heritage

MDPI

Article

A Systems Thinking Approach to the Development of HBIM: Part 1—The Problematic Situation

Lucy J. Lovell *, Richard J. Davies and Dexter V. L. Hunt

School of Civil Engineering, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK; r.j.davies.1@bham.ac.uk (R.J.D.); d.hunt@bham.ac.uk (D.V.L.H.)
* Correspondence: ljl848@student.bham.ac.uk; Tel.: +44-7780720439

Abstract: Building Information Modelling (BIM) is an information management and modelling technique frequently employed by the Architecture, Engineering, and Construction (AEC) sector. The application of BIM to Cultural Heritage (CH), otherwise known as Historic BIM (HBIM), will assist with the ongoing sustainable management of CH. However, the application of HBIM is currently limited by a lack of defined end-user requirements and standard methodology in its application. To address this, the authors propose a systems thinking approach, utilising both the Soft Systems Methodology (SSM) and hard Systems Engineering (SE), for the development of HBIM. Subsequently, this paper presents the results of an extensive survey undertaken with the United Kingdom (UK) Heritage Community to identify challenges faced by the CH sector and utilises the SSM to propose the core purpose of HBIM within the CH sector. The responses to the survey suggest that the development of HBIM should prioritise the promotion of structured information management instead of the generation of detailed geometric models, a key theme of much existing research. Future work by the authors (Part 2 of this work) will continue the analysis of the survey results and utilise SE processes to define end-user requirements for HBIM.

Keywords: HBIM; cultural heritage; BIM; system engineering; soft systems methodology

check for updates

Academic Editors: Marcello La Guardia, Mila Koeva and Mauro Lo Brutto

Received: 8 November 2024
Revised: 19 December 2024
Accepted: 1 January 2025
Published: 9 January 2025

Citation: Lovell, L.J.; Davies, R.J.; Hunt, D.V.L. A Systems Thinking Approach to the Development of HBIM: Part 1—The Problematic Situation. *Heritage* **2025**, *8*, 21. https://doi.org/10.3390/heritage8010021

1. Introduction

1.1. Historic Building Information Modelling

Building Information Modelling (BIM) is an information management and modelling technique frequently employed by the Architecture, Engineering, and Construction (AEC) sector. It typically consists of a 3D model of an asset semantically enriched with additional information. The application of BIM to Cultural Heritage (CH), otherwise known as Historic BIM (HBIM), could assist with the ongoing sustainable management of CH, and contribute to the United Nations (UN) Sustainable Development Goal (SDG) 11 (Sustainable Cities and Communities [1]) by providing an enduring record of CH, and by improving resource efficiency. However, the application of HBIM is currently limited by a lack of defined requirements and standard methodology [2].

There has been extensive research undertaken into the application of HBIM to CH since it was first suggested by Murphy et al. [3] in 2009. However, previous reviews of the prevalent trends in both HBIM specifically [4–8] and BIM for existing structures [9] have revealed a strong focus on accurate 3D model creation. This trend has remained consistent as evidenced by more recent reviews, which either focus solely on model creation and reality capture techniques [10,11] or identify a bias towards studies investigating model creation [2].

Checkland and Howell [12] propose that in any developing field, real practice and available technology often outpace the theory behind it. This can be observed in the field of HBIM where, whilst advances in modelling and data storage techniques are rapid and continual, the understanding of why techniques are developed is, as yet, ill-defined [8]. For instance, in a 2019 article, Ewart and Zuecco [8] reviewed HBIM case studies and found they could not identify any clear justifications for why each case study was conducted.

MIDAS Heritage [13], an existing historic environment data standard, states that "a familiarity with emerging technologies for the production, presentation and dissemination of computerised information will assist users, but specifics are not covered by MIDAS Heritage. Instead, it focuses on the text information stored in information systems. Without such standards new technologies can do little more than present bad data in a deceptively good way". Without similar standards for HBIM, and continuing the current trend to prioritise the technology beyond all other attributes [8], HBIM risks providing no tangible value to information management within the CH sector.

Moreover, HBIM is an information system, which is defined by the National Institute of Standards and Technology (NIST) as "a discrete set of information resources organized for the collection, processing, maintenance, use, sharing, dissemination, or disposition of information" [14]. The quality of an information system and the associated value that it provides is dependent on whether it is fit for purpose [15] and whether it satisfies the end user needs [16–18]. However, the required purpose of HBIM is currently undefined.

Furthermore, a lack of clarity and cohesion in the purpose of HBIM will likely result in the same problems being recurrently solved in differing ways by individual teams, which will consequentially hinder the generation of a consistent framework for HBIM application. This is a risk associated with the advent of any digital technology for the CH sector and is acknowledged by existing Heritage Management conventions, such as the Faro Convention [19]. As such, there is a need for a more structured definition of the purpose of HBIM.

The problems associated with HBIM are succinctly summarised by Ewart and Zuecco [8] who state that "we do not know what HBIM is, who it is for, or why it would be used".

1.2. Systems Thinking

1.2.1. Justification

Given the need for a more structured definition of HBIM, the authors have adopted the use of a systems thinking approach to the development of an HBIM standard, an approach which, to the best of their knowledge, has not been proposed for HBIM previously. Systems thinking is defined by the International Council on Systems Engineering (INCOSE) as "a way of thinking used to address complex and uncertain real-world problems. It recognises that the world is a set of highly interconnected technical and social entities which are hierarchically organised producing emergent behaviour" [20]. Whilst novel to the field of HBIM, systems thinking has previously been proposed as an aid for infrastructure projects [15], which are broadly similar in complexity to Heritage Management. Moreover, Heritage Management is known to consist of many inter-related attributes and requires the input of many stakeholders from different sectors [6].

Furthermore, systems thinking has been proposed for other digital information management developments. For instance, the Centre for Digital Built Britain (CDBB) posited systems thinking as necessary for the creation of a National Digital Twin, a series of interconnected digital twins with a connected network of shared data [21]. Since the CDBB was a partially United Kingdom (UK) government-led initiative [22], adopting their recommendations should support the alignment of HBIM practices with wider digital information management developments within the UK, the region in which this research is undertaken.

Moreover, the CH sector may be better positioned to achieve the long-term goal of the CDBB, which is the creation of a National Digital Twin. Whilst the CDBB concluded that a connected digital system will only arise when "high quality data [can be shared] securely and resiliently across organisational and sector boundaries" [23], the CH sector may be culturally more able to adopt this. Firstly, it is generally accepted that CH is a shared societal resource and responsibility [24]. Thus, much information and data regarding heritage are already made freely available. An example of this in practice is the Historic Environment Records (HERs), described as "information services that provide access to comprehensive and dynamic resources relating to the archaeology and historic built environment of a defined geographic area" [25]. Whilst the systems are usually managed by local authorities, HERs are public resources. There are also a number of projects actively encouraging greater public contribution to these systems. For instance, the 'Know Your Place' project [26] allows members of the public to add their own heritage data to a public resource.

Furthermore, much CH management is carried out by building preservation trusts and charities, as opposed to purely commercial entities, meaning there may be fewer issues regarding organisational willingness to share proprietary data. Therefore, the cultural acceptance of more open data might be theoretically easier to achieve, although there may still be some limitations caused by proprietary data sources. A notable development that occurred during the production of this article, and which reinforces the authors' belief that the CH community is the best place to achieve the goals of the CDBB, was the public launch of the Arches for HERs platform in the UK [27]. The Arches for HERs platform is an open-source platform designed for data management and visualisation in the CH sector. Whilst this has many similarities to HBIM systems, the visualisation capabilities of the Arches platform are provided via integration with Geographic Information Systems (GISs), which provide wider location data. GIS and HBIM technology integration is currently limited by a lack of interoperability [28,29] and there is ongoing research to address this [30,31].

1.2.2. Applying Systems Thinking to HBIM

Systems thinking is a diverse term that encompasses many, sometimes contradictory, ways of thinking. Given the over 100 years of research into systems thinking, it would be impossible within the scope of this article to detail all the divergent disciplines within the systems thinking field. For an interesting work that provides some insight into the field, the authors refer readers to Ramage and Shipp [32]. Therefore, it is necessary to explain here what systems thinking approaches will be applied to the development of an HBIM standard. These can be broadly categorised as the Soft Systems Methodology (SSM) [33] and 'hard' Systems Engineering (SE) [34]. This paper (Part 1) will detail the application of the SSM to HBIM development. Part 2 will address the application of SE to HBIM development.

The SSM was first developed in the 1970s [35,36] and has been pioneered primarily by Lancaster University in the UK [12,32,37]. The main difference between SE and the SSM is that SE ignores worldviews and sees the world as systemic, e.g., an entity or situation has known boundaries and relations and can be explicitly defined. Whereas the SSM accounts for the influence of differing worldviews and approaches the process of learning as systemic as opposed to the world itself [38], e.g., real-world experiences are complicated and influenced by lived experience and thus cannot be explicitly defined but the methodology used to investigate a situation can be.

Whilst the SSM originated as a set of defined actions [33,35,39], it is now better described as a set of principles that can be adapted and applied to differing systems as needed [38]. The SSM is, in principle, an almost philosophical approach aimed at linking ideas with human experience [12]. Its use within the development of information systems is well established [12,32,37] yet the SSM still has its critics within the 'hard' systems thinking field. In order to link the concept of human experience, the SSM studies involve the engagement of actors (stakeholders) associated with a problematic situation. Stakeholder involvement with HBIM development is rare in the available case studies [8,11], with the notable exception of Liu et al. [40] who utilise stakeholder requirements to define the Level of Development guidelines for heritage assets.

The SSM is useful for structuring reflections on a problematic situation, of which CH management is arguably one. Differing worldviews result in differing implicit assumptions about a problematic situation, which may not be evident to outside entities. Whilst there is a difference between a study conducted with the intentional use of the SSM and a study that happens to use the SSM, this does not mean the latter is not useful [33]. There is a concept of the "internalised SSM" where thinking is carried out automatically but reflections are conducted using the SSM language, which helps to structure debate. Within the context of this research, the SSM has been applied retrospectively.

Within the SSM, a purposeful activity is an action taken to improve a problematic situation. In this case, the problematic situation is the management and maintenance of Cultural Heritage. The aim is to improve a situation rather than solve a problem, hence the use of the term problematic. The SSM consequently involves the definition of the core purpose/essence of a purposeful activity system, in this case, the application of HBIM to the management and maintenance of Cultural Heritage, known as a root definition [33]. Checkland and Scholes [33] suggest the simplest root definition involves "a system to do X by Y in order to achieve Z" where X is the what, Y is the how, and Z is the long-term aim.

In this way, the SSM can be used to define the core purpose of HBIM with regard to CH management. The SSM has been applied for this purpose for other information systems and there exist a number of case studies detailed by Checkland and Holwell [12]. Consequently, this will contribute to the mitigation of the current problems outlined in Section 1.1. Further details of how the SSM has been applied to this research are detailed in Section 2.3.

1.3. Aim and Objectives

The intention of this paper is to investigate the 'problematic situation' (the management and maintenance of built Cultural Heritage) as experienced by the Heritage Community. The Faro Convention defines the Heritage Community as "people who value specific aspects of cultural heritage which they wish, [. . .], to sustain and transmit to future generations" [19]. This research engages a subset of the Heritage Community involved in the management and maintenance of built heritage within the UK.

The aim of this paper is to utilise the SSM to answer the questions 'what is HBIM, who is it for, and why would it be used?'. As such, this paper can almost be considered a direct response to the work of Ewart and Zuecco [8].

The objectives of this study are as follows:

1. Establish how data are currently managed within the Heritage Community.
2. Establish both current working practices within the Heritage Community and organisational features that may impose constraints on an HBIM system.
3. Identify how participants perceive HBIM and how they would envision using it if it were available.
4. Propose a root definition of HBIM.

The research recorded in this article is focused on the experiences of the UK Heritage Community. Future stages of the work will expand the scope of the research (see Section 1.4).

Whilst this paper only explicitly addresses the SSM element of systems thinking (SE is applied directly in Part 2 of this paper series), the content of this paper has a direct application to the wider SE approach. Within the SE process of systems design, there are the concepts of system verification and validation. This is explained by INCOSE as "verification ensures you built the system right. Validation ensures you built the right system" [37]. A system can only be considered valid if it behaves as expected in its intended environment and achieves the desired purpose. The authors believe that without defining the core purpose of HBIM, achieved herein with the SSM, it will not be possible to validate any proposed HBIM system. This must be defined before any requirements can be defined. Furthermore, a 2007 article by the Royal Academy of Engineers [15] states that "true requirements are based on a full understanding of what the stakeholders are seeking to achieve—the underlying needs, how the systems will be used and in what environment". The content of this article seeks to provide this understanding. Hence, whilst the requirement definition element of SE is detailed in Part 2 of this study, Part 1 also directly attributes to the SE approach.

1.4. Research Context and Previous Work

1.4.1. Research Context

This section provides a brief overview of the ongoing study being undertaken by the authors. For a detailed account of previous work undertaken, please refer to Section 1.4.2. The overall intention of this study is to aid the standardisation of the application of HBIM to CH. The scope is intentionally broad, encompassing CH as a whole. The reason for this is that the authors believe that the tendency to focus on specific HBIM use cases leads to too many disparate approaches and is detrimental to the practical application of HBIM. This is discussed in greater detail in Lovell et al. [2]. Furthermore, all existing BIM standards (e.g., ISO 19650 [41], etc.) make no distinction between the type of asset to which BIM will be applied. It has been suggested that it is a lack of standardised procedure that most severely limits the field of Asset Management as a whole [42]. So, whilst it is true that, for instance, applying HBIM to a historic church may differ considerably from applying HBIM to naval heritage, this difference is no more considerable than applying BIM to a new hospital as opposed to a new office building. The authors believe the purpose of an HBIM standard is to act as a guiding framework that can be adapted as needed for a specific use case. This is the same purpose of the ISO 19650 [41] standard for BIM for new construction.

Figure 1 is a simplified depiction of the ongoing study being undertaken by the authors. Stages 2 and 3 are encompassed by Part 1 and Part 2 of this research. The discussion below details key activities, their scope, and general motivation. Its inclusion is necessary to address potential limitations with the research presented herein.

This study involves the following key activities, which correspond to the numbered items in Figure 1:

1. This stage has two key activities. The first activity was a literature review of 178 articles on HBIM to determine the current state of the field [2]. The second activity involved reviewing academic literature, grey literature, and published standards to evaluate different ways of working with Cultural Heritage and to identify theoretical information requirements for HBIM [43,44]. Stage 1 of this study had an international scope. See Section 1.4.2 for more details.
2. Stage 2 involves distributing a survey to members of the UK Heritage Community and evaluating their responses. The survey encompassed over two hundred questions

and contained many free-form answers. Hence, the scope was intentionally limited to ensure the feasibility of analysing all responses with the limited resources available to the investigators.

