

# A NEW WORKFLOW FOR CREATING HBIM MODELS: LINKING POINT CLOUDS AND AUTO-GENERATED POINTS OF INTEREST USING UNITY FOR EXTENDED REALITY-COMPATIBLE METADATA MANAGEMENT

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## Abstract

To digitally preserve and make historically significant buildings accessible, virtual museum tours and other customised applications are currently being developed at the great expense of time. This paper proposes a simple and handy workflow that makes it possible to automatically enrich any 3D model with freely available metadata about the site. Within the game engine Unity, an API searches internet database entries based on the coordinates of the cultural site. The search results (various media types) are reflected in the 3D model. Using Extended Reality, such an HBIM model can quickly be made available to the public.

## Introduction

The historical heritage of humanity is at constant risk of damage or destruction from natural disasters and armed conflicts. The recent destruction of the ancient site of Palmyra, Syria by the Islamic State showed that the physical preservation of such sites cannot be taken for granted. To digitally preserve and make accessible historically significant buildings, virtual museum tours and other customised applications are currently being developed at the great expense of time. Furthermore, there is no standardised workflow; rather, a different procedure is chosen for each building.

In this paper, we first give an overview of the fields of action in HBIM with particular regard to the desired level of detail and the participation of the public, which has become more of a focus in recent years. This is followed by a summary of the general steps in creating an HBIM model. In the following analysis, metadata management is highlighted as a process that has hardly been standardised so far. This is due to the heterogeneity of all possible buildings considered for HBIM and the individual availability and type of metadata such as texts, photos, or videos in each case. Therefore, this paper focuses on automated metadata management.

We propose a workflow in which metadata does not have to be entered manually in a time-consuming way. Instead, public internet databases are automatically searched for building-related information using an application programming interface (API) and the known coordinates of a building. For this purpose, we suggest the API of OpenStreetMap as well as the Google Places API. A call

is most likely possible from a game engine (the workflow is based on Unity) and the found data can then be attached to the 3D model. This workflow makes it possible to involve the general public in creating an HBIM model and to relieve experts, which means that more buildings can be digitised in total. In this paper, we limit the extent to the outer sides of buildings (the building itself), but it can be extended to the inside as well. Due to the use of a game engine, processing an HBIM model using Extended Reality (XR) is uncomplicated. We illustrate the functionality of the API using the example of the *Einhardsbasilika* in Michelstadt, Germany, a Carolingian church building from the 9th century. In the conclusion, we summarise the advantages and disadvantages of the proposed workflow.

## Why HBIM?

The term *Heritage Building Information Modelling* (HBIM) emerged in the 2000s as a distinction from *Building Information Modelling* (BIM), when BIM evolved from Computer-aided Design (CAD) (Counsell & Arayici 2017). Occasionally, the ‘H’ of HBIM is understood as an acronym for ‘Historic’ (see (Murphy et al. 2009)).

Counsell & Arayici (2017) describe the fundamental stages of development in the early days of HBIM. Initially, only wireframe representations were possible. In 1995, the first significant use of Virtual Reality (VR) takes place for the reconstruction of the Lascaux caves. Based on the UNESCO conferences in the early 2000s (e.g. ‘Heritage Management Mapping, GIS and Multimedia’ in 2002), it becomes clear on the one hand how much HBIM was derived from geographic information systems (GIS).

On the other hand, the ‘Charter for the Preservation of Digital Heritage’ adopted in 2003 pushes the integration of external media (texts, databases, videos, audios, software, ‘Web 2.0’). In 2012, UNESCO renewed this approach with the idea of creating a 3D reference system for all kinds of cultural sites through HBIM, which would allow filtering and analysis of information (Counsell & Arayici 2017). Littlefield (2017) considers the relevance of these external media types to be the biggest difference between HBIM and BIM. Furthermore, HBIM’s claim is to also make the non-existent, implicit (knowledge)

visible and to create space for different meanings and interpretations.

