to-BIM. A site is surveyed with close- range photogrammetry [6–9], TLS [9–15] or more advanced methods such as Unmanned Airborne Vehicles (UAVs) for hard-to-reach places (Zerbinatti et al. 2020), or a combination of methods [16–18]. Simultaneous Localisation and Mapping (SLAM) is a novel data- acquisition technique that is also in use [19]. Research into heritage-data acquisition often deals with the accuracy and completeness of the data, such as the Grade of Accuracy metric [20,21] or other metrics [9,15,22]. Also BIM extraction of the produced point cloud in manual, semi-automatic and automatic ways is subject to scan-to-BIM studies [10,17,18,20,21,24–26]. (2) Another focus point in HBIM deals with the missing aspects that relate to BIM, such as the terminology of historical building elements. Because BIM is designed for the AEC industry, it is mostly concerned with the development of new constructions. Predefined classifications of many HBIM elements are lacking and there is no unified way to include the historical data. To overcome these problems, some authors create their own element classifications that are characteristic for HBIM [13,24,27]. (3) A regularly posed question is whether to use BIM for heritage, or a 3D GIS counterpart, such as CityGML [28,29]. The scale varies a great deal in heritage projects: there are buildings of limited size; building groups such as monasteries [4]; and whole city blocks that are subject to digitisation regarding heritage [29]. Overall, much effort has been put into HBIM/GIS studies [30–32]. (4) BIM data models for heritage have received less attention than the previous three areas. Attempts have been made to formalise the information in metadata using the Level of Information (LoI) approach [33] or the Levels of Knowledge (LOK) approach [4]. Another approach that is currently under development is the Level of Information Need (LOIN), that is in the ISO standard 19650. LOIN is aimed at a gradual system that is more adaptable and based on project specifics [34]. While these metrics provide insights into the completeness of the information found in BIM, they do not provide the semantic data in a defined way. Other attempts at the formalisation of metadata are found in the damage assessment of heritage buildings, where data models are defined and software to support these models is created [22,23]. Likewise, data models for heritage documentation have been covered by Noardo [35]. While damage assessment and heritage documentation have some common ground with the conservation plan, a HBIM data model for this purpose has not yet been developed and needs standardisation.

HBIM allows us to share information about heritage values and material properties simultaneously in one system for all professionals. Furthermore, different forms of other information related to the building can be stored, such as photographs of frescos and interesting building features, vaults, windows as well as the results of different material surveys, the locations of elements that were already destroyed or removed with their 3D representations as they were before and descriptions of their significance. This information can later be used for research purposes, to develop renovation plans and cost estimations, or presented to the public, for example, using tools such as augmented reality in a virtual reality museum, as explored by other researchers [36]. In this way a new level of interactivity between users and virtual environments capable of communicating the tangible and intangible values of the remains of ancient times are being evolved [21]. Therefore, it is no surprise that HBIM is becoming increasingly adopted by public and private stakeholders, as well as end-users and professionals in the fields of heritage and construction.

The need for guidance and standards in BIM with respect to heritage is becoming increasingly pressing [9]. In particular, the exchange of information between software applications used in the construction industry needs standardisation. The leading organisation in this domain is buildingSMART. The Industry Foundation Classes (IFCs), as a neutral and open specification for BIM data models, are used by many software vendors. Furthermore, the world standardization organization, the International Organization for Standardization (ISO), has created a technical committee TC 59/SC 13 called the Organization of Information about Construction Works, and a technical committee of the European Committee for Standardisation (CEN) established a subcommittee CEN/TC 442 Building Information Modelling. Liaisons between these standardization bodies ensure the completeness and inclusiveness of the process, as well as the smooth acceptance of the adopted standards (European Commission et al., 2017). Even though the IFC is evolving constantly, there is still room for improvement in terms of interoperability and supporting heritage-specific issues ([27]; Noardo et al. 2020 [13,22,25,28]). An extension to the IFC schema to formalise the missing classes and subtypes that mainly refer to elements that are only found in historical buildings has also been developed [13,25]. Another piece of research demonstrated how to represent a huge number of specialized information models with the appropriate LOD and Grade of Accuracy in a BIM environment and comply with the IFC/RDF format [37]. Conversion between, and integration of, IFC and CityGML has also received attention [28]. However, the research in this area is not yet fully developed and at this moment there is no overarching conceptual model that takes on the versatility of the data found in conservation projects. There is an identified research gap of demo cases where conservation plans could be integrated into the HBIM process, and the process could be formalized and available as a pilot case for others to learn from.

1.3. Research aims

While some HBIM research areas, such as scan-to-BIM, GIS/HBIM integration and HBIM modelling elements are well explored, less attention has been given to the standardisation of HBIM data models. This research aims to provide a new methodology for data flow with less friction in the cultural heritage revitalization, renovation and restoration process. Part of this research was a demonstration of a new approach to a conservation plan, where data from it are being holistically integrated with an architectural plan in a HBIM project as a 3D model with semantic information attached. In this way, everyone can understand the complexity of the protected cultural heritage and why some elements are protected, unique or of special value in terms of preservation. This attempt does not try to deal with an overarching HBIM data model that deals with FEM as well as damage assessment, stratigraphic analysis and archiving, but rather to add a small piece to the standardisation of the required data model, focused on the conservation plan. It is pursued to find the data that are needed in the process and to develop a model that adheres to these needs. By using such a methodology, the results of revitalizing heritage buildings would be smoother, efficient and satisfactory for the stakeholders involved. A case study from Slovenia is used to test the feasibility of the research. Therefore, although the scope is limited to the Slovenian context, it could be adapted to other countries.

2. Material and methods

The conservation plan describes the historical origin of the building, its cultural heritage values and provides guidelines for the conservation in a standardized way ([38,39], Annex 1). The

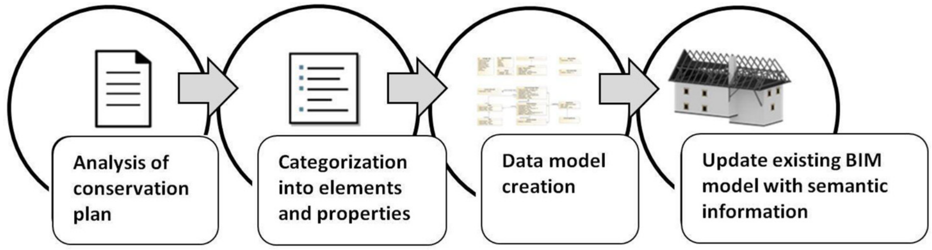


Fig. 1. Methodology workflow.

current Slovenian conservation plan contains textual descriptions, with photographs and floor plans for context. When an architect or engineer develops new plans in the case of renovation or restoration, these documents are not part of the integral design; rather they are separate documents that are read only by a small selection of people. In that sense the conservation plan in its current state is outdated.

But the data from it can be integrated with an architectural plan in a BIM project as a 3D model and thus accessed not only by specialists, but by a variety of stakeholders (e.g., civil servants, (sub)contractors and owners), so that everyone can understand the complexity of the protected cultural heritage and why some elements are protected, unique or of special value in terms of preservation.

A better approach than a conservation plan in textual format with images as the only aid would be to create a 3D model, where semantic and spatial data that can traditionally be found in the conservation plan or conservation-restoration project are integrated and offered to everyone who is collaborating in the project of renovation, restoration or revitalization of the built heritage. To achieve such a model, four steps need to be taken: (1) the relevant data should be extracted from the conservation plan's document; (2) the data should be categorised into elements and attributes that can be included in the BIM model; (3) a data model is needed to serve as a basis for how to include the data in the BIM; and (4) the data model should be translated in such a way that it can be implemented in the chosen software. This research is built up in the same manner. The chosen software in our case is Autodesk Revit, because the existing BIM model of the case study was modelled in this software. An illustration can be found in Fig. 1.