3. Stage 3 involves employing SE processes to define system requirements in response to the survey responses. This has been completed and will be detailed in Part 2 of this research.
4. Stage 4 involves recirculating the proposed HBIM system requirements to other members of the Heritage Community. The intention is to broaden the scope of the research to an international context. This will help identify any region-specific variations or variations due to asset type. It will also gather perspectives that may have not been encompassed by Stage 2 of the research. The member feedback will be used to validate and adapt the proposed requirements as needed.
5. The final stage of this study being undertaken by the authors will involve the comparison of the validated requirements with available technology (Stage 5a) and the existing standards and literature (Stage 5b). This will enable the authors to make recommendations as to how standards should be adapted for HBIM and how the proposed requirements can be achieved in practice.

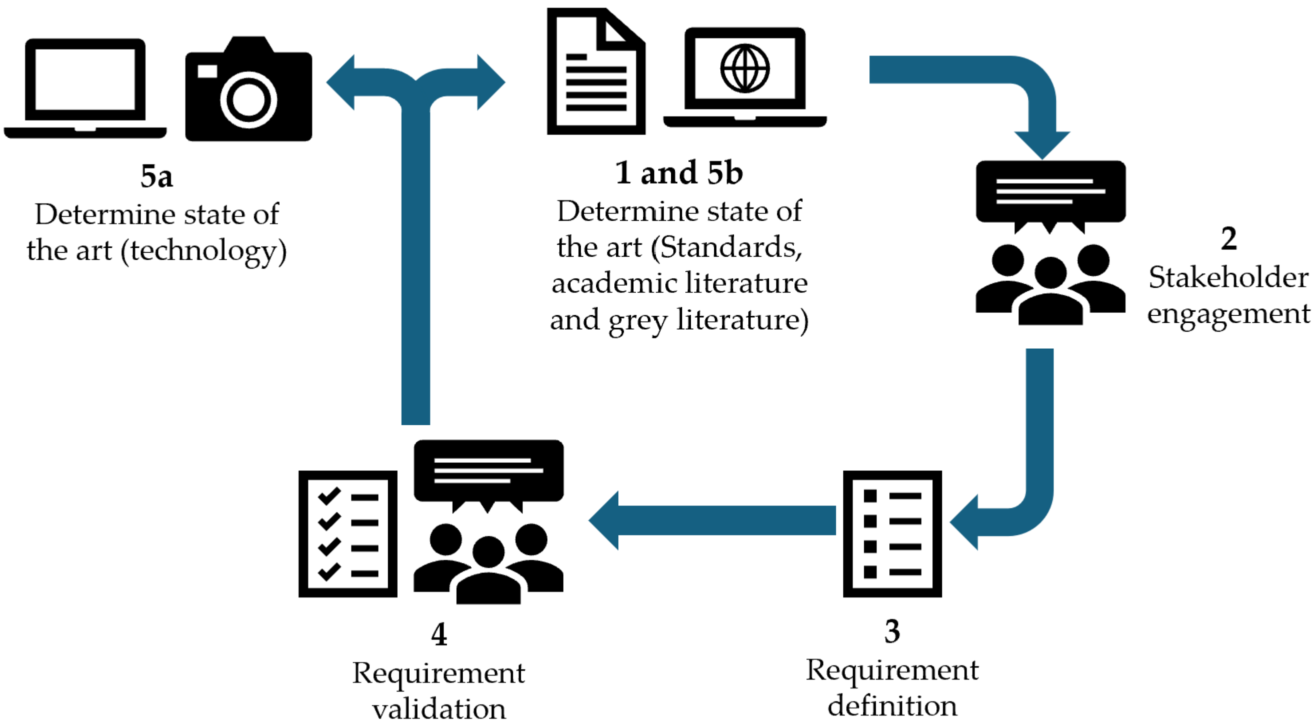

Figure 1. A pictorial representation of the ongoing study this article is a part of.

As previously mentioned, the theory associated with developing technology often lags behind its practical use [12], e.g., the 'how?' is established before the 'why?'. Therefore, it is to be expected that others will have already developed methods for achieving the proposed requirements. The intention of this work is not to claim to be the originator of any such method, it is only to provide evidence to justify why a method should be used.

Figure 1 is depicted as a cyclic approach because, although this study conducted by the authors will only complete the five stages once, the management of CH and the application of HBIM is not a static situation. To ensure the longevity of HBIM, this study should be repeated either to refine the proposals for specific use cases or to reflect any changes in the field as a whole.

1.4.2. Previous Work

In a previous work [43], theoretical information, functional, and modelling requirements for BIM-enabled Facilities Management (BIM-FM) were identified from the literature. This included the identification of six information requirement categories. Subsequently, in Lovell et al.'s study [44], a further six information requirement categories specific to HBIM were identified. The proposed theoretical information requirements for HBIM are shown in Table 1.

Table 1. Theoretical information requirements for HBIM identified by Lovell et al. [44].

Information Category	Information Requirement
Geometric surveys: This is defined as the geometric information gathered with which to create the model. These data will typically be provided by techniques such as photogrammetry or laser scanning. These techniques produce point clouds, which are a collection of thousands of points that provide a 3D representation of an area.	The geometric survey
	Details about the geometric survey, e.g., method and who carried it out
Information (data) about the fabric of the asset: This is defined as the physical material/structure that makes up the asset.	Material data, e.g., what materials are used
	Architectural data, e.g., floor plans
	Current building fabric status data
Condition assessments: This is defined as inspections of the physical condition of an asset, which can include, but are not limited to, assessments of decay or energy performance.	The raw data from the assessment
	The results and recommendations of the assessments
	Details about the assessments, e.g., method and who carried it out
Legal requirements: This is defined as any requirement that may affect your ability to carry out certain work. This may include a planning regulation (e.g., Grade Listing, etc.) or statutory document (e.g., other requirements such as conditions of bequest).	Planning regulations
	Statutory documents affecting the asset
Historical information: This is defined as archaeological data (including data about lost heritage) and major changes to an asset (not regular conservation work) over time. **It does not refer to historical significance.**	Archaeological evidence
	Changes that have occurred over time
Environment data: This is defined as more detailed data about the specific environment (or space) of an asset, which may affect its condition or performance. This may be at a large scale (e.g., a whole building) or a smaller scale (e.g., light levels in a specific room affect a specific object).	Light levels (internal and external)
	Vibration levels
	Weather
	Dust levels
	Humidity
Safety and security information: This is defined as any information related to the safety and security of the asset. This could include fire evacuation drawings, locations of fire alarms, and accessibility information such as wheelchair-accessible routes.	Fire safety
	Health and Safety (H&S)
	Potential threats/risks and vulnerabilities
	Security
	Accessibility information
Space data: This is defined as information about how the physical space of an asset is broken down and used. This may include, but is not limited to, room allocations (space breakdown), which areas are open to the public/private (space usage), occupancy limits, average footfall (visitor information), etc.	Space usage
	Space breakdown
	Visitor information

Table 1. *Cont.*

Information Category	Information Requirement
Maintenance manuals/instructions: This is defined as information provided or required to help plan and/or carry out maintenance and conservation work on an object.	Required equipment
	Minimum level of performance
	Whether the maintenance can be performed by a normal user or requires skilled personnel
	Intervention type (work required)
	Intervention frequency
	Previous maintenance including conservation history
Historical significance: This is defined as the tangible or intangible significance attributed to the importance of the asset, e.g., how it evidences a way of life/practice, architectural or structural importance, associations to notable figures, etc.	For education
	To inform management decisions
Location data: This is defined as information about the wider location surrounding the asset. This may or may not be owned by you. For example, a local river may be prone to flooding and a risk to your asset. Alternatively, it may be information about the grounds surrounding the asset itself, e.g., the boundaries of the land.	Setting of the asset (e.g., grounds)
	Nearby physical hazards
	Related assets nearby
	Other generic locational information
Objects not part of the building's fabric: This is defined as important objects not necessarily considered part of the building, which could be artistic (e.g., tapestries, artwork, sculptures, etc.) or other moveable assets (e.g., old factory machinery, furniture with a specific significance, etc.).	Moveable objects
	Artistic objects

A survey was subsequently designed to enable the wider Heritage Community to validate the proposed requirements and to contribute to the creation of a standard methodology for HBIM. The survey had two parts of which the first was intended to determine existing working practices within the heritage sector and how people involved in the management and maintenance of heritage currently manage their data. The first part of the survey asked participants about their experience working with heritage, how they currently manage heritage information, and how they would use an HBIM system if available. The second part was intended to validate the theoretical information requirements and will be covered in future work by the authors. This report will detail the results of the first part of the survey only.

2. Method

2.1. Participant Identification

Snowball sampling [45] was employed to identify participants for the survey. All participants were members of the Heritage Community (see Section 1.3), and the only inclusion criterion was that they had some experience in the management or maintenance of heritage. Within this criterion, 'management' is an intentionally broad term. Asset management refers to managing an asset at an organisational level to maintain its value in line with organisational objectives [46]. What constitutes maintaining the value of heritage is hugely case-specific and, as an example, could involve activities such as allowing a site to exist untouched, ongoing small-scale maintenance, or major interventions to adapt or reinstate an asset [47]. Therefore, within the context of this research, the director of a heritage visitor attraction may be considered equally involved in the management of heritage as a tradesperson working on an adaptive reuse of heritage project.

Whilst the exclusion criteria may appear contradictory to the definition of Heritage Community, which refers to anyone who has an interest in CH and thus encompasses other, excluded actors such as members of the public, it is individuals involved in the management and maintenance of heritage who will take on the financial and resource requirements associated with HBIM. Therefore, as also suggested by Liu et al. [40], the authors believe the insights of individuals involved in the management and maintenance of heritage are the most crucial to the early development of HBIM. Future development of HBIM may address the wider Heritage Community but this is beyond the scope of the current research.

The initial set of participants was identified from the authors' existing links to industry, and via participants' association with known heritage organisations or historical assets. Snowball sampling was used to leverage the expertise of as many different heritage experts as possible. It was correctly assumed that participants working within the CH sector would have a greater awareness of individuals and organisations who would be willing to participate, which may have not been known by the authors of this paper.

The final survey was a Microsoft Forms survey and was distributed as an online link via email. Participants were also given the opportunity to complete the survey in interview format. A total of thirty-three participants completed the survey, of which five participants undertook the survey in interview format. The questions were the same regardless of the delivery method.

Ethical approval for the survey distribution was granted by the Science, Technology, Engineering and Mathematics Committee at the University of Birmingham. All survey distribution and data storage were undertaken according to the approved application.

Survey collection occurred over a period of six months. The anonymised survey responses and a blank copy of the survey itself are openly available on the UBIRA E Data Repository and are accessible at the following address: https://doi.org/10.25500/edata.bham.00001189 (accessed on 24 October 2024).

Since the questions did not vary between the interview format and the online survey format, the responses are reported together to enable direct comparison.

2.2. Survey Reduction–Pilot Studies

During the development of the survey [44], pilot surveys were carried out with participants with no experience in either BIM or heritage to ensure the accessibility and clarity of questions and responses. The finalised survey was then made available as an interview or an online questionnaire. The questions were the same regardless of format.

A secondary pilot survey was carried out using the initial sample of participants (Section 2.1). It was found that the original survey was considered excessively long, discouraging potential participants from completing both parts. Of the fourteen participants who completed the secondary pilot, three only completed the first part and one only completed the second part. Consequently, some questions were removed from the survey, and it was reduced to a one-part online questionnaire. Since the questions were not altered, the responses from the secondary pilot questionnaire are included herein. Further discussion of the removed questions is given in later sections as appropriate.

As a result of the pilot surveys, 'translocation' was added as an additional proposed function of HBIM. Translocation is the process of moving a structure from one location to another. It is extremely rare in practice and is a highly controversial approach within the Heritage Community. In reference to translocation, the Royal Institute of British Architects (RIBA) Conservation Guide [48] states that "many would say it is not conservation at all". However, several of the participants had experience working with 'living museums', which recreate historical settings mainly via translocated structures and HBIM has been utilised by others for translocation purposes [49]. Hence, translocation was added to the survey.

2.3. Applying Systems Thinking

The SSM typically begins with the process of 'finding out' about a problematic situation and establishing relevant 'worldviews'. The 'finding out' stage applied to this research was the distribution of the survey created by Lovell et al. [44] (Section 1.4). The responses gathered from the survey that contribute to the 'finding out' stage (Section 3) were grouped into the following topics:

- Information about the participants of the survey, including their job areas and experience, the type of heritage they work with, and their previous experience with BIM (Section 3.1).
- Information regarding how data are currently managed within the Heritage Community (Section 3.2).
- Current working practices within the Heritage Community and organisational features that may impose constraints (Section 3.3).
- How participants perceive HBIM and how they would envision using it if it were available (Section 3.4).

The intention is that the responses detailed in Section 3 will grant an understanding of the problem situation (the management of CH) and will reveal worldviews that may have influenced any answers provided by the participants.

A reflection on the questionnaire results created by applying systems thinking is detailed in Section 4. As stated in Section 1.2.2, within the SSM, the root definition defines the core essence of the purposeful activity undertaken to improve a problematic situation. The creation of a root definition typically involves the consideration of elements defined by the CATWOE mnemonic [33]. These are as follows:

- **C**ustomers: Those affected negatively or positively by T;
- **A**ctors: Those carrying out T;
- **T**ransformation process: Change from input to output;
- **W**eltanschauung (or worldview): The worldview and associated assumptions that provide context to T;
- **O**wners: Those responsible for making T happen or not;
- **E**nvironmental constraints: Elements outside the system that are "taken as given".

In Section 4, the SSM is applied to define a root definition and associated CATWOE for HBIM.

The root definition is accompanied by a pictorial representation of the transformation process. The pictorial representation is a hand-drawn image presented in this article. This is an intentional choice and should not be considered detrimental to the quality of the approach. The use of hand-drawn images, similar to doodles, has been used extensively in the SSM since its inception [12,32,33,35,36,38,39] and is intended to reflect the organic nature of the method [33]. The point of modelling (representing a thing) within the SSM is to present complex realities in an accessible and understandable manner. The originators of the method acknowledge that the models are much less complex than would be needed to detail all the realities of the real world and suggest that their way of writing is "[not] of a kind that would appeal to an ivory-tower purist" [12]. However, hand-drawn, cartoon-like images have been recognised by others for their 'sensemaking' applicability [50]. They capture an honest perception of a situation without being influenced by preconceptions about the right way to do things [51].

Future work, encompassing system requirement definitions for HBIM and the second part of the questionnaire, is detailed in Section 5.

3. The Problematic Situation

3.1. About the Participants

3.1.1. Experience and Expertise

A total of thirty-three participants answered the survey. Their participant IDs, job titles and organisations (where appropriate, consent was obtained), and job areas (see Section 3.2.1) are detailed in Table 2. The participant IDs are used to refer to answers given by specific participants throughout this report. All participants were members of UK organisations.