Referencing building-related and not directly building related data in an HBIM model is a challenge. Littlefield (2017) mentions cross-referencing between a building in the form of point clouds and other site surveys, remembrance projects (e.g. the spoken word) and supplementary archive material as a possible example. In terms of the best possible preservation and adequate representation of the cultural heritage, such a far-reaching approach would be desirable, but technically difficult to implement.

Edwards (2017) provides a pragmatic argument for the increased use of HBIM. It points to the supportive role of HBIM for traditional heritage conservation, according to which in the United Kingdom barely 800 people with heritage expertise are entrusted with the management of nearly 600,000 legally protected listed buildings. In summary, there is great potential for the automation of heritage management while maintaining quality and authenticity.

### **Depth of detail in HBIM**

Counsell & Taylor (2017) emphasise that understanding a model as a simplification of reality is a central issue in HBIM. Analysis, filtering, and sorting out of information takes place in all work steps to create an HBIM model, which is why the later use of an HBIM model must be kept in mind early on. Hichri et al. (2013) point out that historic buildings, in contrast to modern buildings, consist of irregularly shaped components that can hardly be derived from a predefined component catalogue as in BIM. This procedure, which is widespread in BIM, can at most be applied at the level of spatial and urban planning in HBIM, since here the geometrically correct shape of buildings is not the main focus and their cubature can be represented in a simplified way. Adding semantic information using labels or the geometric modelling of individual components using Non-Uniform Rational B-Splines (NURBS) can be alternative solutions (see Banfi (2020)).

An HBIM model does not always focus on visual representation. In a large-scale context, geo-referencing is sufficient, whereby information is not linked to individual components but to coherent parts of a structure (Counsell & Taylor 2017).

### **Participation of the public**

Participation plays an important role in HBIM (in contrast to BIM, as noted by Counsell & Taylor (2017)). Those responsible for the reconstruction and (digital) archiving of cultural heritage are experts, but the target group in the broadest sense is the general public. This results in a communication flow that demands more participation and inclusion than, for example, a BIM project work with a defined start and endpoint. Counsell & Taylor (2017) highlight participation using the example of online mapping services, where geo-referenced information can

be entered by anyone. In this way, non-experts become knowledge distributors, though there is always the question of the validity of the contributed information.

Although the information would predominantly refer to 2D, because of low-cost technologies (such as smartphones with integrated sensors, cardboard VR and augmented reality (AR)) it is only a question of time until three-dimensionality comes into focus. Corresponding tools such as Street Views from Google could pave the way for a new level of active public involvement in HBIM. Dewidar (2017) calls this involvement of nonexperts such as local communities and other volunteers 'participatory sensing' and emphasises the role of social media platforms for coordination and communication.

### **HBIM modelling**

The individual steps of modelling an HBIM model are not standardised. Rather, they are subject to the respective requirements of a cultural heritage and further project related boundary conditions such as the project scope, financial possibilities and expertise. Banfi (2020), as an example, distinguishes between four phases:

1. Data collection
2. Scan-to-BIM process
3. Information mapping
4. Information sharing

Pocobelli et al. (2018) compare similar phases for modelling heritage buildings with BIM processes and identifies discrepancies between the standardised BIM process and various approaches in HBIM that are adapted to the respective use case.

With progressive digitisation, certain developments can be observed in all phases. While analogue maps and photographs used to play an important role in data collection, CAD-generated plans and supplementary media types such as audio and video files now play an important role. In the area of data collection, the recording techniques have changed. In addition to the classic terrestrial laser and photogrammetry, drones are increasingly being used, which can record the entire cubature of a building within a short time with extreme precision. The intersection to the step of information mapping is represented by the conversion of the recorded point clouds into a 3D model using suitable software such as Autodesk ReCap, Metashape, Pix4D, or Faro Scene. There are modelling techniques concerning grades of generation (GOG) and grades of accuracy (GOA) for detail accuracy, as they are also known from BIM with the levels of detail (LOD) (Pocobelli et al. 2018). For the conversion to a 3D model, it must be considered whether this is primarily used as a whole for visualisation or must be subdivided granularly into its components. In the transition to the last phase, information sharing, the question arises about the storage and retrieval of metadata, i.e. all data associated with a heritage. Concepts of persistent storage often reach their technical limits (see Banfi et al. (2019)), but are often aspired to, as this allows