The data model is first created as a UML schema (see paragraph 4.3) and transferred into tables with properties (see paragraph 4.4). Single properties are aggregated into property sets. The properties are added to Revit using shared parameters. As the openness and standardisation of the data is one important factor in this research, the information in the conservation plan will not be saved in a Revit file, but rather an IFC file. Therefore, the Revit BIM model should be exported using the IFC schema. While the IFC4 Design Transfer would be the preferred schema, because it is more complete and has more geometric capabilities than previous schemas, it also has known exporting issues (see for example Trzeciak and Borrmann [40]. Therefore, the older IFC2 × 3 Coordination View 2.0 is chosen. On top of that, for this research the geometric quality is not as important as is the semantic quality of the model that stems from the added properties and property sets. To ensure the added properties and property sets are exported with the model, property-set mapping is used. In this process, properties from schema A (the Revit data model) can be mapped to properties from schema B (The IFC schema). As the properties were designed with the IFC export in mind, this is a 1:1 mapping. The use of IFC for data quality control is further explored in Oostwegel et al. [41].

2.1. The case study: Mrak's homestead near Bled

For our case study Mrak's homestead in Rečica pri Bledu (Rečica near Bled), Slovenia is chosen. The house has a simple late-baroque design that is characteristic of a rich farmhouse from the mid-18th century. It consists of a residential house and a barn. After the death of the last owner in January 1992, Mrak's homestead closed its doors for almost a quarter of a century. In 2008, the Decree on the Proclamation of Mrak's Homestead as a Cultural Monument of Local Significance was adopted. In 2014, the Municipality of Bled bought it from 49 heirs after a long and complicated process. In 2017, the municipality left the cultural monument to the management of the Bled Culture Institute. The house is well preserved from its time because the late owners did not care much about modernization. Researchers thus found a gem that looks like a building frozen in time for a century. There are just three light bulbs in the house and no running water, and all of the furniture and other objects are still intact.

The main goal of the municipality is to preserve the house as it was found. But not just as a museum, but as a modern heritage interpretation centre for the old ways of farming. The plan is that the house becomes a cultural tourist destination and is included in the set of diverse cultural and tourist offers in Bled. However, first and foremost the building needs a lot of restoration work (for example: new roof, new plasters, new flooring, and new windows). The Institute for the Protection of Cultural Heritage of Slovenia was therefore asked to provide guidelines for a restoration. As part of the process, a conservation plan was produced. Based on the stated guidelines, an architectural plan was drawn up and the owner applied for a building permit.

This research uses an existing BIM model of Mrak's Homestead (see Fig. 2). The point cloud of the building was captured using photogrammetry, and the Revit software was used to produce the BIM model. A geodetic survey was used to georeference the model. The Level of Development (LOD) was of little use for HBIM, where buildings are already existing (for an explanation see [4], p. 6). Consequently, the LOK concept is used to describe the quality of the HBIM model. It has been produced at LOK300 (advanced research) and the aim is to upgrade it to LOK400, used for the conservation and intervention processes [4].

3. Theory

3.1. The role of the conservation plan in preserving culturally significant objects

The protection of cultural heritage concerns both movable and immovable, and tangible and intangible properties. In Slovenia, the conservation plan is a legal document designed to help preserve cultural heritage and monuments. It is prescribed in the Law on the Protection of Cultural Heritage as a part of the administrative process, where the owner of a cultural heritage monument, prior to any work being carried out, must obtain the cultural heritage

Fig. 2. Point cloud of Mrak's homestead (left) and the BIM model (middle) and facade (right).

terms of use and guidelines from the Institute for the Protection of Cultural Heritage of Slovenia. In the terms of use for cultural protection, the requirement to prepare a conservation plan can be listed as a condition for obtaining cultural protection consent, or, in cases where building permission is needed, a heritage opinion is issued. A part of the process is derived from Anglo-Saxon heritage practices. In EU countries, however, there are differences in the definition of cultural heritage and the procedures of conservation and restoration. In Italy, for example, buildings are considered as any other heritage assets that need to be protected, which is different from England, where only specific items are added to the List of Buildings of Special Architectural or Historic Interest. In England there is no unique system for the protection of cultural heritage. As other researchers report, the institutional Italian system is organised hierarchically and includes the ministry, its offices and private owners, which leads to good control of the interventions. On the downside, a lack of works, especially the private enterprise, is a consequence of this approach. In contrast, the horizontal English system can relate the different stakeholders and thus avoid delays in renovation works as protected buildings are to be enjoyed and used, like any others [42]. The Slovenian general structure of the documents comes from James Semple Kerr 'Conservation Plan' (first edition 1982) that is of Australian origin. However, for some topics in the process, such as damage assessment, the standardised methods of Italy have been considered and used.

3.2. Conservation-plan preparation process

Fig. 3 illustrates the process of conservation and restoration from start to finish. When an owner decides that a building needs to be renovated or restored, the first person that they contact would be an architect, to make a feasibility study. For such a study, the architect needs to capture the current state of the building. Next, the owner asks the cultural heritage institute to create the terms of use (or guidelines) for the renovation or restoration. If anything is to be built, or if the building is a monument, building permission is needed. In such cases, it is normal that a conservation plan is required. Otherwise, the guidelines are created and only a consent is needed from the cultural heritage institute [43]. However, the decision about whether a Conservation Plan is needed lies with the cultural heritage institute. Whether a heritage building is a monument is decided by the heritage institute too, on the criteria for declaring a monument that are defined in the Cultural Heritage Protection Act. The difference between heritage and a monument is decided on multiple factors; however, it boils down to the fact that heritage can be defined as a monument when it either (1) represents a distinct achievement of creativity; (2) makes a valuable contribution to cultural diversity; (3) is an important part of the area or heritage of Slovenia; or (4) represents a source for understanding historical processes, phenomena and their connection with the current culture and space ([44], article 11).

The plan is prepared in the same way for all types of cultural heritage monuments. The first part of the Conservation Plan is the basic document dealing with the preservation and is put together in the so-called Map 1. In cases where the heritage object is complex and consists of many different parts, or is made of many different materials, a Conservation Plan can be upgraded with a separate, more precise document, i.e., the Heritage Elements Survey or Map 2 ([39], Annex 1).

When there is a clear intention to make extensive changes with respect to a heritage object or implement conservation-restoration work, another document is added that is focused on the execution. The Conservation–Restoration Project, or Map 3, defines the different materials used in the heritage object, the state of the materials based on an investigation and the defined conservation-restoration works, clearly divided into separate technologies. The last map (4) contains all the annexes ([39], Annex 1).

The conservation plan provides a holistic overview of the monument and all its components. It contains all the information needed to preserve the common heritage (see Fig. 4). The basic document (map 1) of the conservation plan consists of four sections: (1) understanding heritage - "What do we have?", (2) assessing cultural significance - "What is its significance?", (3) assessing the vulnerability of the heritage object, "Why is it vulnerable?", and (4) developing policies - "What should we do with it?". Understanding the heritage is the first part of the conservation plan, where a general awareness of the heritage needs to be appreciated, i.e., understanding the development, comparisons with similar examples, etc [39].

An assessment of the significance of cultural heritage plays a major role in the decision- making process in terms of the way the heritage is preserved. The significance of cultural heritage affects all the decisions about its future (from daily maintenance to long-term management). It is assessed by an evaluation procedure that investigates a combination of heritage values or criteria, based on its history, aesthetics, social role, and others.