Table 2. Participant job roles and organisations ([. . .] suggests anonymised).

Participant ID	Job Title	Organisation	Job Area
1	Museum Manager	[. . .]	GM
2	Carbon and Sustainability Manager	University of Birmingham	GM
3	Contracts Manager	[. . .]	AEC
4	Operational Programme Manager	[. . .]	GM
5	Site Engineer	[. . .]	AEC
6	Head of Service—NDSU	BCC [Birmingham City Council]	GM
7	Data Manager	University of Birmingham	GM
8	Head of Historic Buildings	Historic Royal Palaces	HM
9	Committee Member and Trustee	The Moseley Society	HM
10	Facilities Manager (Head of Facilities and Asset Management Department)	Birmingham Museums Trust	HM
11	Assistant Building Surveyor	National Trust	HM
12	Collections and House Officer	National Trust	HM
13	[. . .]	[. . .]	HM
14	Head of BIM and Digital Assets	University of Birmingham Estates	GM
15	Senior Building Surveyor	[. . .]	HM
16	[. . .]	[. . .]	HM
17	Secretary	Romsey & District Buildings Preservation Trust	HM
18	[. . .]	[. . .]	HM
19	Project Development Manager	[. . .]	HM
20	Project Manager Conserving the Historic Estate	[. . .]	HM
21	Author and Editor	[. . .]	HM
22	[. . .]	[. . .]	HM
23	[. . .]	[. . .]	AEC
24	Archaeological Illustrator	[. . .]	HM
25	Architect (Director)	Rodney Melville & Partners	AEC
26	HBIM Coordinator	[. . .]	AEC
27	[. . .]	[. . .]	AEC
28	Engineer	[. . .]	AEC
29	CEO	Heritage Lincolnshire	HM
30	Head of Infrastructure	Severn Valley Railway	HM
31	Chief Executive	Portsmouth Naval Base Property Trust	HM
32	Infrastructure Manager	Gloucestershire Warwickshire Steam Railway	HM
33	Head of Building Conservation	English Heritage	HM

GM = General Management, HM = Heritage Management, AEC = Architecture, Engineering, and Construction (see Section 3.1.2 for explanation).

Almost 75% of the participants had over ten years of experience working with heritage assets (Figure 2) and approximately 66% of the participants held positions as heads of departments or organisations. Together, the participants had experience encompassing over eighty different types of heritage incorporating eight different types of protective status. The types of heritage include, but are not limited to, historic buildings, historic parklands, stone structures, lakes, railways, and bridges.

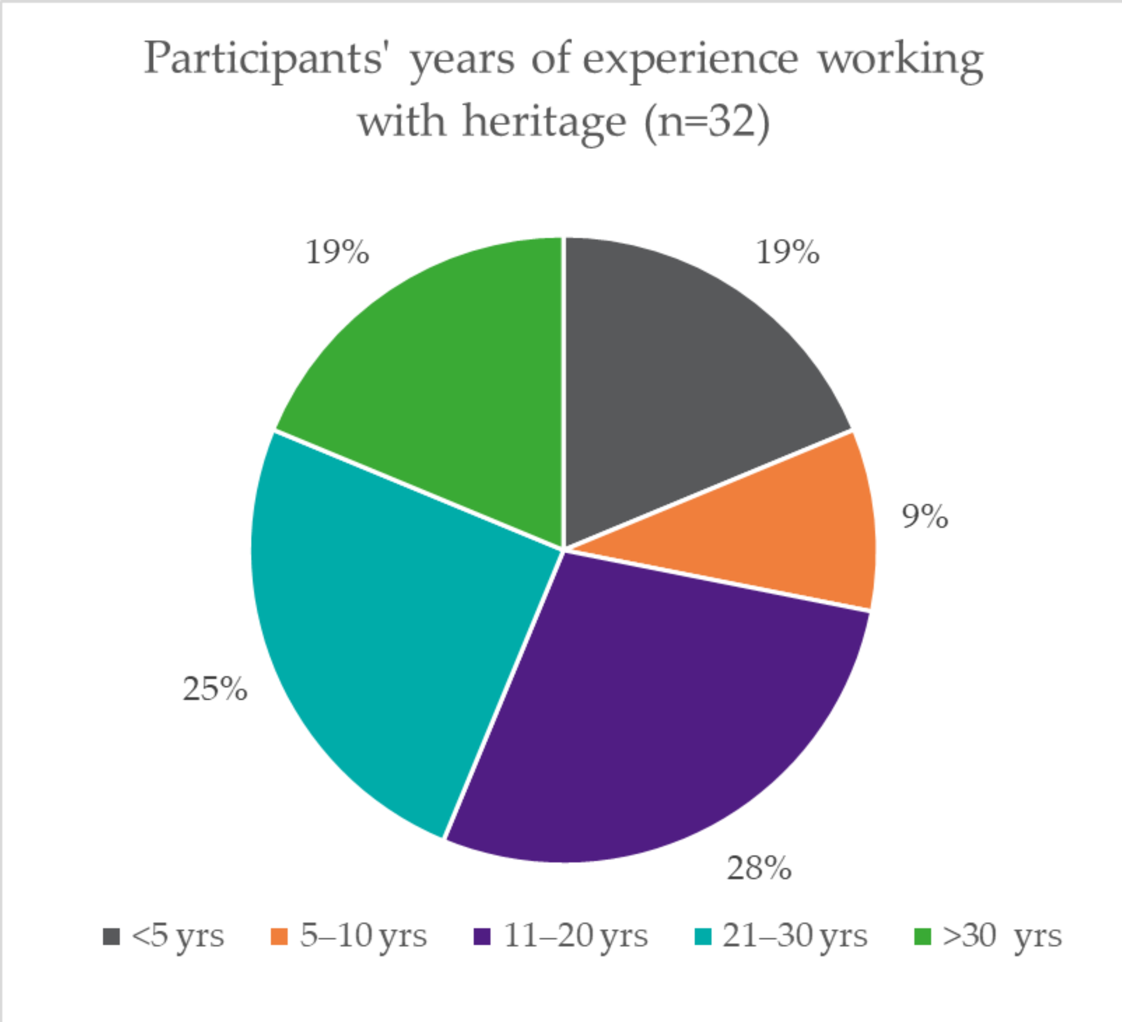

Figure 2. Graph showing how many years of experience participants had working with heritage.

The majority of participants had obtained some form of official qualification they felt relevant to their role whilst three had not cited 'on the job' experience. Qualifications were typically associated with higher education (e.g., architecture, history, and engineering degrees) but also included qualifications from professional bodies (e.g., Chartered Institute of Building (CIOB) and the Royal Institution of Chartered Surveyors (RICS)) or Continuing Professional Development (CPD) events run by various organisations.

3.1.2. Roles

The participants were grouped into three broad job areas so that any differences in perspective (e.g., different worldviews) could be inferred. These job areas were as follows:

- Heritage Management: This refers to individuals who are involved in the management and maintenance of heritage assets specifically.

- General Management: This refers to individuals who are involved in the management of a number of assets, which includes some heritage assets, or individuals who look after an asset because of the function it serves.
- AEC: This refers to individuals involved in the AEC industry. This incorporates both organisations specialising in heritage projects and organisations that typically deal with non-heritage assets.

The management categories incorporate activities associated with both Asset Management (AM), defined as "coordinated action of an organisation to realise value from assets" [46], and Facilities Management (FM), defined as "organisational function which integrates people, place, and process within the built environment with the purpose of improving the quality of life of people and the productivity of the core business" [52]. The key distinction between 'Heritage Management' and 'General Management' is that individuals involved in Heritage Management were managing assets specifically because it was an asset known to be historically significant and there was a wish to preserve the asset. Individuals involved in Heritage Management were typically associated with charities or trusts founded to look after heritage as opposed to purely commercial organisations.

Over 60% of the participants worked within Heritage Management, with approximately 20% working in AEC and 15% working in General Management (see Figure 3). This was not unexpected given the search method for participants. The initial sample of participants was primarily generated via the participant's known association with a heritage asset or organisation. Hence, these were typically public organisations or trusts founded to look after heritage. Identifying individuals within the AEC sector and the General Management field was more difficult as it relied on the existence of sufficient public information regarding an organisation's heritage activities or the authors' own knowledge of appropriate participants. The lack of participants in the General Management field can also be attributed to the fact that many potential participants chose not to partake in the survey as they did not believe they had any expertise regarding heritage. One participant, who did complete the survey, even went as far as claiming they had no experience working with heritage and it was just a coincidence that two of the assets within their management portfolio were Listed buildings.

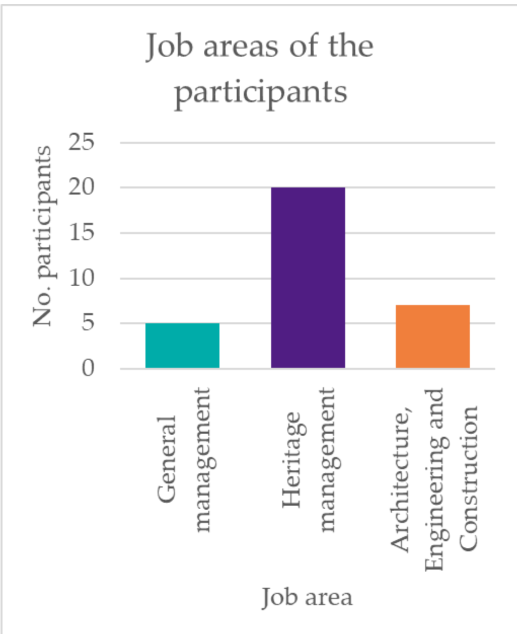

Figure 3. Graph showing job areas of the survey participants.

However, the value of insight from individuals who do not have what may be considered a conventional heritage background should not be understated as they help provide a more balanced perspective. This is a sentiment increasingly championed by international communities as evidenced by conventions such as the Faro Convention [19], which suggests that anyone with a desire to preserve and pass on heritage should be able to contribute at some level to the development of official policies. Furthermore, the authors believe that the development of HBIM must incorporate cross-sector expertise so that any proposed processes can be used by owners of mixed-use sites, e.g., university campuses, which may consist of both brand new and heritage structures.

3.1.3. BIM Knowledge

Whilst over 75% of participants had encountered BIM before, just under half of them only had theoretical experience of BIM (Figure 4). Theoretical experience usually originates from personal interest or academic experience. The participants with BIM experience typically originated from large, national institutions (e.g., English Heritage (EH) and National Trust (NT)) or had experience from previous roles. One participant was a member of the National Steering Group (UK) for HBIM.

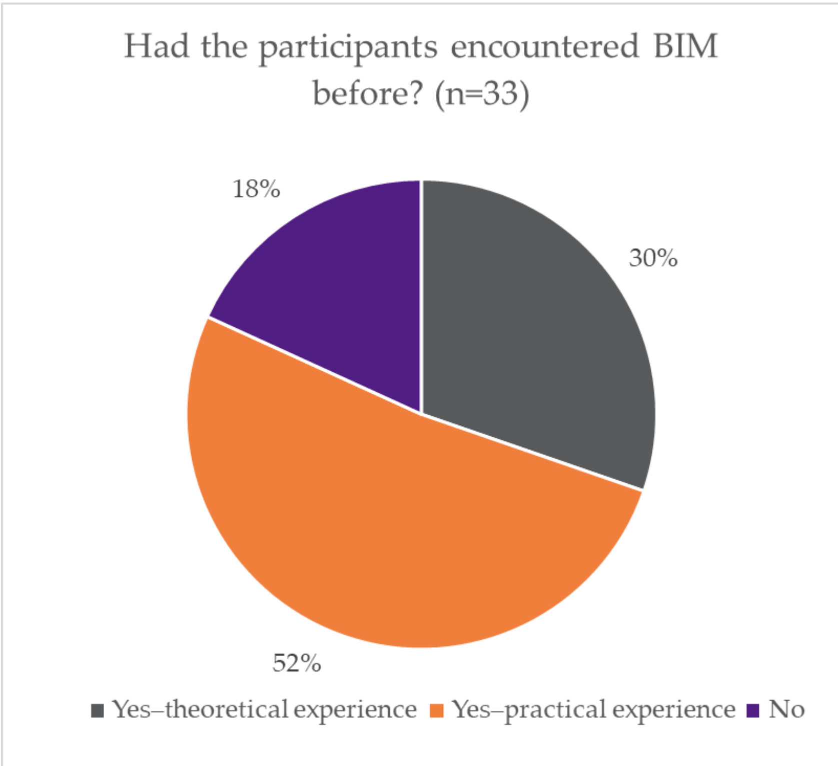

Figure 4. Graph showing if participants had encountered BIM before as well as if their experience was practical or theoretical.

3.2. How Heritage Information Is Currently Managed

3.2.1. What Information Do Heritage Practitioners Possess?

Participants of the survey were initially not provided with the theoretical information categories (in Table 1) so as not to inadvertently influence their responses [53]. In the first half of the survey, the Participants were asked to detail any information they already possessed about the assets they worked with. Table 3 presents the information stated as already possessed by the survey participants (right column) against the theoretical information categories from Table 1 (left column). The definitions for each information category are included in Table 3 to minimise ambiguity. Where an information type provided by a participant may be attributed to multiple categories, the category with the strongest correlation was chosen. For instance, records of the asset's form over time could be considered as 'information about the fabric of the asset' but is instead incorporated under 'historical information'. Table 4 contains information types stated as already possessed by the survey participants that were deemed not to be encompassed by the proposed information categories. For both Tables 3 and 4, non-identical but similar answers were grouped together. The most frequently cited existing information types were drawings (architectural or unspecified), photographs, and surveys of the asset condition (various types).

Table 3. The information stated as already possessed by the participants of the survey.