information to be specifically linked to individual building components. This contrasts with approaches to outsource metadata to external databases and retrieve it in a targeted manner. Information sharing itself has changed considerably with the development of the internet, freely accessible knowledge databases and the spread of VR and AR. This means that HBIM models can theoretically be made available to an unlimited number of users, with varying degrees of interaction or input, and for a wide range of devices.

### **Analysis**

It becomes apparent that the path to an HBIM model is not a uniform process. The mentioned works of other authors differ from each other in their approach, especially in the area of the software and interfaces used. This is due to the respective use case, the desired level of detail and the hardware, software, and programming skills available at all. It can be stated that the early phases of model creation, starting with data acquisition through terrestrial laser scanning, photogrammetry, or aerial photography, is well researched (see Pocobelli et al. (2018)). This also applies to the field of data processing, i.e. the conversion of point clouds to a 3D model (see Hichri et al. (2013) and Brumana et al. (2019)). There is most need for research in the later phases, i.e. in the enrichment of a building model with metadata, its visualisation, and the inclusion of heterogeneous user groups.

The authors themselves point to several problem areas: Pocobelli et al. (2018) call for the development of tools to store and share metadata (which is insufficient in an (H)BIM model alone). They point to other authors such as Micoli et al. (2013) and Pauwels et al. (2013) who suggest the use of game engines such as Unity and Unreal. Through them, metadata should be accessible with one click. In recent publications (see Banfi et al. (2019), Banfi (2020) and Banfi & Previtali (2021)), the Unreal engine is often used for this purpose. For users without programming knowledge, this game engine offers a wide range of out-of-the-box possibilities in the area of navigation (e.g. as first or third person) and visualisation (natural and artificial lighting). In addition, game engines allow the rapid implementation of a multi-device application (VR/AR/second-screen/desktop application).

A disadvantage of game engines is that metadata and other information related to a building must be entered manually. Due to the different media types (photos, videos, texts, ...), different user interactions and interfaces have to be implemented, which may be time-consuming.

### **Heritage sites are diverse**

In the following section, two very different heritage sites are described. Based on them, a workflow will be developed, which results both from the analysis in the previous section as well as from the demand to create a workflow for as many use cases as possible.

### **Einhardsbasilika**

The Einhardsbasilika is a building of Carolingian origin in Michelstadt, south of Frankfurt am Main. It is considered one of the best-preserved Carolingian buildings in Germany. It was built in the 9th century AD as a three-nave basilica and was rebuilt or extended several times in the following centuries. It is an example of a single building that has changed constantly over time depending on its use (church, monastery, warehouse, museum). Much of this change is well documented, for example in documents and drawings (Staatliche Schlösser und Gärten Hessen 2022).

### **Palmyra**

Palmyra is an ancient oasis city in present-day Syria with UNESCO World Heritage status. It flourished as a trading city under Roman and Persian rule until the 3rd century. The complex extends over a large area and includes numerous buildings, each with its individual architectural and cultural history. Tourist development did not take place until the 20th century, until then there were no major changes to the townscape. In 2015, large parts of Palmyra were destroyed and looted by the Islamic State (UNESCO World Heritage Centre 2022). Since then, efforts have been made to make Palmyra accessible to the public again, at least digitally, based on data recordings shortly before and after the destruction.