The presentation of an assessment of the cultural significance needs to be evident and clear. To do that the levels of significance are defined and graphically illustrated (in a table or plan). Six levels of cultural significance are used: remarkable, high, medium, low, meaningless and disruptive/disturbing ([39], Annex 1 p. 4). In this way there is a clear distinction between the remarkable components of heritage (which must not be altered or lost) and those of lesser importance (where changes are permitted).

The section on the vulnerability of the heritage follows the assessment of the cultural significance. Heritage can be vulnerable for a variety of reasons, for example, natural and other disasters. The significance of the cultural heritage needs an assessment of the potential threats that are not immediate. It can also have immediate threats from climatic and environmental impacts, improper handling, human intervention or factors that cause damage to the material and thereby reduce or even destroy its cultural significance

The fourth section of the Conservation Plan defines the policies for the preservation of the heritage object. Policies derive from the identified assessments of cultural significance and its vulnerability.

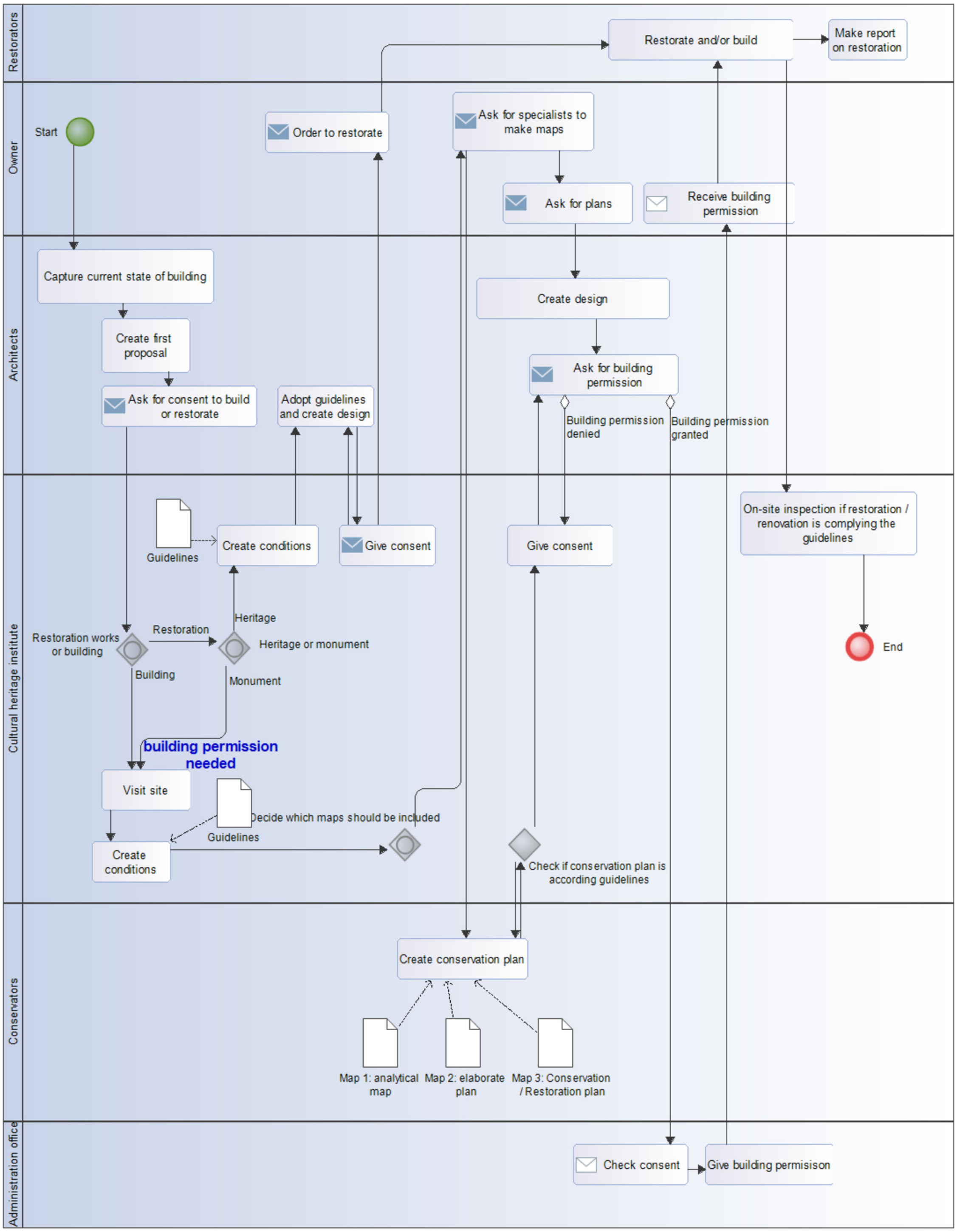


Fig. 3. Data flow in the current situation.

They are in the form of rules that are not proposing a final solution, but are rather a basis of the decision process for how to preserve the heritage. The policies define the general principles of the protection of heritage, methods for the conservation of protected values and to provide guidelines for the future development and changes of heritage.

The architect needs to create plans that conform with the conservation plan. This will be checked by the cultural heritage institute. If the institute agrees, building permission can be granted and the renovation or restoration can begin.

3.3. Wider view on the usual workflow when revitalizing old buildings

The process of the conservation plan is usually conducted separately from all the other processes related to the planning for a historical building under protection management. All the actions related to acquiring funding are usually a precursor to a feasibility study for revitalisation, including the business plan and the return on investment, as well as all the social aspects like defining a new programme. Based on the feasibility study the spatial

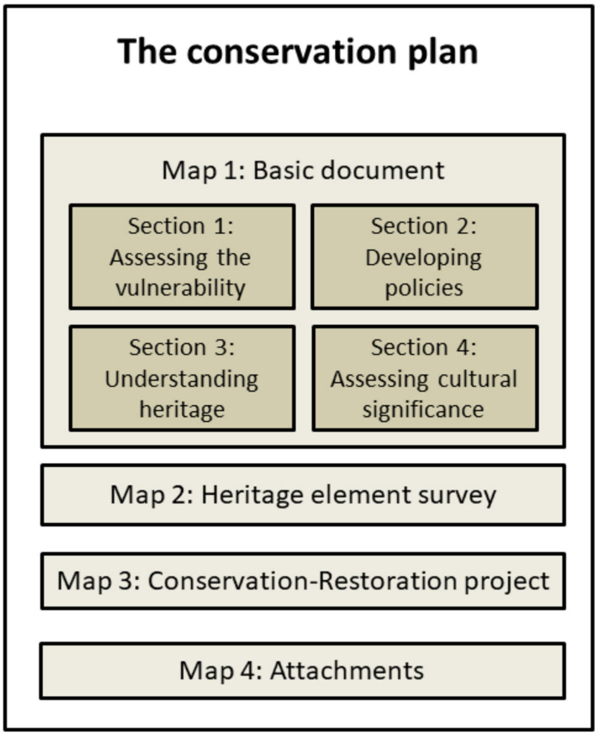


Fig. 4. Schema of the conservation plan.

requirements are developed without interaction with the conservation planning process (see Fig. 5). This brings many misconceptions into the planning, friction in the process, misunderstandings, unavailable data and so on. BIM communication with one central, live, data-storage point, where all the 3D (analytical survey); 4D (Historical Evolution); 5D (Diagnosis); 6D (Cultural Context); and 7D (Preventive Conservation) are also available, would make the process much better [4,45].

3.4. Integrating the conservation plan in HBIM: what should be considered?

The conservation plan describes the historical origin of the building, its cultural heritage values and provides guidelines for the conservation in a standardized way [38]. In the conservation plan, individual elements, such as the smoked kitchen, stone window and door frames, bread oven with pottery tiles, colour layers of the wall painting in the house, are allocated in time and materials. All these data are mostly described in text, pictures and some floor plans, usually in 2D. Therefore, it is sometimes difficult to understand where some elements are located or what is their value or the relationship between them. Spatial data are decoupled, as the document is built on categories (descriptions of rooms, windows, doors, etc.), instead of proximity (describing all the features in one room). Guidelines on how to restore the elements can be found at the end of the document. A method is needed to not only to obtain details on one category, but also which of these features in the same category also belong to the same room and how the features need to be restored . This should be achieved with a few clicks in an interlinked system or database.