Theoretical Information Category	Information Already Possessed by the Survey Participants
Geometric surveys: This is defined as the geometric information gathered with which to create the model. These data are typically provided by techniques such as photogrammetry or laser scanning. These techniques produce point clouds, which are a collection of thousands of points that provide a 3D representation of an area.	Laser scans (explicitly specified) and other 3D scans (exact type unspecified by participants) Measured surveys
Information (data) about the fabric of the asset: This is defined as the physical material/structure that makes up the asset.	Architectural drawings (new and historic) including plans, layouts, and elevations Unspecified drawings (new and historic) Information about the materials Conservation and architectural reports Information about historic architectural families Drain surveys Descriptive documents Mechanical and Electrical installation surveys
Condition assessments: This is defined as inspections of the physical condition of an asset, which could include, but are not limited to, assessments of decay or energy performance.	Various surveys, e.g., building, environmental, asbestos, timber, structural, plaster, mechanical, and electrical Condition surveys/reports (historic and new) Results from visual inspections Consultant reports
Legal requirements: This is defined as any requirement that may affect your ability to carry out certain work. This may include a planning regulation (e.g., Grade Listing, etc.) or statutory document (e.g., other requirements such as conditions of bequest).	Previous planning applications Documents supporting previous planning processes Legal records Compliance records, e.g., asbestos
Historical information: This is defined as archaeological data (including data about lost heritage) and major changes to an asset (not regular conservation work) over time. It does not refer to historical significance.	Record/assumptions of the building's use over time Record/assumptions of the building's form/any changes over time Information about former capital projects [it is assumed here that a capital project involves some kind of major change] Archaeological reports/surveys/collections
Environment data: This is defined as more detailed data about the specific environment (or space) of an asset that may affect its condition or performance. This may be at a large scale (e.g., a whole building) or a smaller scale (e.g., light levels in a specific room affect a specific object).	Environmental parameters affecting integrity
Safety and security information: This is defined as any information related to the safety and security of the asset. This could include fire evacuation drawings, locations of fire alarms, and accessibility information such as wheelchair-accessible routes.	Health impact assessments

Table 3. *Cont.*

Theoretical Information Category	Information Already Possessed by the Survey Participants
Space data: This is defined as information about how the physical space of an asset is broken down and used. This may include, but is not limited to, room allocations (space breakdown), which areas are open to the public/private (space usage), occupancy limits, average footfall (visitor information), etc.	- [No information types given]
Maintenance manuals/instructions: This is defined as information provided or required to help plan and/or carry out maintenance and conservation work on an object.	Records of previous maintenance work (cyclical and reactive) Records of previous conservation work Records of statutory testing Building maintenance plans Service plans Historic operation and maintenance plans Standard operating sheets Working documents for heating, lighting, Closed-Circuit Television (CCTV), and Audio–Visual (AV) systems Information about cleaning
Historical significance: This is defined as the tangible or intangible significance attributed to the importance of the asset, e.g., how it evidences a way of life/practice, architectural or structural importance, associations to notable figures, etc.	Reports/research on asset history and significance Historical background Architectural heritage surveys Archival sources regarding the holding's provenance Secondary sources relating to the asset history Original accounts from the asset's construction Building gazetteers
Location data: This is defined as information about the wider location surrounding the asset. This may or may not be owned by you. For example, a local river may be prone to flooding and a risk to your asset. Alternatively, it may be information about the grounds surrounding the asset itself, e.g., the boundaries of the land.	Maps Topographic surveys Site level drawings
Objects not part of the building's fabric: This is defined as important objects not necessarily considered part of the building, which could be artistic (e.g., tapestries, artwork, sculptures, etc.) or other moveable assets (e.g., old factory machinery, furniture with a specific significance, etc.).	Asset registers

At this point of the survey, the information stated as already possessed by the survey participants encompassed all but one of the theoretical information categories proposed by the authors. The only omitted category was 'space data'. However, it is arguable that 'layout information' contributes to the 'space data' category. This provides initial evidence to support the validity of eleven of the twelve proposed information categories.

It was found that respondents also indicated information types that fall outside of the previously proposed categories presented in Table 3. Thus, Table 4 presents these information types within three newly defined categories of information. A fourth category, 'other', is included for completeness and encompasses any information type given by the survey participants that cannot be justifiably grouped under another category by the authors. The three categories in Table 4 represent an addition to the work outlined by Lovell et al. [44]. However, as these categories were not included in the survey, they are not discussed further herein. Future work should seek to provide further validation of these categories.

3.2.2. Evaluation of How Information Is Currently Stored and Managed

It was anticipated that participants would disagree with the statement that "the information they currently possess is sufficient for their purposes" as other research previously concluded that the likelihood of information being missing increases with an asset's age [55]. However, within this survey, less than 30% (eight participants) of the participants disagreed with the statement (see Figure 5). Furthermore, when specifically asked what challenges they face with how they manage heritage information, only 15% (five participants) of the participants referred to the insufficiency of data as a key challenge with regard to how they manage heritage information. Comments regarding challenges caused by insufficient data included a lack of knowledge of hidden services (e.g., drainage, plumbing, and electrical), information being owned by previous owners or external organisations who are unable/unwilling to provide it, and poor record keeping in the past.

Table 4. Information stated as already possessed by the survey participants that is not encompassed by the previously proposed categories.

New Information Category	Information Type Already Possessed by the Survey Participants
Visual depictions: This is defined as images, drawings, or surveys that provide a visual representation of all or part of an asset.	Matterport data Drone surveys (Note: whilst both drone surveys and Matterport surveys can provide geometric data, the exact drone survey was not specified. Furthermore, Matterport surveys are not typically used for geometric data, instead, they are typically used to create virtual tours [40]. The authors are aware of one participant who only uses Matterport scans for its virtual tour capability and it is possible to undertake a Matterport survey without collecting geometric data, hence the inclusion within this category. Photographs and paintings (historic and current).
Management plans/policies: This is defined as documents recording or dictating the strategic management objectives of an asset.	Management data and records Conservation policies Conservation management plans
Project files for proposed and/or previous capital work: This is defined as information created or required as part of the conception and design stages of a capital project (assumed to correspond with suggested information exchanges for RIBA stages 0–4 [54]).	Schedule of work Feasibility studies Company minutes and correspondence Specification of work Business plans Intended design plans from architects
Other	Detailed BIM models Historical/archival records (unspecified) Other reports (unspecified) Consultants' reports (unspecified)

A potential explanation for the unexpected result in Figure 5 can be inferred from the challenges associated with storing heritage information suggested by the participants. Almost 30% (nine participants) of the participants, many of whom had agreed with the statement, referred to having too much data, stored in too many disparate ways to be easily accessible. Similarly, seven participants suggested challenges regarding storing information in a long-lasting and easily accessible manner. This challenge was also reported where a lack of defined structure and process in digitised systems had resulted in information being lost or misfiled. In some cases, participants reported having to rely on institutional knowledge of where and how information was stored. This is not practical long term since three other participants referred to information being lost due to staff turnover.

It may thus be concluded that the problem is not related to the sufficiency of the data but rather the complexities associated with managing such large data volumes over a long period of time. This further supports the argument for a defined data standard for HBIM.

To gain further insight, participants were asked how they currently store and manage the information they possess. All answers received (three participants did not provide answers) indicated either hard copies, digital copies, or personal experience as presented in Figure 6. All but one of the participants who answered the question stored some information in a digital format and six participants referred to storing data in a specific digital FM or AM tool. Overall, the responses revealed a strong trend towards the digitisation of data, with several participants discussing ongoing work to digitise resources that remained as hard copies, and four stating that, whilst they possessed some hard copies of documents, these were purely archival resources.

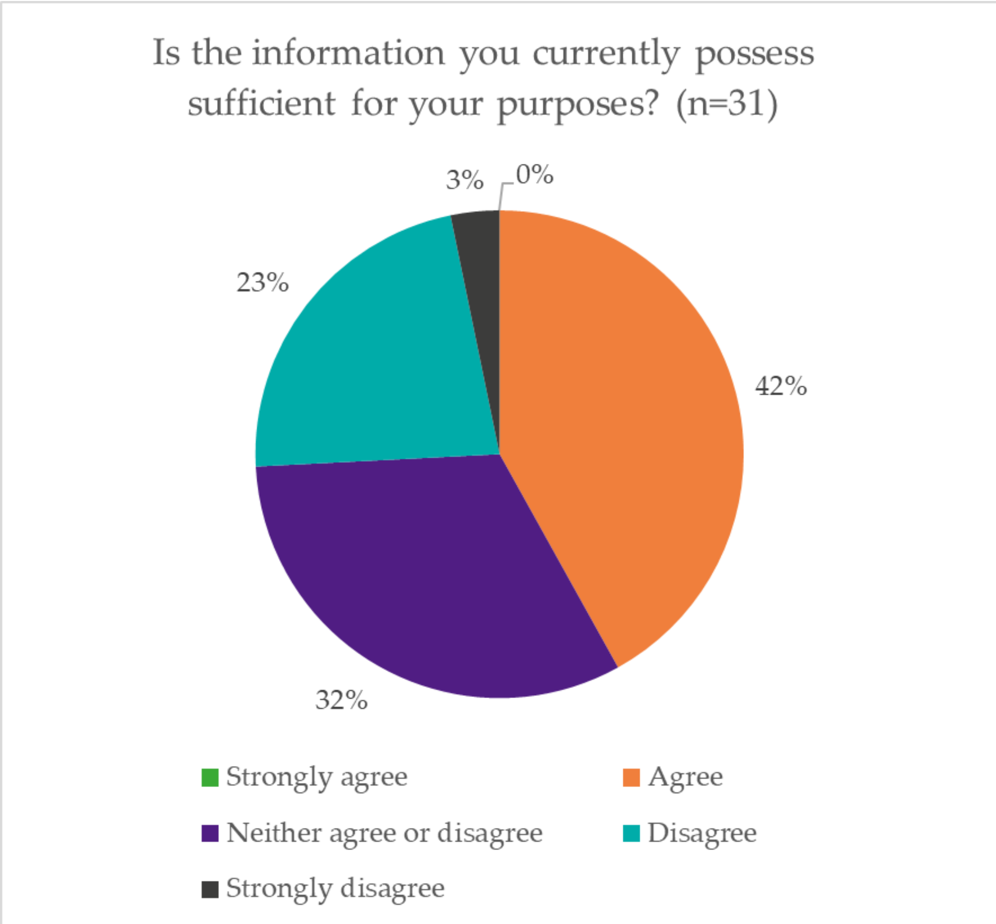

Figure 5. Graph depicting participants' opinions on the information they currently possess.

Throughout the whole survey process, the desire from the participants to use digital solutions for Heritage Management and better information and tools to share with their successors became evident. The positive attitude from the participants of the survey, many of whom held positions as heads of departments or organisations, thus suggests a positive outlook.

Whilst some perceived barriers to HBIM implementation (see Section 3.4.12 for full details) also became apparent when participants were asked what challenges they face with how they currently manage heritage information, we believe that they can be overcome.

For instance, whilst two participants suggested challenges regarding the willingness of other stakeholders to adopt new digital tools, Brunet et al. [56] found that this can be overcome when influential members of organisations champion digital tools.

Furthermore, several participants mentioned a lack of resources regarding both the time and money needed to implement these solutions. However, the cost and time needed must be compared to the existing issues experienced by the participants regarding the inability to find information easily and the consequential cost and time implications imposed by this existing poor information management [57,58]. From this comparison, it becomes clear that providing the new digital tools have clearly reported structures and processes, thus allowing them to be resilient to technological changes [42], the initial investment required to implement them will be recouped over time.

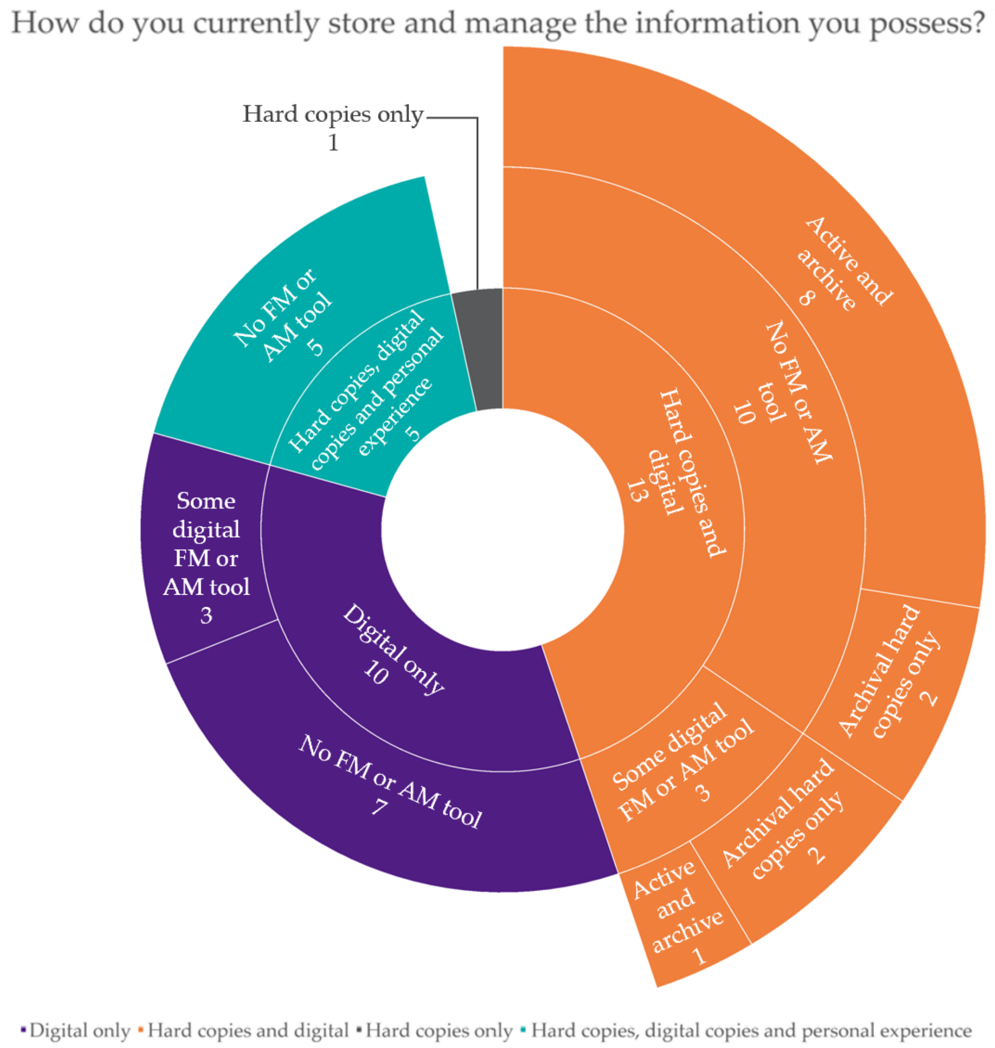

Figure 6. Graph depicting how heritage practitioners currently store and manage the information they possess.

3.2.3. Types of Digital Tools Already in Use by the CH Sector

To gain additional clarity on the types of digital tools currently utilised by the Cultural Heritage sector, participants were asked if there were any specific tools or software that they used to store and manage information. Approximately 66% (twenty-one participants) of the participants stated that they did use specific tools or software. The exact software and tools varied substantially across different job roles and sectors so only generic classifications are included in this section. The tools used tended to reflect the digital maturity of the participant's organisation, with those just beginning to digitise their data tending to use simpler, readily known tools, such as Microsoft Word or Excel, and storing their data on internal [file] servers. Moreover, many organisations used cloud or web-based servers with the most common response (nine responses) being SharePoint, a collaborative, web-based document management system. Several organisations were using more advanced Common Data Environments (CDEs) [59], such as Business Collaborator, ProjectWise, and Bentley CDE. Others were using alternative information management databases and tools such as the Autodesk BIM360 suite and PostgreSQL. Another common theme was software for design and visualisation including but not limited to the following: Geographic Information Systems (GISs) (e.g., QGIS, PostGIS, and ArcGIS), as-is capture tools (e.g., Matterport and Metashape), Computer-Aided Design (CAD) tools (e.g., AutoCAD, Revit, FreeCAD, and Sketchfab), and other modelling tools (e.g., Trimble Business Centre, LumenRT and OpenRoads Designer, etc.).