### **A new approach**

The Einhardsbasilika and Palmyra illustrate that heritage sites differ greatly in their construction history, size and number and type of metadata. The previous analysis has shown that there is no uniform concept for the management of metadata so far, and rather a new approach has been chosen for each building. In particular, the maintenance of metadata and its visualisation have so far proven to be cumbersome and time-consuming. Therefore, we propose a workflow to quickly and easily link metadata from heritage sites of different types to the respective building. We emphasize that our approach does not depend on the current condition of the building, since the goal is not to refine or digitally enhance the as-built state. Instead, the approach concentrates solely on the quantity and quality of the available metadata. Specifically, the workflow should have the following characteristics:

- Compatible for structures and building complexes of all sizes
- The possibility of involving non-experts
- Traceability of the working method to preserve authenticity
- Flexible handling of metadata
- Only initial programming effort
- Simple model maintenance, if necessary
- Simple multi-device approach
- Uncomplicated visualisation using XR

## Proposed workflow

### Development environment

We propose the game engine Unity as development environment for realising the workflow. Although the Unreal Engine is widely used in HBIM for visualisation, this is not the case in BIM. Here, Unity is often used, which is mainly due to its easy extensibility through C# scripts and numerous plugins. In addition, the visual programming often used in the Unreal Engine has narrow limits in terms of transparency and extensibility.

The general recommendation to use a game engine can be derived from other authors. Statham (2019) compared platforms that are suitable for the visualisation of 3D building models in the context of HBIM, public participation, and the guidelines of ICOMOS and UNESCO on heritage management. In summary, a wide range of metadata can be stored in game engines because of the high level of customisation. Platforms such as *3DHOP* and *Sketchfab* are therefore mainly suitable for visualisation alone. Other platforms such as *Google Arts & Culture* (GAC) are specifically designed for heritage sites and offer curatorial tools, for example, but can hardly be customised, especially in the area of user participation. In game engines, this is possible, but requires an initial programming effort.

### Procedure

The analysis shows that there are already numerous established procedures in the field of HBIM to make buildings accessible to interested parties or to conserve them. However, the manual effort of post-processing the recording (especially for laser scans) is very high and there is a lack of automation approaches. The approach presented in the following is intended to provide technically less experienced end-users an easier access to the digitisation of buildings worth preserving. Depending on the use case (for example, if the interior of a building is also to be considered), iterative workflow steps and branched procedures are also conceivable.

The proposed workflow should provide a way of recording and digitising individual buildings as well as entire ensembles and enriching them with information. The focus here is not the accurate recording of the smallest details, but much more the economic preservation and digitisation of existing buildings for interested parties as well as for sustainable documentation.

Due to the high costs and the high processing effort, laser scans are only suitable to a limited extent for the proposed use case, although the level of detail is the highest of all technologies considered. An economical and efficient option is photogrammetry. Using overlapping images, digital 3D objects can be derived and a (mesh) point cloud can be created. This methodology has proven itself in the use of drone-generated aerial photographs and might also be used here. The increase in accuracy could be further improved by using LiDAR (Light Detection And

Ranging) sensors, but this is not standard for many UAVs (unmanned aerial vehicles) and is not necessary. It is also not used in the example process described in the following.

Our proposed workflow is shown in Figure 1 and will be explained in the following.