The conservation plan brings together multiple users with different viewpoints that bring together new information, as well as multiple stakeholders that use the information (with varying expert levels). This makes the openness of the information crucial, as well as its interoperability. Therefore, IFC is essential as an open-data format (that can be opened by everybody). Further, it is important to note that for each building, the documentation that is needed is considered. Firstly, for each heritage object, it is decided which maps are needed. Moreover, some monuments are of such importance that there are experts in each specialisation, while other, smaller heritage buildings only need one conservator who does everything. Lastly, the amounts of documentation in the maps also differ: for example, the damage assessment in some heritage sites should be carried out extensively by civil engineers (in the case of cracks) or biologists (in the case of mould or other biological processes). However, not all sites need this. Therefore, the data model that is developed should be seen as separate building blocks that can be in a conservation project, but do not have to be.

4. Results

4.1. A proposal for a frictionless workflow to supply the data needed for HBIM

The main advantage of using HBIM is creating a workflow where everyone is supplied with the relevant data at the time they need it for the decision-making process and analysis. This should be compared with the old process of renovating, conserving and preparing for use, where data were not usually integrated and available to all the stakeholders, not even to all the engineers, let alone other relevant experts, such as those covering the social and economic aspects of the project. Therefore, cultural heritage experts preparing guidelines for renovation and restoration were frequently seen as unwanted, additional trouble in the process, since their work and the knowledge they conveyed in the conservation-and-restoration process was not visible or available to the other experts involved. The proposed process that is tested in this research, as well as on the demo model of Mrak's homestead HBIM, integrates the different experts' inputs into the same model (see Fig. 6). Through interviews with experts and the investigation of Slovenian legislation on cultural heritage [39,43,44], a data model was developed that captures the essential information found in a conservation plan in a format that can be integrated in a BIM model. In this way a common data environment has been created and tested (see Fig. 8 and compare it with Fig. 3), which other experts can now make use of. Using the property set mapping function in Revit for IFC exports, user- defined semantics can be exported to IFC in the form of property sets, which makes our work completely IFC compliant. Using IFC as a data carrier has multiple advantages: experts can open information attached (geometry and semantic data) in any free IFC viewer and help themselves to develop an understanding of the cultural heritage protection point of view about different possibilities for the revitalization and restoration of this built structure. In addition, most proprietary BIM software can open files using the IFC schema, thus making it interoperable for many domain experts. For example, economics experts can now see different data about which elements must be protected and which are not as important and can be changed, which would greatly improve the ability to correctly access a business- feasibility study and the return on investment for different revitalization options. Based on information accessible to everyone involved in the process, new ideas for the revitalization programme can be explored and discussed, taking values defined as cultural heritage as an asset not an obstacle.

4.2. New data-flow proposal

The main gain of HBIM is that the processes and decisions are not taken in a linear fashion, but rather in parallel, i.e., many experts can work simultaneously and have the data on heritage value that they need for their decisions (see Fig. 6). Furthermore, with

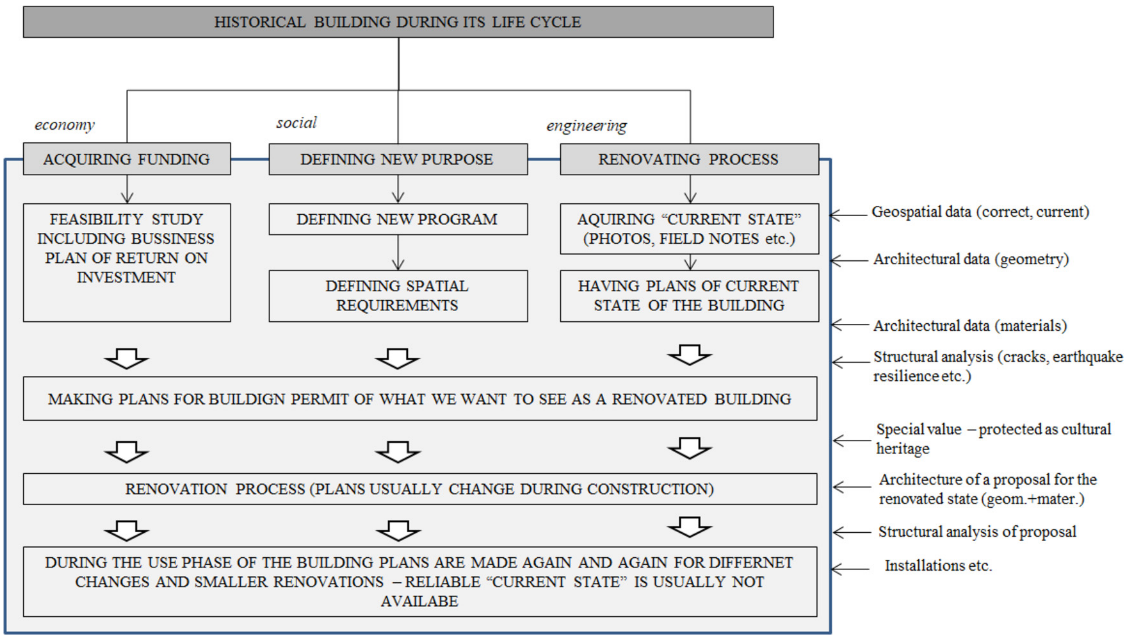


Fig. 5. Current workflow in a building protected as a cultural heritage revitalization process.

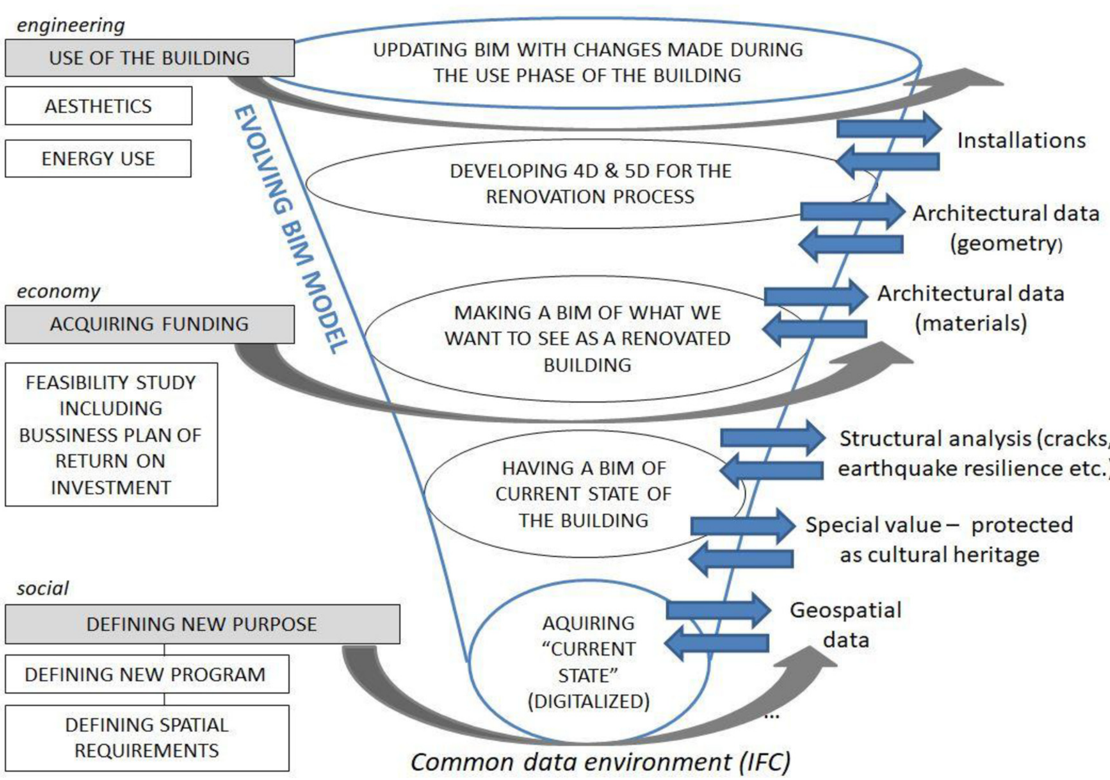


Fig. 6. Using IFC as an integrated approach to align processes in the field of heritage.