Whilst the exact software varied across the participants, it is interesting to note that many of the software stated are utilised as BIM tools across the AEC industry (Revit, Business Collaborator, and Bentley CDE appear particularly prevalent). Whilst the relevance of design and visualisation software to BIM is easily understood, the importance of collaborative data management platforms such as SharePoint should not be underestimated. Undue emphasis is often placed on the modelling component of BIM. However, BIM's primary function and benefit is arguably as a standardised information management tool. CDEs are an essential element of BIM implementation. It should be noted that simpler solutions, such as SharePoint, with proper organisational governance, structure, and access rules, can be configured as basic CDE systems for a project utilising BIM. The trend towards digitisation observed from the survey results and the fact that many of the participants are already using BIM-aligned tools suggests that the application of HBIM to the CH sector is not an insurmountable task.

3.3. Working Constraints

3.3.1. Importance of Working Constraints

This section reviews the current working practices of the participants. An adequate understanding of current working practices should help ensure that suggested system requirements for HBIM are viable within the current CH sector.

3.3.2. Accessibility of Assets

Participants were asked whether the assets they worked with were private, open to the public, or a combination of both. Almost all participants stated that they worked with assets that were open to the public in some way (see Figure 7). Those who responded with 'both' typically worked with a portfolio of assets where one asset of a larger estate may be private, or they worked with a larger asset that had some private areas, e.g., staff-only areas. For some, the assets were private only because they had not yet been developed for public access. It is worth noting that 'public' incorporated both visitor attractions, holiday lettings, and functional buildings, e.g., university buildings.

When asked if the accessibility of the assets had any impact on their role, it was determined that the biggest impact came from assets being open to the public. No impacts were given for private assets. There was some disparity between individuals involved in management roles (both Heritage Management and General Management) and those involved in the AEC sector. For those involved in management, the biggest and most recurrent impact given was that maintenance had to occur during closed periods and that major projects resulted in prolonged periods of shutdown. Conservation activities thus require a greater degree of planning, and many organisations undertook seasonal shutdowns to accommodate this. A further impact given includes increased concerns regarding vandalism/arson, which may be due to less controlled access afforded to public assets. Several participants stated that there were increased Health and Safety (H&S) management requirements when assets were open to the public.

For many participants, mostly those involved in Heritage Management, there was an expectation within their organisations that assets would be public and there would be considerable public engagement involved in all aspects of their work. This was due to participants advising of charitable remits including learning responsibilities and a desire to return heritage assets to the communities within which they originated. For example, Participant 8, Head of Historic Buildings at Historic Royal Palaces (HRP), emphasised this point stating that the public is "the most/only way to sustainably manage assets of the scale and significance of the palaces". The inherent public ownership of heritage is a concept discussed in the Faro Convention [19] and by UNESCO et al. [60]. The importance of public engagement and education opportunities was reiterated in a later question where Participant 30 stated that these two aspects had been requirements for obtaining external funding (in their case Heritage Lottery Funding). It is evident that any proposed HBIM system should incorporate this need for public engagement/ownership.

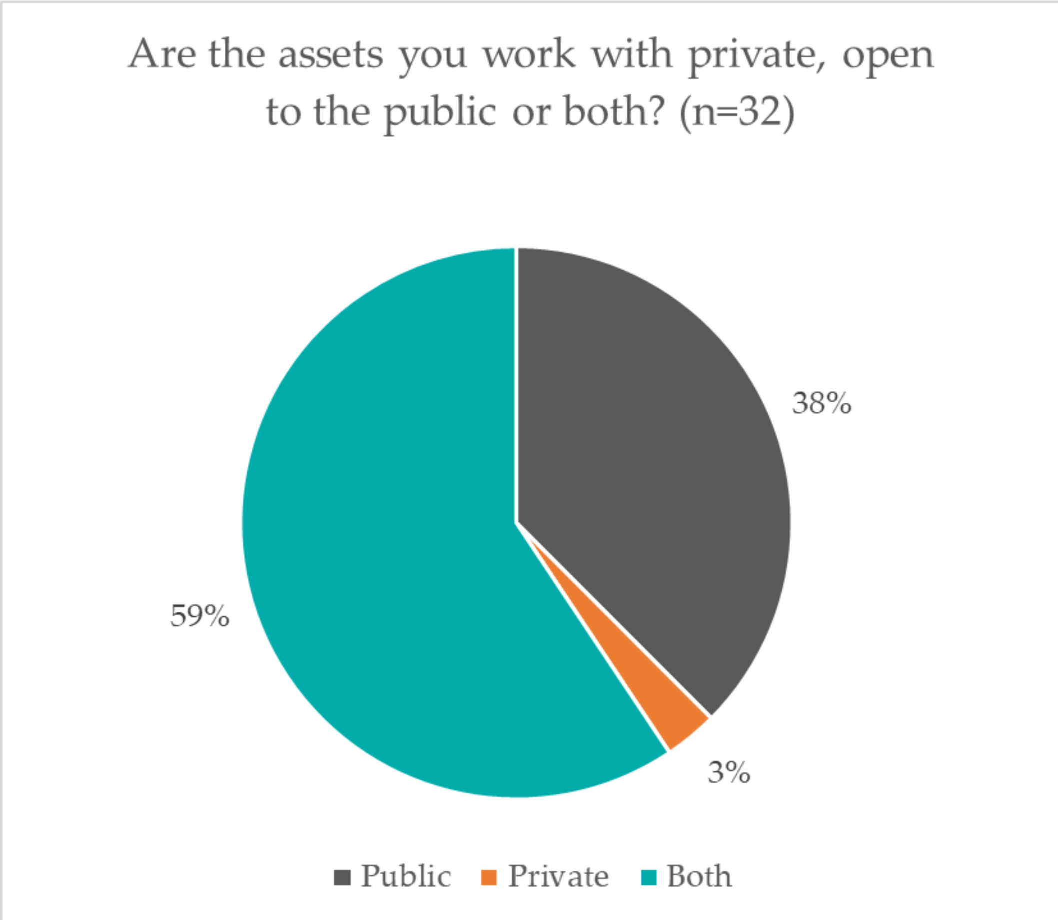

Figure 7. Graph depicting whether the assets the participants worked with were private, open to the public, or both.

Individuals in AEC roles typically cited differing approaches to projects involving public assets compared to private assets since "the public" is considered a more powerful stakeholder. Therefore, the opinions and engagement of the public during planning and design stages were considered much more important as they affected the asset's intended use and the public was likely to cause issues with projects if they were unaware of, or disagreed with, any work undertaken.

3.3.3. Working Locations

The pilot version of the questionnaire asked participants where they worked from on a typical day. Thirteen of the fourteen participants who answered the question stated that they worked on sites or had a hybrid working pattern of home/office or site-based locations. For many, the hybrid working pattern had been triggered by COVID-19 but was deemed unlikely to change. The fourteenth participant (Participant 9) worked from home but occasionally undertook maintenance in person. It was clear from the initial sample of results that any HBIM methodology should account for remote access from varying locations. An HBIM that can only be accessed from one location/computer would be incompatible with current working patterns.

3.3.4. Organisation Size

Participants were asked how many people were involved in the management and maintenance of heritage at their organisation (Figure 8). The purpose of the question was to determine approximately how many people would need access to any information stored within an HBIM system. A total of 70% of participants responded that over ten people were involved in the management and maintenance of heritage at their organisation and only approximately 7% of participants worked alone. Several interviewees who answered that over twenty people were involved in the management and maintenance of heritage at their organisation stated that they were including both the core team (one of which consisted of only ten people) and any external contractors/volunteers.

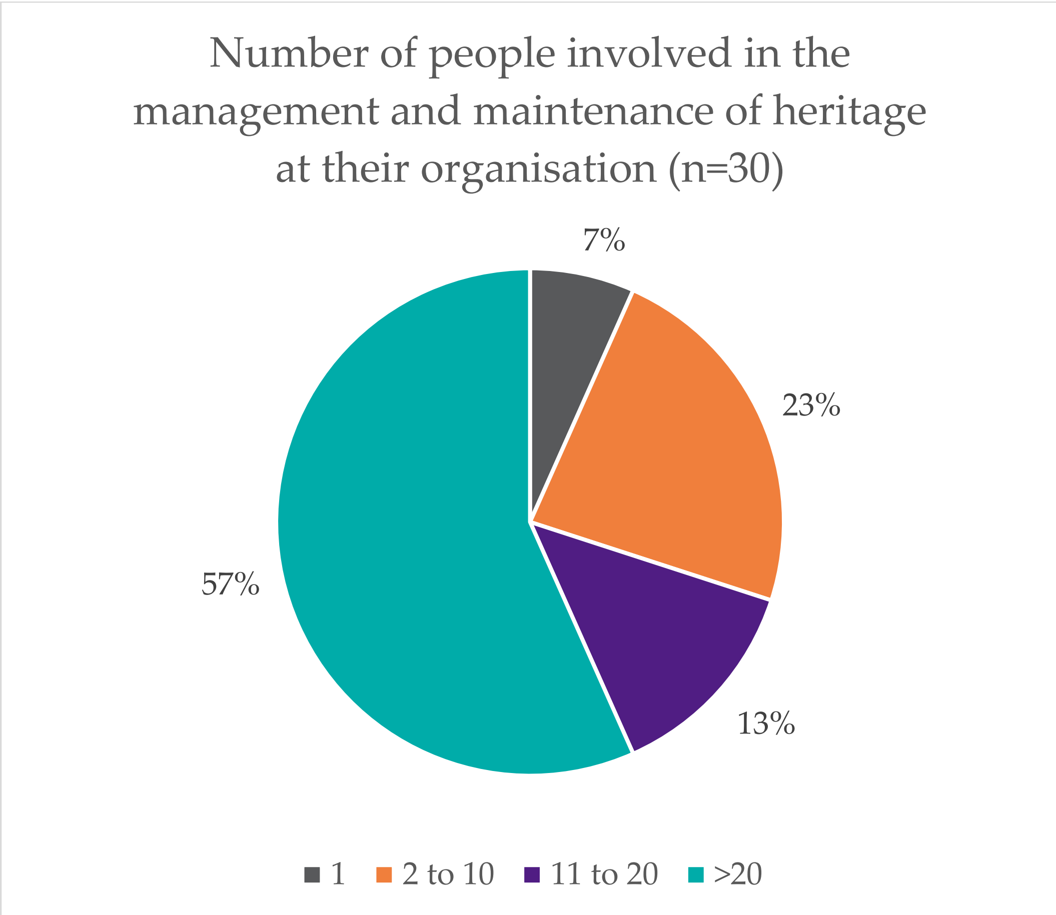

Figure 8. Graph depicting the number of people involved in the management and maintenance of heritage at each organisation.

3.3.5. Challenges of Working with Heritage

The participants were asked what key challenges they face with regard to working with heritage. The purpose of the question was to identify potential constraints to HBIM but also to identify challenges experienced by heritage practitioners that could be overcome or alleviated by the use of HBIM. The key challenges, in order of frequency, are shown in Table 5.

Table 5. Challenges of working with heritage.

Challenge of Working with Heritage	Details	Participant No.
Money	Over 65% of the participants cited money-related challenges. This challenge encompassed a lack of available funds, lack of available resources, high cost of materials and labour, and difficulty accessing external funds or fundraising.	1, 4, 6, 8, 10–11, 13–22, 24, 29–33
Availability of skilled labour	Participants mentioned a growing lack of heritage skills or difficulty finding contractors with appropriate expertise.	3, 8, 13, 17, 20, 22, 26, 29–31
Planning/legislative/listing constraints	Participants talked about extra constraints imposed by having to comply with heritage protections or satisfy external heritage stakeholders (e.g., conservation officers). This also limited the scope of any interventions and increased the time to gain planning consent.	2, 4, 6, 9, 11, 17, 19, 24
Historic materials	Challenges regarding the materials in use. This included trying to stop the further degradation of materials reaching their end of life, the ingress of plant life, and a lack of homogeneity in material properties.	3, 12, 19–20, 28, 31
Client aspirations and expectations	This included disparity between the "purest vision and the practical vision" (Participant 6) as well as a limited understanding of the legislative implications of heritage significance.	6, 14, 23, 25
Climate change	Climate change or impacts of climate change, e.g., increased flooding.	8, 22, 31
Access requirements	Both gaining access as a worker and allowing access for the public.	12, 20, 24
Insufficient time	Insufficient time to plan work, carry out activities, apply for funding, etc.	1, 10, 24
Insufficient staff	Insufficient staff to plan work, carry out activities, apply for funding, etc.	1, 4, 10
Access to historical records/information	Limited access to historical information for planning future interventions or informing activities.	5, 17–18
Limited long-term sustainability	A general lack of long-term sustainability including a lack of forward planning within organisations.	20, 22
Public perception	The impact of public perception (see Section 3.3.2).	24

HBIM may provide a viable solution to mitigating some of the identified challenges. For instance, whilst HBIM cannot impact the physical access capabilities, it may be used to plan activities or access possibilities in advance. This is comparable to 4D sequence planning in BIM already utilised by the AEC industry [61,62]. Likewise, easier access to information may reduce the time and resources needed to plan activities or apply for funding.

Many of the given challenges were inter-related. For instance, several participants mentioned limited time for planning and limited available staff, but Participant 31 explained that this was caused by limited funds. Since money is a limiting factor, initial HBIM implementation should endeavour to use low-cost solutions as much as possible. However, using HBIM to address some underlying issues could justify an increased implementation cost for HBIM. For instance, the scarcity of skilled labour was also credited with increasing labour costs. One organisation was seeking to address this by supporting the development of heritage skills. HBIM has previously been used/suggested as an educational tool [63–66] so this capability could potentially be repurposed to aid training about heritage skills/crafts in the future. Furthermore, viewing public engagement and education as an inherent function of HBIM would allow it to be used to ease and reduce required resources for external funding applications for future interventions.