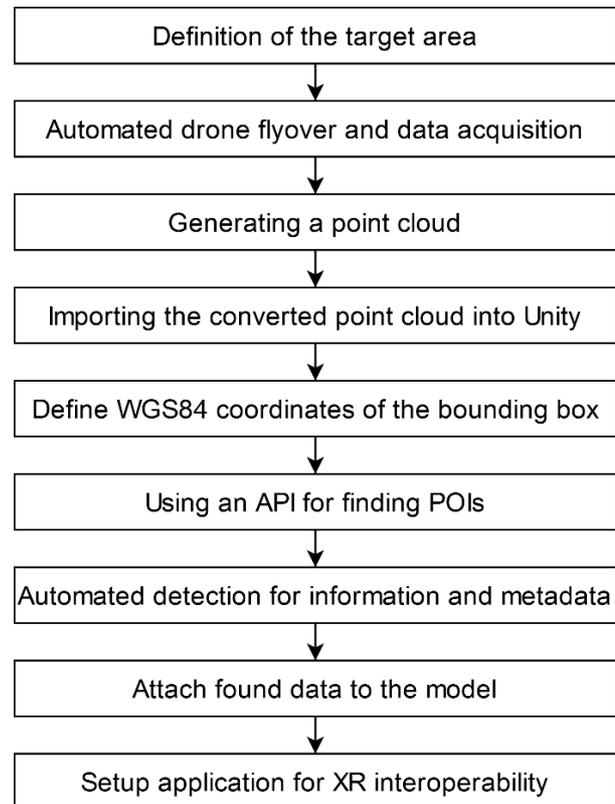


Figure 1: Proposed workflow for capturing heritage sites and attaching metadata

The workflow should be as automated as possible. It starts with defining the area to be captured, which is one of the few manually required steps in the proposed workflow. The flight planning software of the chosen drone can be used for this, for example. Often this is already offered by the pilot software of the drone, and by defining the area an automated flight route is suggested. However, areas of particular interest should be flown more closely, which is why post-processing is recommended. When planning the flight, it is also important to ensure that not only images are taken at a steep angle from above, but that flatter images are also taken to achieve a high image quality of the façade. However, it is not possible to record interiors using this methodology. Instead, it is possible to manually combine further point clouds and models of interior shots in the game engine with the exterior model. Finally, a series of photos or a video recording is the result of the aerial survey. Video recordings can be separated into images according to their FPS (frames per second, e.g. using *ffmpeg*), which can then be used for processing using photogrammetry.

The point cloud can be processed using various software such as Autodesk ReCap, COLMAP, or Pix4Dmapper. Open-source software such as WebODM is particularly suitable for the implementation of an automated workflow due to the modification possibilities. The photogrammetry process results in a point cloud with meshed textures that can then be imported into the Unity game engine (see Figure 2).



Figure 2: 3D model of the Einhardsbasilika in Unity, generated from photogrammetric data from a drone flight.

The global coordinates of the area flown over should be known from the flight planning or the flight itself. They are needed to link the data automatically with information about sites of interest. For this purpose, existing databases should be used. Various map services offer APIs for connecting external programs, which can be used to query databases. The best-known map service is Google Maps, which provides such an interface via the Google Places API, although this is subject to a fee. In contrast, the open-source project OpenStreetMap also provides access to very extensive geo-databases for free. These are used in the following examples, but other possibilities like web crawling are also conceivable. The communication with the API is fully automated by Unity.

For the communication with the OpenStreetMap databases, *Overpass turbo* is used, which provides an API (Raifer 2022). The area is bounded by defining two corner points in the WGS84 format (i.e. in the format Lat: 49.687518° (N), Lon: 8.996612° (E) for the Einhardsbasilika), thus creating a bounding box (see Figure 3). According to the interface definition of the API, it must be ensured that the coordinate points are arranged in ascending order (from south to north and from west to east).



Figure 3: Bounding box of the overflow area of the Einhardsbasilika

Within the bounding box, so-called amenities are filtered, and the result is returned in a JSON format. Below is an example of an HTTP request for filtering all points of interest within the bounding box, as an Overpass turbo request (Listing 1) as well as a cURL query (Listing 2). All points of interest (POIs) such as bars, restaurants, churches, but also park benches and cash machines are summarised under the term amenity. Filtering for meaningful POIs is possible within the Unity application.

```
[out: json][timeout:25];
(
  node["amenity"](49.68699,8.99648,49.68806,8.99739);
  way["amenity"](49.68699,8.99648,49.68806,8.99739);
  relation["amenity"](49.68699,8.99648,49.68806,8.99739);
);
out body;
>;
out skel qt;
```

Listing 1: Overpass turbo request

```
curl --location -g --request GET
'
  http://overpass-api.de/api/interpreter?data=
  [out: json][timeout:25];
  (
    node(49.68699,8.99648,49.68806,8.99739)["amenity"];
    way(49.68699,8.99648,49.68806,8.99739)["amenity"];
    relation(49.68699,8.99648,49.68806,8.99739)["amenity"];
  );
  out;
```