the right setup, the data are interconnected. In the traditional conservation plan, elements are described in a table sorted with respect to their type (window, door, room). However, there is no spatial sorting system (e.g., sort by room), which can be achieved using BIM. Added to that, where traditionally the description was separated from the interventions, in BIM these are linked to the heritage element, and can be viewed conveniently together in its properties panel . Lastly, the data can be filtered based on the properties, such as querying all the elements that have high significance. While all this would be possible with a relational database too, the additional value of HBIM is that each element has an easily accessible spatial representation, if open data standards such as IFC are used. This makes the context easier to understand too.

In the suggested workflow (see Fig. 7), at the start of the conservation-restoration project, the current state of the building is captured using scan-to-HBIM techniques. Using feasibility studies, a first idea of renovation can be proposed and brought to the heritage office, using the HBIM as the data carrier. The heritage

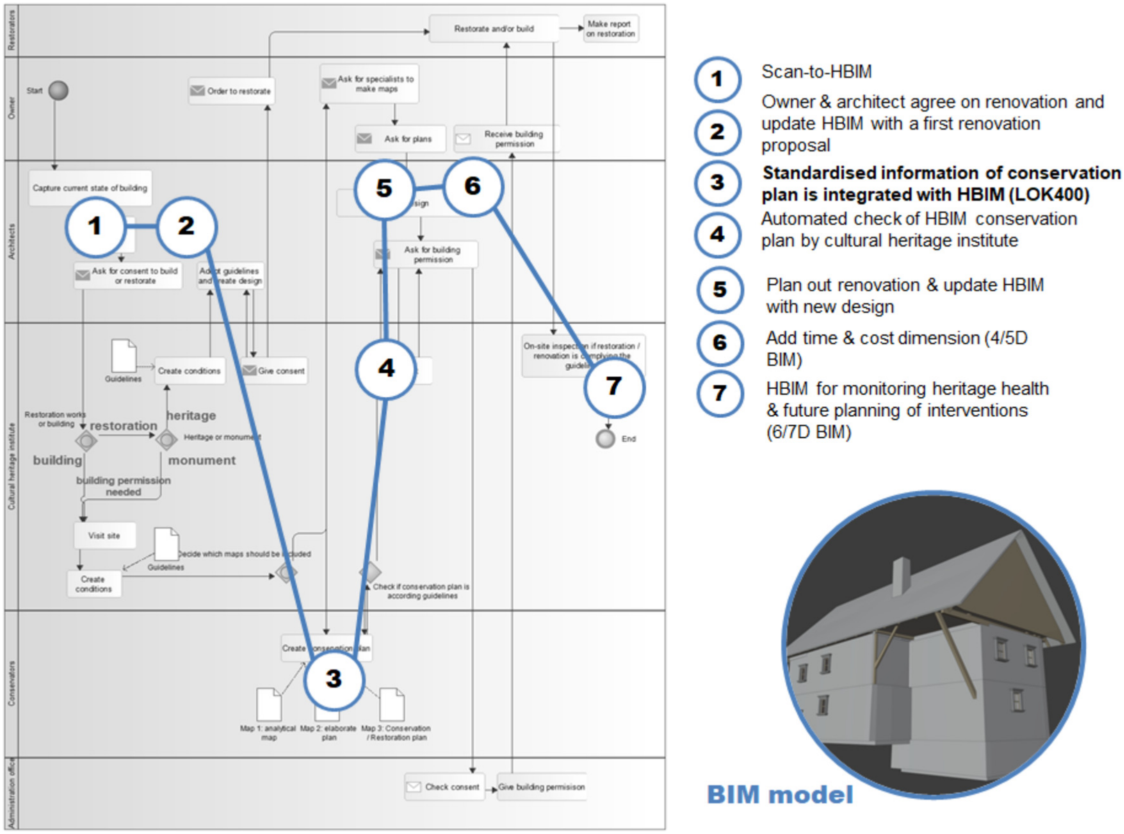


Fig. 7. Flow of data in updated process with integration BIM. Current research is trying to achieve no. (3).

office requests conservation experts to assess the building thoroughly and, using the data model provided in this research, to update the HBIM with similar information as previously found in the conservation plan. If this 3D conservation plan has sufficient detail, according to the heritage office, it can be used as the basis for the new design, renovation or restoration in future stages such as the design, construction or monitoring phase.

4.3. A new data-model suggestion

Based on the existing conservation plan, an HBIM data model for that purpose is developed (see Fig. 8). The elements inside the plan are organised into relevant categories that have a meaning in BIM. The conservation plan in the data model in Fig. 8 is equivalent to one project in the BIM software. The data model borrows many elements from previously developed data models for HBIM, but is different in that it does not only address one aspect of the conservation plan, but tries to address them all. It takes elements from Mora et al. [19] and Masciotta et al. [23] that are concerned with damage assessment and inspection and enhances these with elements from the existing conservation plan document of Mrak's homestead. The latter part deals more with the understanding of heritage rather than the technical documentation that is damage assessment. The data model can have one or more cultural heritage objects that are the actual subjects of the study. In the current research, only one heritage object exists: Mrak's homestead building. However, a large project, such as a monastery, could have multiple building parts: a chapel, a garden and multiple buildings.

The cultural heritage object is composed of 'heritage elements'. These are the architectural building blocks that are defined with the BIM: the walls, the windows, roofs, doors, etc, that contain some information that could also be found in a traditional conservation plan. Each heritage element can, but is not required to, be subdivided into multiple semantic surfaces, which are meant to extend the information about single elements. The need for semantic surfaces can be illustrated using the wall finish. In many heritage structures, the finish on the walls is not homogenous: a part of the wall could be covered with culturally significant wall paintings, while another part is plaster. In that case surfaces are needed to distinguish multiple surfaces on the BIM wall element. Surfaces and heritage elements have heritage materials assigned. This extends the regular class of materials with extra information that could usually be found in the conservation plan. It includes information about the specialisation that the material belongs to, such as stone, wood or wall paintings, relevant for conservation specialists in that area. It also includes information about the state of the material and which interventions should be made during the restoration. A further categorisation is made within the spatial layout of the heritage building. Rooms and the spaces within the rooms, or areas can be defined, which are not only identified by their location, but also by the time period they existed in.

For each cultural heritage object, a user defines a heritage-type attribute that has the following enumeration values, as defined in the Rules on the Registry of Types of Heritage and Protection Guidelines [43]: (1) Archaeological sites, (2) Buildings, (3) Parks and gardens, (4) Buildings with parks or gardens, (5) Memorial buildings and places, (6) Other facilities and devices, (7) Settlements and their parts, (8) Cultural landscape, and (9) Other. The ninth option is for custom and undefined heritage types. A definition of each individual heritage type can be found in the Rules on the Registry of Types of Heritage and Protection Guidelines. A construction period attribute can be defined. Next, a demolished attribute is defined, which is of the Boolean type (true/false, if true, then the heritage is demolished). When demolished is True, elements must also have the demolished period attribute defined. A demolished period attribute is of the type period.