3.4. Uses of HBIM

3.4.1. Overview of Section

The authors of this paper previously determined that the intended use of an HBIM tends to alter its form and contents [2]. For instance, a participant who wishes to use HBIM as a virtual tool used to share heritage with the public is likely to request a high degree of geometric accuracy for model elements. Thus, the preferences of the participants may cause implicit bias in their later responses. Consequentially, Section 3.4 aims to determine potential uses of HBIM and to identify any implicit assumptions the participants may have. The participants were provided with the following explanation of what HBIM is for the purpose of this study:

"BIM is the process of creating an intelligent 3D model of an asset which also contains extra information about 'objects' within the asset. This information includes geometric information (e.g., dimensions of a window) and non-geometric information (e.g., details of the materials that make up a structure or manufacturers handbooks). A HBIM is a BIM model of a historic asset. Essentially, all the information about an asset should be stored and accessible within the model alongside a visual representation of the object. BIM software allows people to plan activities, create schedules and design new constructions. BIM can also be used as part of augmented reality/virtual reality (AR/VR) tools to create virtual experiences".

Subsequently, seven potential use cases of HBIM (Section 3.4.2) were proposed to the survey participants and they were asked to indicate their preference (Section 3.4.3). The use cases were intended to reflect example use cases of HBIM from the available literature. For each use case, participants were then given the option to detail if they had a specific use in mind and if they wished to provide any other comments. In many cases, the specific use and other comments had a degree of overlap, so the results are discussed together. These responses are detailed for each respective use case in Sections 3.4.4–3.4.10. The final section (Section 3.4.11) details any further use cases identified from the survey responses that were not proposed initially.

3.4.2. Proposed Use Cases

Table 6 presents the potential use cases of an HBIM that were proposed by the authors in the questionnaire and the definitions provided to participants. 'Translocation' was added as an additional option during the secondary pilot stage.

One of the questions removed from the questionnaire after the secondary pilot stage was "what do you use the information [you already possess] for? e.g., to inform new work". From the thirteen participants who provided responses, the answers can be summarised as follows:

- Informing funding applications, planning, and design of new work/capital projects.
- Evaluating, planning, undertaking, and recording maintenance.

- Understanding the significance and/or function of an asset.
- Informing decisions.
- As a record, e.g., of asset condition or function, or of work undertaken.
- Planning activities.
- To share knowledge with others.

Table 6. Proposed uses of a future HBIM with the definitions provided to the participants.

Potential Use of HBIM	Definition
Renovation projects	Defined as work to upgrade or change an asset. This could be for aesthetic, structural, or energy performance reasons.
Restoration projects	Defined as any work attempting to return an asset to its original condition.
Conservation projects	Defined as actions/work to maintain an asset in its current condition. This includes day-to-day and ad hoc maintenance.
As a virtual tool used to share heritage with the public	This is envisioned as an educational tool (potentially incorporating AR/VR) that could contain information about the intangible heritage of the asset or be used to teach others about conservation, etc.
Asset Management	Defined as managing an asset at an organisational level to maintain its value in line with organisational objectives.
Facilities Management	Defined as managing the asset and its contents for day-to-day running. This involves planning maintenance, managing resources, space management, and monitoring energy performance.
Translocation	Defined as moving a structure from one location to another. It may be intact for the relocation; dismantled from its original site and rebuilt somewhere else; or it may be recreated from already dismantled parts at a new location.

It can be inferred that the answers provided correspond with functions of HBIM proposed by the authors of this paper in Table 6, e.g., planning maintenance would be a Facilities Management activity. Hence, it was deemed that minimal additional value could be inferred from the question besides providing some further justification for utilising HBIM for a specific use case, and it was removed from the final iteration of the survey.

It was observed that there was some level of disagreement with the use cases given between the participants. Views on 'restoration' and 'renovation' appeared particularly contentious since for many within a conservation setting (essentially those participants from within the Heritage Management job sector) restoration and renovation are considered bad practices and, for some, were not recognised terms. This was revealed as a current debate for the sector with Participant 29 saying, "there's a whole debate around this [. . .] as to why I wouldn't want to do [restoration projects]". However, there were some participants who had undertaken renovation and restoration projects as defined by Table 6, so the use cases can be considered acceptable in this instance. Likewise, as mentioned previously (Section 2.2), the translocation of heritage structures is extremely rare and is considered controversial by many [48]. However, three participants had been actively involved in translocation projects in the past, so removing the use case would have removed a potentially valuable perspective.

There was also some disagreement from the participants regarding the definitions provided. For instance, Participant 33 from EH referred to 'conservation' as the "careful management of change" [67] and suggested the definition given was more applicable to the term 'preservation'. However, UNESCO defines the conservation of Cultural Heritage as "the measures taken to extend the life of cultural heritage while strengthening transmission of its significant heritage messages and values. In the domain of cultural property, the aim of conservation is to maintain the physical and cultural characteristics of the object to ensure that its value is not diminished and that it will outlive our limited time span" [68]. For the purpose of this study, this can be argued to be sufficiently comparable to the definition given in Table 6.

The occurrence of differing definitions within the CH sector has been identified in a previous work by the authors [44], observing that there are many differing definitions of what heritage itself is. It was thus also assumed by the authors that this disparity might be true for other terminology within the CH sector. Hence, the definitions in Table 6 were provided to participants to ensure that, regardless of whether a given definition was universally accepted, the answers provided by participants could be directly compared. Furthermore, altering the definitions according to participant feedback would have made any future comparison of previous answers invalid, so it was decided that the uses and definitions would remain the same. The research outlined in this paper does not seek to provide definitive definitions for any of the proposed use cases or settle the debate regarding the appropriateness of certain activities within a conservation setting, it only aims to suggest potential use cases; therefore, no further comment is provided on the suitability of these terms.

3.4.3. Participants' Preferences

Figure 9 depicts the preferences for the seven proposed use cases of HBIM according to the participants of the survey. The participants were asked to indicate their agreement with the statement "a HBIM would be beneficial for the following purpose:". There were five response options with an associated 'use score': strongly agree (use score = 2), agree (use score = 1), neither agree or disagree (use score = 0), disagree (use score = -1), and strongly disagree (use score = -2). The 'use score' is purely intended to enable comparison of the proposed use cases with a higher, positive score indicating a greater agreement that HBIM would be beneficial and a more negative score indicating greater disagreement. Neither agree nor disagree had an associated use score of zero as it was assumed to be a neutral response. From the collected responses, an average use score for each option was generated using Equation (1).

$$Average\ use\ score = \frac{Sum(use\ score \times No.responses\ for\ agreement\ level)}{No.responses\ for\ use\ case} \tag{1}$$

The average was used to account for the fact that the question about translocation was added after the secondary pilot stage, so there were fewer responses.

The results are depicted in Figure 9. 'Asset Management' achieved the highest amount of 'strongly agree' responses. However, the use of HBIM as a 'virtual tool used to share heritage with the public' was the most popular use case, achieving the highest average use score. This may be due to the expectation of the organisation that the heritage they worked with would be publicly accessible in some way (see Section 3.3.2). Translocation had the largest amount of non-positive responses. This was because the practice of translocating structures is very rare [69] and thus many of the participants had no relevant experience. Participants who explicitly stated that they did have experience with translocation all strongly agreed that an HBIM would be beneficial (Participants 3, 5, and 18). Whilst there is some difference between the seven use cases, there is no significant preference for any one case (evident from the minimal variation in average use score). As such, it can be argued that CH management favourably encompasses more than one of the use cases detailed and HBIM should not be siloed into a specific use case.

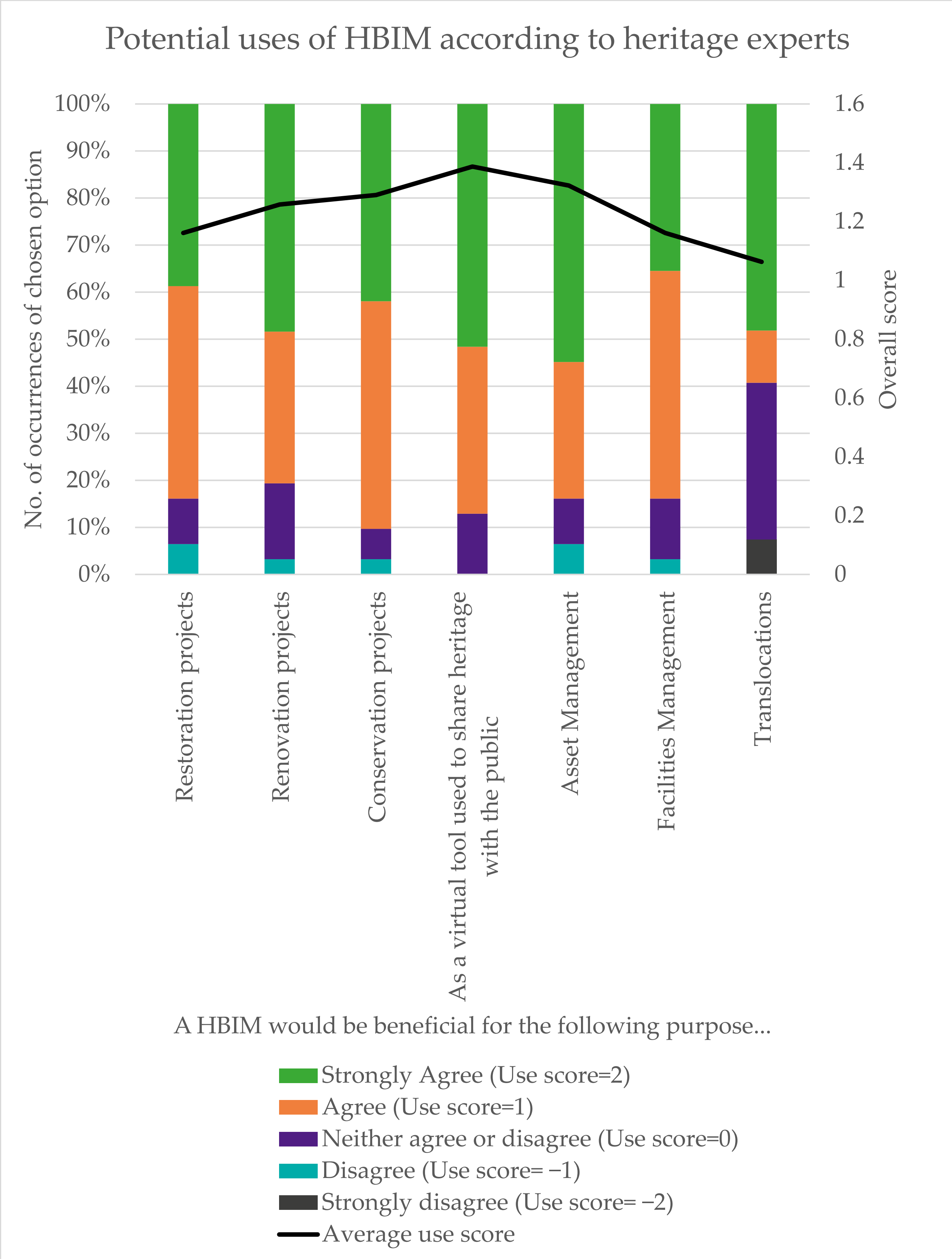

Figure 9. The potential uses of HBIM according to survey participants. The average use score was calculated using Equation (1).

Figure 9 demonstrates that the participants were mostly positive about the benefits of HBIM for all given use cases. No use case had more than 10% of participants disagree with the statement and the average use score was greater than 1 for all use cases, indicating a notable amount of 'strongly agree' responses. However, it must be acknowledged that these results present a degree of positive bias and, as such, should not be assumed to be representative of the whole Heritage Community. It was noted that approximately 10% of organisations who responded to the survey inquiry declined to participate because "they did not believe HBIM would be useful [to their organisation]". This does not necessarily mean these views are correct but their responses express their view with the information they had available at the time. Furthermore, Cohen et al. [53] suggest that survey participants are typically reluctant to provide responses that are deemed extreme, e.g., strongly disagree. Only one participant provided no positive answers (providing four negative and one neutral) and another provided four neutral and one positive.

3.4.4. Renovation Projects

Three key beneficial functions of HBIM can be identified from the answers provided regarding renovation projects. The first function pertains to the ability to make more informed decisions. Participant 6 referred to previous experience undertaking a renovation project on an asset they managed and expressed an opinion that a 3D model of the asset's previous condition would have been more beneficial than the 2D photographs they had to inform the new renovation. A similar sentiment was shared by Participant 3 who believed having a 3D model would provide a clear picture of the intended end product of a renovation. Furthermore, Participant 2 suggested it "might be useful when determining the practicality of building fabric and services upgrades". Participant 5 suggested that 3D scans would "give an indication of the status of the building and where there could be issues such as structural or superficial".

The second beneficial function of HBIM is the collation of complete asset data in a single repository, especially with regard to historic data, which herein refer to any data that are not current. Several participants mentioned the requirement for all data to be easily accessible and any changes to be traceable, with Participant 8 citing benefits regarding "avoiding any data loss through poor storage and loss of organisational knowledge" and Participant 20 suggesting it could save time by not "duplicating work done previously". Some participants specified changes as changes to the fabric of their assets, with Participant 8 specifying that it would allow them to have a historic store of data for places that are "hard/impossible to view" and would allow them to, for example, "understand how much of a 16th century roof survives, and how much was replaced in the 17/18/19/20/21st century". Most participants did not specify the type of historical data, so it must be assumed that they were referring to all data types.

The final beneficial function was regarding improving the sustainability of an asset. This consisted of assessing the current energy performance of an asset to evaluate energy efficiency and determine areas for improvement or for making strategic alterations/upgrades to an asset to achieve an eco-friendly design.

A total of 16% of the participants provided neutral responses. The respondents advised that this was primarily due to the expertise of the participants and the relevancy of the subject to their job role, with one claiming insufficient BIM knowledge to know if it would be useful and another stating that they had no renovation projects planned. Other participants stated that the model would need to be accurate. The theme of energy assessment was also provided, with Participant 11 suggesting a specific use case of "assessing the current energy performance of existing objects and what upgrades could be made".

Participant 32 provided the only negative response for renovation projects. This was credited to the age and the simplicity of the asset, meaning that they believed CAD drawings would be sufficient. Interestingly, Participant 33, who did not recognise the term 'renovation' within their organisation, provided a positive response to this section.

Within this section of the survey, further barriers to HBIM implementation were identified. The first barrier, suggested by Participant 18, who had used models for this purpose in the past, was that there was a lack of incentive from external parties, in their case architects, to utilise the models or engage in collaborative working. This could be overcome by enforcing HBIM as a contractual requirement for external parties. Two participants who provided positive preferences stated that the cost of implementation would be prohibitive. However, using HBIM for energy efficiency reasons could provide justification for this cost. Participant 10 described the ever-increasing price of energy as "an absolute killer". Therefore, since BIM can be used as a live tool for managing energy usage [70], it could enable organisations to use energy more efficiently and thus reduce costs. This may be especially true for heritage assets where stringent climate control is often mandatory for delicate assets [71]. It would also provide tangible evidence of energy efficiency and carbon neutrality, which Participant 10 cited was difficult to prove as it stands.