Listing 2: cURL request

Listing 3 represents the result of the queries. The result was requested here in JSON format, but other formats such as XML are also possible.

```

{
  ...
  "elements": [
    {
      "type": "node",
      "id": 8328057310,
      "lat": 49.6869960,
      "lon": 8.9970203,
      "tags": {
        "amenity": "bench",
        "backrest": "yes"
      }
    },
    {
      "type": "way",
      "id": 40284751,
      "nodes": [
        485959176,
        2026914143,
        2026914140,
        ...
      ],
      "tags": {
        "addr:city": "Michelstadt",
        "addr:postcode": "64720",
        "amenity": "place_of_worship",
        "building": "yes",
        "historic": "building",
        ...
        "wikidata": "Q1307629",
        "wikipedia": "de:Einhardsbasilika (Steinbach)"
      }
    }
  ]
}

```

Listing 3: Result as JSON

The result of the request can then be interpreted and further processed within the Unity application. Depending on the amenity type, the POIs are categorised into nodes (small objects such as benches), *ways* (larger objects with an outline), or *relations* (grouping of individual objects).

The result is then searched for relevant POIs. If these are found in the flight area, a maker can be automatically set in the application, for example. Depending on the complexity of the amenity, the position of the maker is contained directly within the element description, as in the case of nodes (latitude and longitude), or in the form of sub-nodes (as in the case of amenities of the type *way*). For more complex structures, they define the outline shape. For each sub-node, the coordinates can be retrieved separately or are already included in the query. In our example, the Einhardsbasilika is located in the flight area and has the type *way*. Further information such as the address, the amenity type (here: place of worship) and the link to a Wikipedia article is also included. If the link to a Wikipedia article exists, it is linked to the marker in Unity.

By using Unity, preparing the application for XR for a non-expert end-user is easily possible. If, as in this example, a user clicks on the perimeter of the basilic or enters it in an immersive XR environment, the linked Wikipedia article is displayed and/or read aloud. Wikipedia represents here only one data source of possible information possibilities. Based on the name of the object, web searches are also possible and other sources, such as YouTube, can be integrated into the application. This is also possible for building ensembles such as Palmyra. The more sources that can theoretically

be accessed, the more important it would become to provide the user a possibility to pre-select data sources and types.

## Discussion

The literature research shows that there are already several approaches using modern technologies to create HBIM models of historic buildings and ensembles. This makes sensitive or hard-to-reach places accessible to the interested public. However, it also became apparent that this process involves a great deal of manual and time-consuming post-processing, especially concerning the persistent storage of metadata. Therefore, an automated workflow was proposed in this work, which makes it possible to automate the conventional approach to a large extent. Especially the enrichment of the HBIM model or the point cloud with general information can be carried out in a fully automated way and the challenge of persistent storage can be solved by linking external data. The feasibility of the approach to link geo-referenced information was demonstrated using the OpenStreetMap API and the Einhardsbasilika in Michelstadt, Germany.

In addition, the potential of the Unity game engine in the HBIM area was demonstrated. Due to the somewhat higher initial programming effort compared to the otherwise mostly used Unreal game engine, programming knowledge is required for the setup. However, by specifying API calls, it is possible to create an application that an end-user can use without programming knowledge. This also applies to the visualisation using XR. The type of visualisation and the desired user interaction only need to be specified once. The following assignment of content and its placement in the model based on the coordinates can be carried out automatically.

Finally, it should be kept in mind that the workflow is a technical proposal that does not allow any statement about the quality of the linked information. To increase the reliability of the linked information, the origin of the metadata sources should be indicated, so that the user can evaluate the quality for themselves. As an alternative, it is also conceivable to use the API to access a separate server that only certain people or experts can access and enter content. Linking the data (as opposed to persistent storage) also requires a permanent internet connection to retrieve the data and stream any linked videos.

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