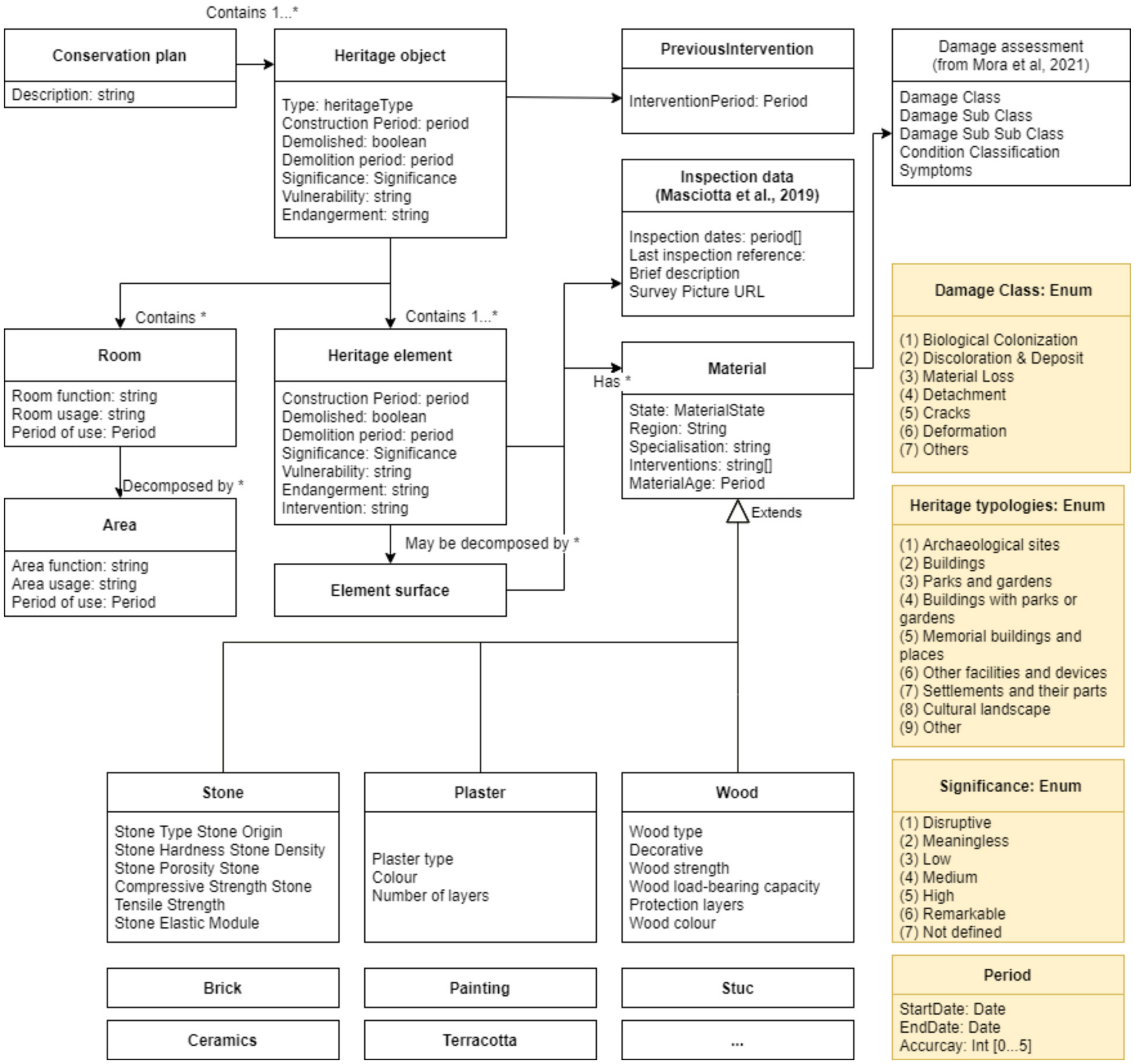


Fig. 8. A newly proposed data model for HBIM.

A significance attribute (cultural, historical, social) has the following enumeration values, as defined by the Rules on the Conservation Plan, Annex 1 [39]: (1) Disruptive; (2) Meaningless, (3) Low, (4) Medium, (5) High, (6) Remarkable. However, it can also be classed as (7) Not defined. F urther predefined, more specific heritage significance types can be chosen ([43], article 4): (1) culturalSignificance, (2) socialSignificance, (3) economicSignificance, (4) scientificSignificance, (5) educationalSignificance are enumeration attributes derived from significance. Any *Significance are enumeration attributes derived from significance. If a *significance exists, that is not one of the previously mentioned types of significance, a description must be provided.

Materials are further defined into properties per specialisation. Specialisations are stone, plaster, wood, etc., as defined in the Rules on the Conservation Plan. Annex 1: Conservation plan [39]. It also has a material state, which is a short description of the circumstances of the material, such that, if there is some damage, it can be further expanded in a damage assessment. The damage-assessment data model that is explored in Mora et al. [19]. is similar to the Slovenian assessment. Therefore, the structure is in line with that research. Furthermore, in the map 3 of the traditional conservation plan, the list of required interventions that are following the damage assessment is ordered by the specialisations. The Intervention attribute defines a list with these interventions and is part of the materials class . Lastly, the age of the material can also be specified, to enhance the understanding of the significance of the heritage element.

4.4. Translation of data-model requirements to semantic data in HBIM

Revit allows users to construct custom attributes through shared parameters (see Table 1). These can be defined for specific element types, such as a project, a wall or a window, or as generic parameters that can be added to each element type. These parameters only have a limited set of types that can be used. For example, a date-time does not exist, but should be expressed in a text parameter. The data model defined in Section 4.3 is translated into the Revit data types. In Table 2, the parameters implemented in the Revit model are found.

The shared parameters are defined with Revit and saved in a text file. A demonstration HBIM enriched with semantic data rel-

Table 1
Conservation plan documents ([39], Annex 1).

Map nr.	Name	Description
1	Basic document	Information about the authors of the conservation plan; the monument and its values and vulnerabilities. It also provides general guidelines for the preservation and protection of the monument
2	Heritage element survey	Information about specific elements in the heritage building (significance; vulnerabilities; photos)
3	Conservation-Restoration project	Ordered list of interventions that will be executed. It also contains a list of responsible persons for each category.
4	Attachments	All the extra information

Table 2
Attributes added in Revit.

Attribute	Entity	Description	Revit data type
Description	All	Description of heritage object	Multiline Text
Significance Value	All	Conservation value, as described in Section 4.3 1. is disruptive, 6 is remarkable	Integer
Construction Period	All	The construction period consists of a start date and can have an end date	Text*
Demolished	All	Whether element still exists or not	Yes/No
Demolished period	All	If the element is demolished, the demolition period consists of a start date and can have an end date	Text*
Intervention	All	A list of actions that should be taken to restore the element	Multiline Text**
Material state	Materials	Description of the state of the material	Text
Region	Materials	Region of origin of the material	Text
Specialisation	Materials	The specialisation of the conservator that should be in charge of the material restoration (stone/masonry/paintings)	Text
Material Age	Materials	The age of the material consists of a start date and can have an end date for a fuzzy period	Text*
Room function	Rooms	The function of the room during a certain time period	Text
Room usage	Rooms	The usage of the room during a certain time period	Text
Period of use	Rooms and areas	The period of use consists of a start date and can have an end date	Text*
Area function	Areas	The function of a subspace in a room during a certain time period	Text
Area usage	Areas	The use of a subspace in a room during a certain time period	Text
Heritage Type	Project	Heritage Type, as described in Section 4.3.	Integer
Intervention Period	Project	Date of last intervention	Text*
Inspection Dates	All	Date of last inspection of heritage element (from Masciotta et al. [23])	Multiline Text */**
Last Inspection Reference	All	Reference to the source of last inspection (from Masciotta et al. [23])	Text
Inspection Description	All	General description of last inspection (from Masciotta et al. [23])	Text
Survey Picture URL	All	URL to survey picture	URL
Damage Class	Materials	Damage class as defined in Section 4.3	Integer
Damage Sub Class	Materials	Damage sub class (from Masciotta et al. [23])	Text
Damage Sub Sub Class	Materials	Damage sub sub class (from Masciotta et al. [23])	Text
Condition Classification	Materials	Bad, Poor, Fair, Good (From [19])	Text
Symptoms	Materials	Textual description of symptoms	Text