3.4.5. Restoration Projects

Restoration projects were considered comparable to renovation projects by many of the participants with several either referring to their previous answers or grouping the terms within their answers. A beneficial function of HBIM, comparable to those for renovation projects, was the collation of data in a single repository. However, the benefits provided by a single repository varied slightly from those suggested for renovation projects. Participant 10 believed it would reduce the time taken to deliver capital projects by making it easier and quicker to find information and share it with the relevant project members. A couple of participants mentioned a greater ability to review and understand past repairs or alterations to the asset, with Participant 24 mentioning the need to record "historically correct building techniques". Additionally, Participant 5 referred to increasing organisational knowledge over time by building up information regarding uncommon materials or difficult items.

Several participants commented on the usefulness of 3D surveys for restoration projects. Participant 18 had used HBIM for restoration projects before and had found it useful to prepare the geometric model according to historic drawings and then compare the model to new 3D surveys. Participant 5 and Participant 6 believed 3D surveys could be used to assess the current state of the asset before the initiation of the project and decide what superficial or structural repairs may need to be carried out. This could be particularly useful for hard-to-reach areas as it would allow an initial assessment of the cost of the work and the viability of the project without having to invest in access arrangements, an undertaking that can have significant financial implications for heritage. Participant 14 and Participant 10 suggested that 3D surveys or HBIM could be captured continuously through the restoration process to show the progress of the work. The idea of carrying out 3D surveys throughout restoration projects is already utilised in practice. For instance, the Sudbury Gasworks Restoration Trust carried out drone surveys to record the restoration of the Gasworks [72]. It is important to note here that the participants were referring to geometric surveys, not HBIM model objects.

There were two negative responses provided: one by the same participant and for the same reason given for renovation projects, and one solely because a participant disagreed with the principle of restoration in a historic setting (as detailed in Section 3.3.2). However, Participant 29, who disagreed with the principle of restoration, did comment that they "could see how that would be a useful technology".

3.4.6. Conservation Projects

Similar beneficial uses to the previous two sections were suggested: better visualisation of assets, collation of data in one place leading to quicker and better-informed decision making, and the ability to build up a knowledge base for the organisation. Participant 5 went so far as saying "the knowledge can be shared between similar assets to build the data base". The concept of sharing knowledge on a wide scale as part of a National Digital Twin was previously outlined in Section 1.2.1. Whilst it is unclear whether the participant was referring to similar assets within their own organisation or more generally, increasing the quantity and availability of all conservation data could have significant impacts on conservation activities. This is demonstrated by Participant 17 who commented that "conservation of historic fabric is often complex and the result of investigative work and problem solving". They hoped that "HBIM would make it easier to access detail in specific areas. If access is easy, then system users will be more inclined to use the information available. It will preserve the integrity of the work which has been done and ultimately the asset".

Some participants saw the benefits of HBIM for discussions regarding reactive maintenance, saying it would aid discussions and allow information to be shared with external service providers. Tangible evidence for the benefits of HBIM for reactive maintenance in a heritage setting was provided by Participant 12. They referred to an instance where they had used HBIM, overlaid with infrared images, to track water ingress from the damage to the source. Participant 12 stated that "this allowed for repairs to be made to the source, the location of which wasn't always obvious from the area of damage". This is not an isolated occurrence since there are similar instances of this available in the literature on BIM-FM [73].

Another suggestion, made by Participant 24, was that "advice on techniques would be helpful". This could help asset managers plan any conservation work or, as suggested by Participant 10, help train future conservation professionals. Including this information could help alleviate some of the data loss from experts leaving the organisation (Section 3.2.2).

It was clear from the participants' responses that an HBIM used for conservation projects would be an ongoing tool that would be continuously used and updated over time, with several participants referring to tracking information over time. Monitoring and condition reporting is a continuous process and is key for the management of heritage assets. One financial justification for this was provided by Participant 10 who said that if the collections stored/displayed within the asset have significant financial value then "how the building performs is how we maintain the right conditions and the right environment for the collections within them". This desire for HBIM to be a continuous tool differs from the current most common approach to BIM for Asset Management and Facilities Management where the BIM is created and then the information is transferred to another source [74,75]. This confirms the need for a shift in how the application of BIM and HBIM for Asset Management is viewed [43].

Both the neutral and negative responses for this section were due to the fact that the participants did not see the use of the specific assets they worked with.

3.4.7. As a Virtual Tool Used to Share Heritage with the Public

As previously stated, the use of HBIM as a virtual tool used to share heritage with the public received the highest overall score, indicating a strong preference for its use. The perceived benefits were numerous: as a training tool to teach people about traditional construction techniques; to assist with funding applications, such as the Heritage Lottery Fund, or to engage the public with fundraising efforts; to inform others about proposed project plans or keep them informed of project progress; and to increase accessibility to site. Increasing accessibility was the most common benefit and was attributed to a number of factors, such as individuals being physically unable to visit sites, unsafe conditions, ecological issues, rural locations, or a desire to reduce footfall at sensitive sites. The viability of digital tools to increase access to heritage has been previously evidenced by other authors [76–81].

There were no negative responses to whether HBIM as a virtual tool used to share heritage with the public would be beneficial. However, neutral responses were provided by Participants 8, 9, 11, and 32. Participant 32 believed it could be useful to attract young people as volunteers via tools such as VR, and Participant 8 was concerned that the systems would be too complex to be a useful public engagement tool. They thought it could be used to create content for public engagement but noted the need to make the information within it "enjoyable, easy and engaging to work with". This suggests that making information within HBIM accessible to the public is not solely attributed to access controls. A useful example of how HBIM tools may be utilised for public engagement is given in Gaspari et al. [82]. Further concerns expressed by the participants, who otherwise expressed positive sentiments, involved the cost of implementation, applicability to private and sensitive heritage, and making sure the information was appropriate for the target audience to ensure engagement, understanding, and accessibility.

3.4.8. Asset Management

Asset management was the second most preferred use of HBIM, with several participants stating that they believed it would provide significant benefits for the way they managed their assets. Participants 14 and 18 were already utilising HBIM or HBIM-aligned tools for that purpose. Once again, participants saw the benefits of unifying all information about the asset and its contents and recording both historic and new information, such as maintenance records, collection registries, access logs, materials used, and past issues. Participant 33, who strongly agreed that HBIM would be beneficial for Asset Management, specified that they were envisioning "a shared Asset Management Database that functions as a Common Data Environment". Participant 5 also made the suggestion that any system should be "blurred between more modern and historic assets" to enable opportunities for collaboration across sectors. This implies that any HBIM development should be aligned with existing BIM practice, since it is the more mature application, to enable its applicability to both modern and historic assets.

Furthermore, other participants suggested it would provide a clear image of the assets they managed, citing the ability to break down the information from the whole structure to parts of it, with another participant suggesting it would allow them to see how an asset integrates with other assets.

Several participants mentioned the benefits of being able to clearly share information with others of varying levels of asset knowledge. This was in reference to members of management who may work with multiple assets and thus might not have the same level of asset-specific knowledge as the participant or for the purposes of training a participant's successor, consequently reducing the loss of organisational knowledge and ability.

Participants 4 and 10 mentioned the ability to know where an asset was in its lifecycle, with Participant 4 suggesting HBIM would be beneficial for the decommissioning of assets, specifically library closures in their case.

There were two negative responses to the use of HBIM for Asset Management. One was because the participant did not believe it was applicable to their assets (Participant 32) and the other was because the participant was unsure how it would assist them (Participant 6). The latter noted that this was likely due to their lack of familiarity with HBIM as opposed to a reflection on HBIM itself. Of the three neutral responses, one participant believed it was not applicable to their assets and another thought it would be extremely difficult to implement.

Some concerns were raised regarding the individuality of specific organisational needs, availability of funding and cost of implementation, and poor digital literacy among heritage organisations. However, the overall perception was positive with Participant 8 stating that "if you can overcome the creation cost, and up-skill the team so everyone could use the software I think HBIM could bring significant benefits in the way we manage our heritage assets".

3.4.9. Facilities Management

Some similar benefits for other uses were suggested for HBIM for Facilities Management: unification of data in one place, recording of previous maintenance work, and assistance with planning future work. Several participants referred to issues they experience currently. For instance, Participant 6 stated that most of the issues they experienced were associated with new additions to the building such as CCTV and Audio–Visual (AV) systems. Furthermore, Participant 29 referred to their own experience working on restored heritage assets saying, "knowing that, particularly in complex buildings that there's so much reporting and compliance reporting and post construction completion, there's O&Ms [Operation and Maintenance] that normally come over either digitally or in a paper format that they need to stay in the building and in my experience always get lost". Both participants thought that HBIM would be an improvement compared to the current approach of having to search through long O&M manuals or locate information when the storage location was unclear. The hope for virtual O&M information that can be easily used, annotated, and updated was a sentiment echoed by several participants.

As was also suggested in the renovations section (Section 3.4.4), two participants perceived benefits regarding the ability to monitor and improve environmental sustainability. Participant 10 desired the ability to monitor and report tangible evidence of their progress towards carbon neutrality. Participant 2, whose job is directly linked with decarbonisation and sustainability, provided more specific requirements, envisioning "space management through use of sensors to highlight areas of high and low occupancy which could in turn be used to guide energy management e.g., scheduling of lighting, heating or cooling operation times. Similarly, temperature and humidity sensors could be used to monitor environmental parameters to help control comfort of building users and ensure protection of building fabric". They went on to suggest that "HBIM could eventually be used as a platform to automate control of such parameters within acceptable thresholds" alluding to the use of true Digital Twins [83].

There was one negative response to the use of HBIM for Facilities Management and four neutral responses. Among the neutral responses, Participant 13 stated that they could not afford HBIM, and Participant 9 said the maintenance work was only occasional and on a small scale. Participant 21 agreed that HBIM would be beneficial but added that it was not vital in all cases.

3.4.10. Translocation

Translocation was the only use case where any participants strongly disagreed that HBIM would be beneficial. However, of the two negative responses, one provided extra information saying it was not likely to occur on their sites and the other provided no additional information, so it is unclear if they strongly disagreed with HBIM itself or the applicability to their role. However, six of the ten neutral responses also stated that the use was not applicable to their role or organisation. Therefore, whilst from Figure 9 translocation appears to be the least beneficial use case, part of this can be attributed to the fact that translocating heritage is a very rare occurrence [69].

Of the participants who provided positive responses, a few specific benefits were suggested. These included a greater understanding of components and build sequence, accurate details of structure, ensuring new additions such as foundations or new Mechanical and Electrical (M&E) installations existed within the bounds of the existing structure, and recording the exact details of objects before and after transport to ensure no differences or mistakes. The latter two benefits were primarily attributed to having accurate surveys of the structure.

3.4.11. Further Uses of HBIM

Participants were asked to give details of any further potential uses of HBIM that they felt were not covered by the categories provided in the survey. Six participants listed additional uses as follows:

- Participant 17: "Client communication—the ability to abstract a BIM record and represent it to support a report in a simple way so that non-technical readers can get an idea of what's being discussed". They also suggested "linking the building archaeology".
- Participant 18: "Integration with GIS tools for mapping and geospatial purposes. On a large site it is critical to be able to accurately report the location of assets. [It] would allow integrating topographical surveys with BIM models". The participant was aware of some support for this in Free Open-Source Software (FOSS) but not in proprietary BIM tools.
- Participant 21: "Tracing the uses of a place over time. Different circulation routes, public facilities, how entrances and exits changed".
- Participant 22: "If not already covered under previous headings, HBIM could be very valuable in monitoring & reporting of conditions over a continuous/protracted period of time".
- Participant 26: HBIM could be used within the Metaverse.
- Participant 33: "Risk management, version control, design coordination, [Construction Design and Management] (CDM) Reg[ulation]s 2015, H&S file, ongoing asset management".

A recurrent further use given was HBIM as a tool for ongoing Asset Management (Participant 30) and ongoing recording. This suggests that HBIM is perceived as a long-term tool for digital information management by the Heritage Community.

The other further uses suggested by the participants also serve as an additional validation of the theoretical information requirements identified in Lovell et al. [44] as many of the listed uses/functions correspond with the listed information requirements in Table 1. The exceptions to this are risk management, version control, design coordination, and 2015 CDM regulations. However, the CDM regulations outline the H&S requirements for construction projects and are a legal requirement within the UK [84]. Therefore, they should be incorporated within the 'Legal requirements' information category. The remaining are arguably incorporated under the third new information category (project files for proposed and/or previous capital work) suggested in Table 4, consequentially providing initial evidence for the validation of the proposed new category. Furthermore, version control and design coordination are existing capabilities of BIM tools, so they can be incorporated with minimal effort. Risk management utilising BIM tools is an emerging functionality [85].

At the end of the survey, Participant 21 suggested that HBIM could be a "useful way of sharing information with other owners of historic assets. People may not be aware there are similar assets nearby". This reiterates the earlier discussion regarding National Digital Twins (Section 1.2.1).

3.4.12. Perceived Barriers to HBIM Implementation

Previous work undertaken by the authors [43] on the topic of BIM-FM found a disconnect between the barriers to BIM implementation from an academic perspective and from an industry perspective. Therefore, as part of the survey, the participants were asked "What challenges do you think you'd face trying to use/implement a HBIM for the assets you work with?". The challenges suggested throughout the whole survey are listed in Table 7 in approximate order of commonality. Note that as the survey progressed, many participants provided extra comments regarding challenges they anticipated (also presented in Table 7).

Table 7. Perceived barriers to HBIM implementation.

Challenge [of Implementing HBIM]	Detail	Participant No.
Cost	Participants mentioned challenges regarding the cost of HBIM implementation, staff training, and ongoing use.	4, 5, 8, 10, 13, 17, 20, 21, 22, 23, 26, 33
Encouraging uptake	Participants believed it would be difficult to convince others in their organisation, clients, or external stakeholders to utilise HBIM.	14, 17, 18, 29, 32
Upskilling and training users/creators	Participants thought training people to use HBIM or have the skills to implement it would be a challenge.	5, 6, 8, 23, 27
Keeping the system in use and up to date	Participants envisaged challenges ensuring any HBIM system was continuously used and updated.	5, 10, 16, 21, 24
Time/effort/resource required to implement HBIM	Some participants believed the time taken to implement HBIM was not feasible with their available time and resources.	10, 17, 23, 30, 31
Making the user interface uncomplicated and more compelling than existing tools	Participants perceived challenges in making large amounts of data easily understandable and presenting it better than existing tools.	1, 2, 19, 28
Available software/hardware	Participants thought they had insufficient existing hardware/software or that it would be a challenge to gain sufficient hardware/software.	12, 23, 29
Ensuring robust quality control procedures are in place	Participants mentioned there would be a need to/or there would be difficulty in implementing quality control procedures	11, 24

Cost was the most frequently mentioned challenge (approximately 40% of participants). Participant 4 said, "previous requests to have BIM for new builds have been scrapped due to high costs of the system". However, the cost of HBIM implementation compared to the potential benefits resulting from ongoing use for data recording and Asset Management (envisioned by participants in Section 3.4.11) may mitigate this over time. Whilst appropriate business plans would help mitigate the challenge of cost, it is evident that an HBIM system that required too much initial financial investment without justifiable benefit would not be feasible.