* Revit does not have a 'date' data type, so a Text type is chosen with dates formatted by YYYY-MM-DD. Periods (start and end date) are shown as: YYYY-MM-DD/YYYY-MM-DD, where the first date is the starting date and the second date is the ending date.
** Revit does not have a 'list' data type, so a Multiline Text type, with each action on a new line, was chosen.

evant to the conservation plan was built in Revit software (see Figs. 9, 10 and 11). Each parameter is imported into the BIM model of Mrak's homestead, and all the relevant data found in the conservation-plan document are assigned to the element it is about. For example, all windows and doors are documented with a description, a significance value and a construction period. Standard colour coding of the significance is used for the conservation classification that is defined in the Rules of the conservation Plan [39], as is seen in Fig. 9.

While it is favourable to keep the data in the model, as everything is interlinked, visual representations can be produced and exported to other formats to be included in reports (see Fig. 11).

5. Discussion and conclusions

This article tries to convey a method for how to include HBIM in the process of restoration- conservation using the case study of Mrak's homestead. In this research many advantages of using HBIM as a carrier of information within the context of the development of a conservation plan are found. The two main advantages are (1) the data is available to stakeholders of the project who need them sooner in the project; (2) there are significantly fewer lost data and duplications. As opposed to previous research, e.g., into LOK or LOIN, this research does not merely provide insights into the completeness of information, but also provides a start to standardizing the information that is needed according to national laws. The research built upon existing data models of Mora et al. [19] and Masciotta et al. [23] that both emphasized inspection and damages of the heritage in the respective data models. This research adds to that the information necessary for a conservation-restoration project. Furthermore, as a data model compatible with IFC it is not bound to one vendor and can be used to provide further understanding of the heritage.

However, the willingness of the sector to change to a BIM approach is, in our own experience, limited. The reasons for that could be a lack of awareness of the available tools, or limited time to become acquainted with new technologies. The latter is, unfortunately, more apparent in public heritage-protection offices, which are underfinanced and understaffed. This research project, with its demonstration on real buildings intended to be revitalized as a museum, serves as an example to show that with such an approach it is possible and feasible. Experts in conservation have the opportunity to be involved more in the overall processes related to heritage buildings, when it comes to renovation or restoration. While now only the architect will read the plans, updating the BIM with heritage information would not only give all those involved

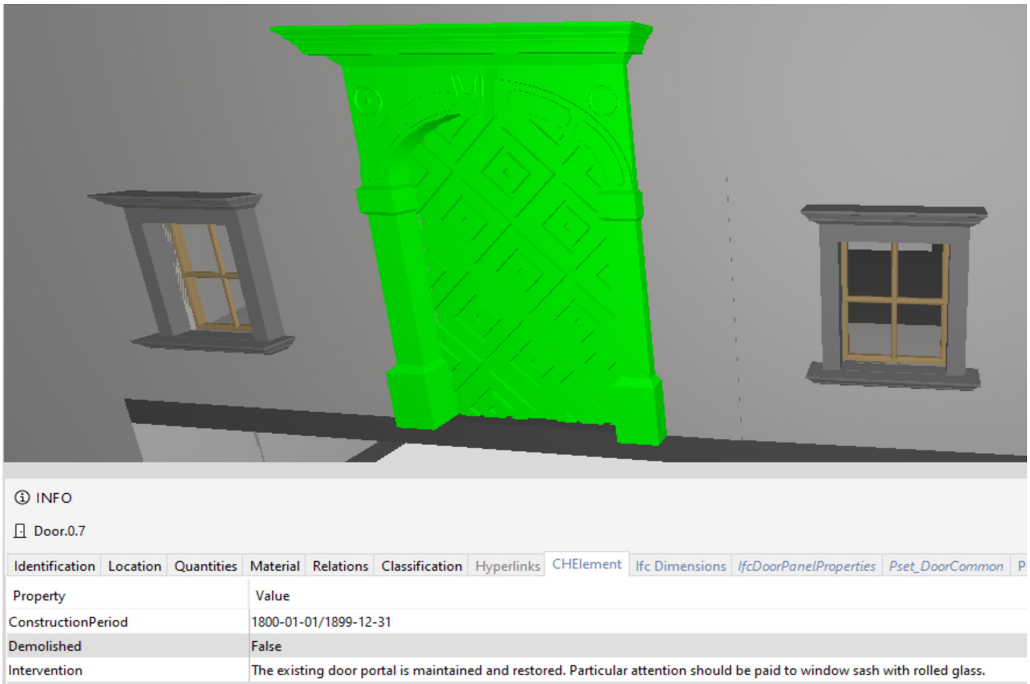


Fig. 9. Close-up of the entrance portal with heritage information in a free IFC viewer.

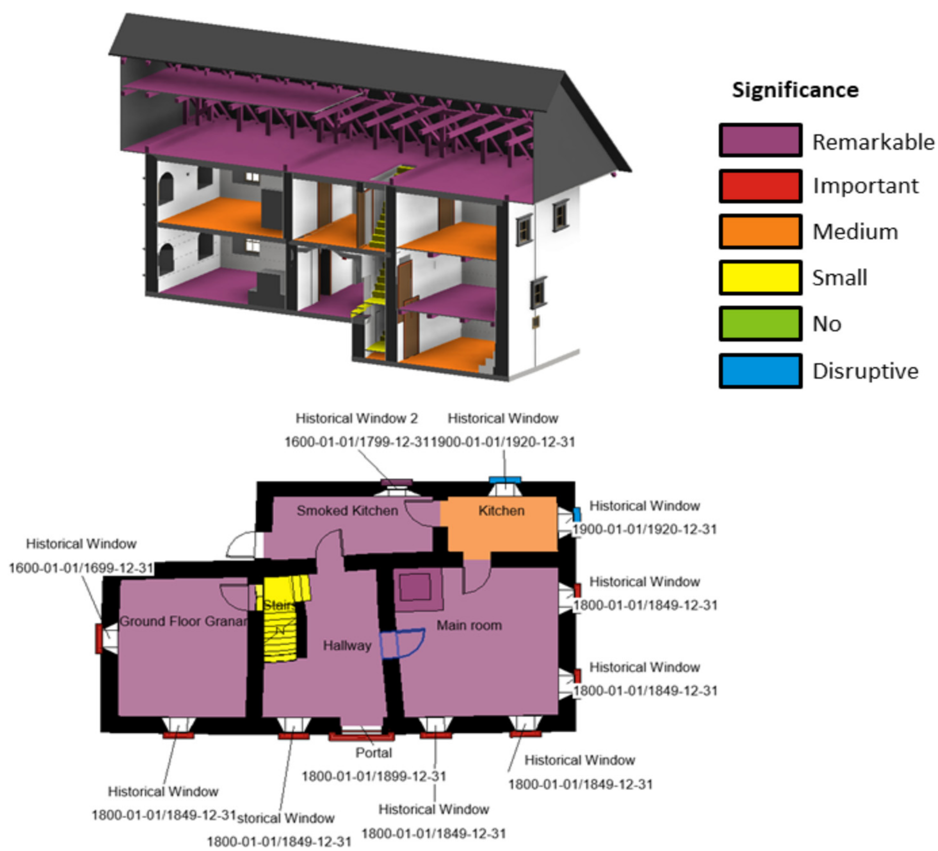
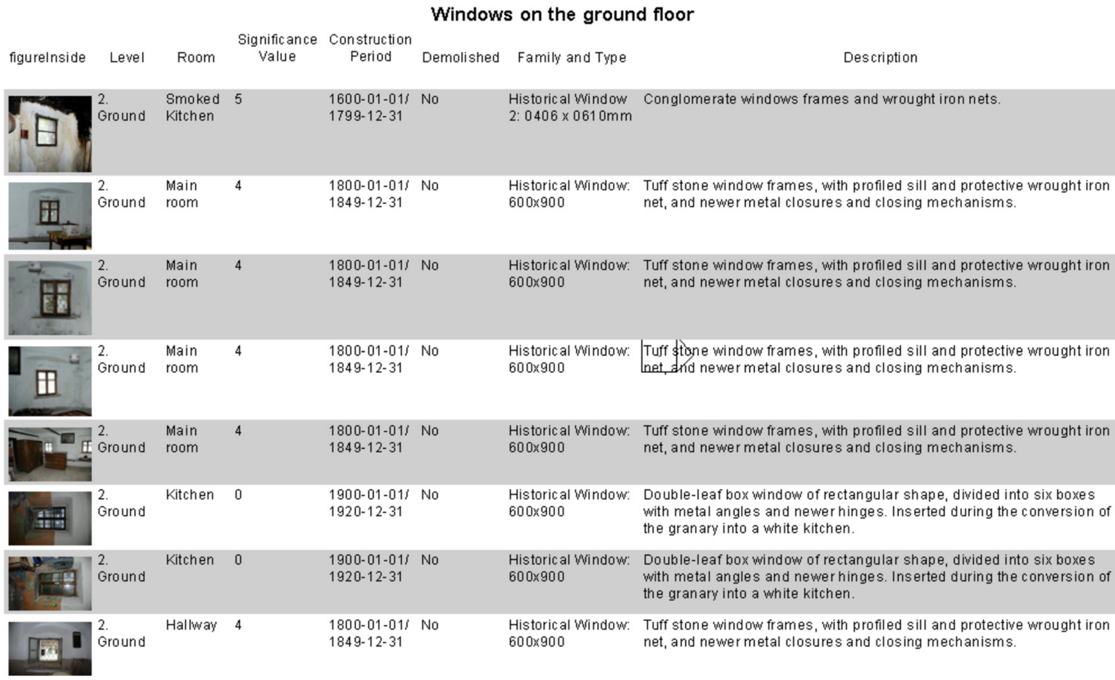


Fig. 10. Revit section with coloured semantic information about significance (up) Revit plan of first floor with added semantic information about construction time period (down). Colouring is automatically implemented using the 'colour scheme' option that colours plans and sections by attribute. Annotations are added as a custom Multi-Category tag that makes use of Revit's shared parameters.



Windows on the ground floor

figureInside	Level	Room	Significance Value	Construction Period	Demolished	Family and Type	Description
	2. Ground	Smoked Kitchen	5	1600-01-01/ 1799-12-31	No	Historical Window 2: 0406 x 0610mm	Conglomerate windows frames and wrought iron nets.
	2. Ground	Main room	4	1800-01-01/ 1849-12-31	No	Historical Window: 600x900	Tuff stone window frames, with profiled sill and protective wrought iron net, and newer metal closures and closing mechanisms.
	2. Ground	Main room	4	1800-01-01/ 1849-12-31	No	Historical Window: 600x900	Tuff stone window frames, with profiled sill and protective wrought iron net, and newer metal closures and closing mechanisms.
	2. Ground	Main room	4	1800-01-01/ 1849-12-31	No	Historical Window: 600x900	Tuff stone window frames, with profiled sill and protective wrought iron net, and newer metal closures and closing mechanisms.
	2. Ground	Main room	4	1800-01-01/ 1849-12-31	No	Historical Window: 600x900	Tuff stone window frames, with profiled sill and protective wrought iron net, and newer metal closures and closing mechanisms.
	2. Ground	Kitchen	0	1900-01-01/ 1920-12-31	No	Historical Window: 600x900	Double-leaf box window of rectangular shape, divided into six boxes with metal angles and newer hinges. Inserted during the conversion of the granary into a white kitchen.
	2. Ground	Kitchen	0	1900-01-01/ 1920-12-31	No	Historical Window: 600x900	Double-leaf box window of rectangular shape, divided into six boxes with metal angles and newer hinges. Inserted during the conversion of the granary into a white kitchen.
	2. Ground	Hallway	4	1800-01-01/ 1849-12-31	No	Historical Window: 600x900	Tuff stone window frames, with profiled sill and protective wrought iron net, and newer metal closures and closing mechanisms.

Fig. 11. Automatically produced schedule with information about each window on the ground floor, including images. While it seems like a regular table, it is directly connected to the BIM model: if anything is modified in the model, it will also be modified in the table.

access to the information, but also an incentive to include it in the process.

Once HBIM is adopted by more people in the heritage field, attention should be paid to where the standard BIM falls short for the use case. One specific example is a better approach to the structural characteristics of the materials in heritage buildings that are often unknown. Even when a BIM is available, it is hard to do any structural analysis in these cases. The structural qualities of materials can only be found by using destructive methods, e.g., using a sample taken from a wall. A structural-materials database per region and time period would greatly enhance HBIM methods, as these destructive methods would not be needed anymore.

The only software used to add semantics to the BIM model in this case study is Revit Autodesk. This is a result of the fact that the researcher that was in charge of the BIM model is the same as the one implementing the conservation plan in the model. However, in reality there are many people who are responsible for their own part in the process. Different software is used, which is fit for a single specialisation. Therefore, there is a risk that the semantic information added to the model is lost when exchanging between parties.

The IFC schema can mitigate these risks, by the standardisation of classes, attributes and properties. There are known drawbacks to IFC, such as incorrect mapping of classes from vendor-specific software to the open-data schema and the limited options for parametric geometry in the schema. Using IFC native software can be one part of the solution there. While the application of additions to the schema can be time consuming, the benefits are many. Definitions of each property are agreed upon and fixed. Different software implements the schema and therefore will be able to support the addition in the heritage domain. Consequently, there will be easier data exchange between the different software vendors. IFC property sets can be used to see immediately which properties are missing and should be added to the model for each element.

To further contribute to the standardisation and interoperability, a Model View Definition (MVD) should be designed for Heritage BIM. According to the stages in the workflow defined in Section 4.1, each stage when data are transferred between partners can be captured in an exchange definition. The standardisation of the exchange brings more clarity and will be beneficial not only between the partners that are usually connected, such as the national heritage agencies, building occupants and conservators, but it will also give insights in terms of similarities and differences between country-specific implementations of conservation plans in international projects. The MVD provides a handle on which data are important, at what stage and how they should be added to the model. Overall, the aim is to have a smoother workflow for the heritage domain using BIM.

Since conservation and restoration plans and guidelines based on analyses are usually prepared by cultural anthropologists and ethnologists, who are not proficient in using geometry-creation tools such as CAD/BIM packages, the workflow suggested in this article would be greatly improved if all of the data that is added to the model (in our case with Revit software) could be added directly in the IFC with a tool such as the Blender add on, which is free and open source. In this case, it would be simpler and quicker to adopt the skills that would lead anthropologists and ethnologists to use such a method of communication more easily.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.culher.2022.02.005.

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