Another perceived barrier was keeping the system up to date and in use. Participant 10 provided evidence that this is an existing issue, saying "[a problem] I'm finding with our [Computer Aided Facilities Management] CAFM system is who then is responsible for ensuring that the data is kept current and updating it when changes occur. [. . .] we find that it's completely out of date and nobody's been staying on top of it because we were all either locked down from Covid or furloughed and not doing anything". Any attempts to implement HBIM as a long-term solution should ensure that appropriate resources are allocated to its upkeep. Some other challenges mentioned by individual participants included having to share information with a wider (sometimes bespoke) audience (Participant 3), potentially not being able to use HBIM in the field (Participant 10), a lack of flexibility and limited information (Participant 15), the complexity of structures (Participant 15), and the environmental sustainability/impact of complex models (Participant 31).

4. Soft Systems Methodology for HBIM

As previously stated (Section 1.2), the root definition defines the core essence of the purposeful activity undertaken to improve a problematic situation. Root definitions for the same purposeful action will vary depending on the CATWOE used. Most importantly, the perception of a situation is influenced by a given worldview. Therefore, there is no single definitive root definition for a given action. Thus, to be considered valid, the root definition should instead be defensible by its authors. The root definition can be considered a sensemaking activity. As stated by Weick et al. [86], "sensemaking is not about truth and getting it right. Instead, it is about continued redrafting of an emerging story so that it becomes more comprehensive, incorporates more of the observed data, and is more resilient in the face of criticism". Simply put, by reading the contents of this paper and the stated CATWOE for the creation of the root definition, the logic behind the root definition proposed by the authors should be evident even if the readers' own internalised worldview may lead them to propose an alternative.

Reflecting on the discussions within Section 3 and the actions they believe would provide an improvement, the authors would thus like to suggest the following root definition for HBIM:

"A system owned and maintained by members of the Heritage Community involved in the management and maintenance of cultural heritage, which, utilising BIM and HBIM technology financially viable to the Heritage Community, contains, in a structured and connected manner, all the information required for heritage management. The system makes information easy to locate to ensure informed management decisions".

Note that there is a distinction between HBIM and HBIM technology. HBIM is a system, whereas HBIM technology refers to the individual hardware and software used to create and manage BIM and/or HBIM, e.g., a laser scanner for point cloud acquisition or Revit for model creation. None of these technologies alone can be considered HBIM, e.g., a model created in Revit could be part of an HBIM system but in isolation is just a model.

The CATWOE used to create the root definition was as follows:

C: Heritage Community;

A: Anyone involved in the management and maintenance of heritage;

T: Unconnected and unstructured information that is difficult to find and gather→ connected and structured information that is easy to find and gather;

W: Organised and easily accessible information will make Heritage Management more sustainable; it can be achieved using HBIM processes;

O: Heritage Community involved in the management and maintenance of heritage;

E: BIM and HBIM technology contain all information associated with an asset, is financially viable to Cultural Heritage owners, and is an ongoing management tool.

Figure 10 is a pictorial representation of the proposed transformation process. It is intended to express the current scenario and desired change as simply as possible without the need for additional textual explanation. The use of hand-drawn images within the field of the SSM is a conscious and well-established choice intended to reflect the organic nature of the method [33]. Please refer to Section 2.3 for further explanation.

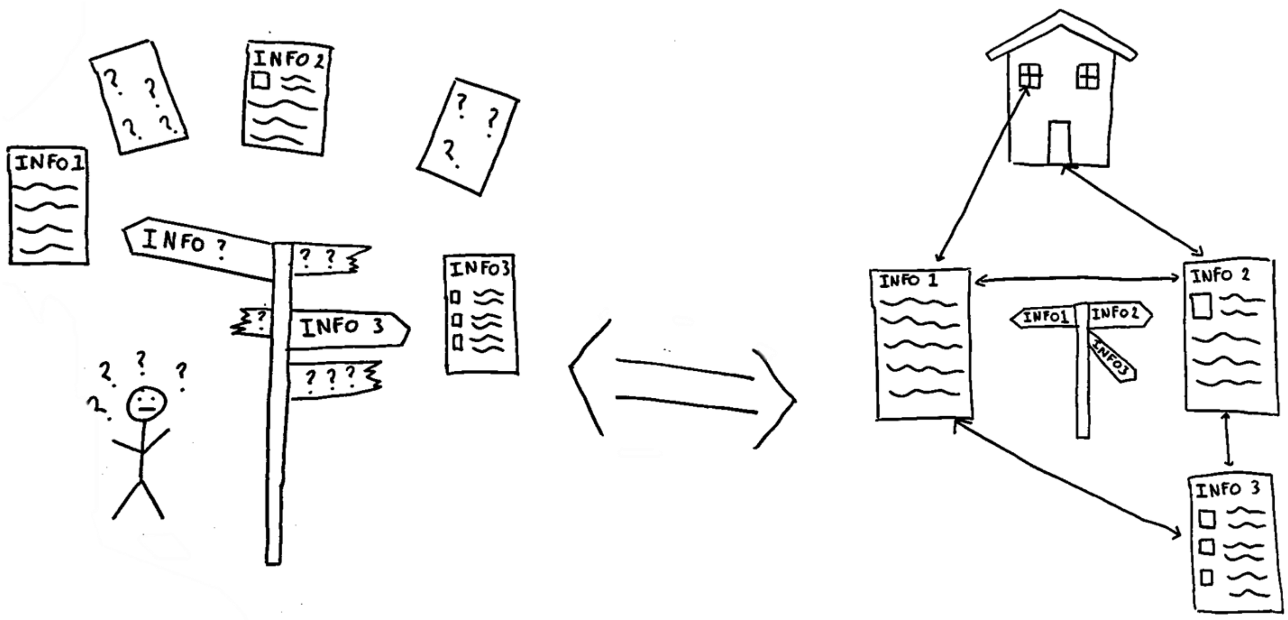

Figure 10. HBIM transformation process.

The key feature of this definition is that the focus is on structured information management as opposed to geometric modelling. As previously discussed (Section 1.1), geometric modelling has consistently been the primary focus of much research in the field of HBIM [2,4–9,11]. Future HBIM development should instead prioritise information management.

The aim of this paper was to utilise the SSM to answer the questions 'what is HBIM, who is it for, and why would it be used?'. The root definition proposes answers for all of these questions as follows:

- What: HBIM is a system that contains, in a structured and connected manner, all the information required for Heritage Management.
- Who: Members of the Heritage Community involved in the management and maintenance of Cultural Heritage.
- Why: The system makes information easy to locate to ensure informed management decisions.

The intention of the SSM is that it can be repeated on an ongoing basis, with each iteration providing incremental improvements to the problematic situation. This study acts as the first iteration of the SSM in the field of HBIM; it should in no way be the last. For instance, the authors would encourage any readers to look at the available data and consider proposing their own root definition. Alternatively, others may repeat this study with different members of the Heritage Community and see how the perception of the situation changes. It is partially from a desire to emphasise the accessibility of the SSM that the HBIM transformation process is drawn free-hand. There is an acknowledged disconnect between the academic development of HBIM and the eventual end users of HBIM [8,11,40,43], but SSM is an approach that should be applicable to anyone without the prerequisite of formal training in SSM.

5. Conclusions and Future Work

This paper presented the first part of a systems thinking approach to the development of HBIM. The management of CH, the problematic situation, was investigated by surveying thirty-three members of the Heritage Community with regards to their experience working with heritage, what challenges they face, what information they already possess, and current and desired features of information management in the CH sector.

It was found that information types already possessed by the survey participants corresponded with eleven of the twelve information categories previously proposed by the authors [44], thus providing preliminary validation of the proposed information categories. An additional three information categories (visual depictions, management plans/policies, and project files for proposed and/or previous capital work) were identified from survey responses.

Moreover, it was revealed that there is a strong desire for and trend towards digital information management within the CH sector, with many participants already utilising BIM-aligned tools. However, actual digital information management implementation is in its infancy and many participants struggle with extensive amounts of data stored in disparate or unknown manners. Perhaps consequentially, when asked to indicate their agreement with seven proposed uses of HBIM, participants were almost entirely positive, with the most preferred uses of HBIM being for Asset Management and as a virtual tool used to share heritage with the public. The latter is supposedly required due to the inherent expectation of public involvement with Heritage Management discussed by the participants.

The Soft Systems Methodology was subsequently utilised to define the core purpose of HBIM. The resulting root definition of HBIM is proposed as follows:

"A system owned and maintained by members of the Heritage Community involved in the management and maintenance of cultural heritage, which, utilising BIM and HBIM technology financially viable to the Heritage Community, contains, in a structured and connected manner, all the information required for heritage management. The system makes information easy to locate to ensure informed management decisions".

This differs from the theme of accurate model creation, which characterises much research into the development of HBIM, and places emphasis on HBIM as a tool for structured information management.

As part of the survey, twelve key challenges with regards to working with heritage, and eight perceived barriers to the implementation of HBIM were identified. In both cases, the most common responses referred to a lack of available funds and the theorised unviable cost of HBIM implementation. Hence, financial viability was included within the root definition. The authors strongly believe that HBIM development governed by the proposed root definition can be feasibly implemented in practice and will provide tangible benefits to the Heritage Community.

The suggested root definition proposes answers to the key questions of this article: what is HBIM, who is it for, and why would it be used?

Future work by the authors (Part 2 of this work) will detail the responses to the second half of the questionnaire. Systems Engineering techniques will be utilised to define the system requirements for HBIM. This will include further information, modelling, and functional requirements, which will enable the development of HBIM in line with the root definition proposed herein.

Author Contributions: Conceptualization, L.J.L. and R.J.D.; methodology, L.J.L.; validation, L.J.L.; investigation, L.J.L.; data curation, L.J.L.; writing—original draft preparation, L.J.L.; writing—review and editing, R.J.D. and D.V.L.H.; visualization, L.J.L.; supervision, R.J.D. and D.V.L.H. All authors have read and agreed to the published version of the manuscript.

Funding: The authors gratefully acknowledge the financial support of the UK Engineering and Physical Sciences Research Council (EPSRC) under grant number EP/W524396/1. The APC was funded by the University of Birmingham.

Data Availability Statement: The original data presented in this study are openly available in the UBIRA E Data Repository and can be accessed at the following link: https://doi.org/10.25500/edata.

bham.00001189 (accessed 24 October 2024). Ethical approval for the survey distribution and data sharing was granted by the Science, Technology, Engineering and Mathematics Committee at the University of Birmingham. All survey distribution and data storage were undertaken according to the approved application. A blank copy of the relevant consent form completed by all participants is available at the same link.

Acknowledgments: The authors would like to thank the School of Engineering at the University of Birmingham for providing access to its scanning equipment and BIM cave and the University of Birmingham Estates for providing access to various assets around campus that helped shape the formulation of the HBIM problem statement and for their contribution to survey responses. The authors would like to thank Samantha Organ and the wider National Trust team for their assistance with survey distribution. The authors would like to thank George Bence for his input to the pilot study and assistance with distributing the survey. Likewise, the authors would like to thank the Heritage Railway Association for distributing the survey among their members. Lastly, the authors would like to acknowledge the invaluable contribution of all the individuals and organisations that responded to the survey itself or participated in the pilot study.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of this study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Abbreviations

AEC	Architecture, Engineering, and Construction
AM	Asset Management
AR	Augmented reality
AV	Audio–Visual
BIM	Building Information Modelling
CAD	Computer-Aided Design
CAFM	Computer-Aided Facilities Management
CCTV	Closed-Circuit Television
CDBB	Centre for Digital Built Britain
CDE	Common Data Environment
CDM	Construction Design and Management
CH	Cultural Heritage
CIOB	Chartered Institute of Building
CPD	Continuing Professional Development
EH	English Heritage
FM	Facilities Management
FOSS	Free Open-Source Software
GISs	Geographic Information Systems
H&S	Health and Safety
HBIM	Historic Building Information Modelling
HERs	Historic Environment Records
HRP	Historic Royal Palaces
INCOSE	International Council on Systems Engineering
LOD	Level of Detail
M&E	Mechanical and Electrical
NIST	National Institute of Standards and Technology
NT	National Trust
O&M	Operation and Maintenance
RIBA	Royal Institute of British Architects
RICS	Royal Institution of Chartered Surveyors
SDG	Sustainable Development Goals

SE	Systems Engineering
SSM	Soft Systems Methodology
UK	United Kingdom
UN	United Nations
VR	Virtual reality

References

1. United Nations. 11: Make Cities and Human Settlements Inclusive, Safe, Resilient and Sustainable. Available online: https://sdgs.un.org/goals/goal11 (accessed on 4 December 2023).
2. Lovell, L.J.; Davies, R.J.; Hunt, D.V.L. The Application of Historic Building Information Modelling (HBIM) to Cultural Heritage: A Review. *Heritage* **2023**, *6*, 6691–6717. [CrossRef]
3. Murphy, M.; McGovern, E.; Pavia, S. Historic Building Information Modelling (HBIM). *Struct. Surv.* **2009**, *27*, 311–327. [CrossRef]
4. Yang, X.; Grussenmeyer, P.; Koehl, M.; Macher, H.; Murtiyoso, A.; Landes, T. Review of Built Heritage Modelling: Integration of HBIM and Other Information Techniques. *J. Cult. Herit.* **2020**, *46*, 350–360. [CrossRef]
5. García-Valldecabres, J.; Pellicer, E.; Jordan-Palomar, I. BIM Scientific Literature Review for Existing Buildings and a Theoretical Method: Proposal for Heritage Data Management Using HBIM. In Proceedings of the Construction Research Congress 2016: Old and New Construction Technologies Converge in Historic San Juan, San Juan, Puerto Rico, 31 May–2 June 2016.
6. Pocobelli, D.P.; Boehm, J.; Bryan, P.; Still, J.; Grau-Bové, J. BIM for Heritage Science: A Review. *Herit. Sci.* **2018**, *6*, 30. [CrossRef]
7. López, F.J.; Lerones, P.M.; Llamas, J.; Gómez-García-Bermejo, J.; Zalama, E. A Review of Heritage Building Information Modeling (H-BIM). *Multimodal Technol. Interact.* **2018**, *2*, 21. [CrossRef]
8. Ewart, I.J.; Zuecco, V. Heritage Building Information Modelling (HBIM): A Review of Published Case Studies. In *Advances in Informatics and Computing in Civil and Construction Engineering*; Springer International Publishing: Cham, Switzerland, 2019; pp. 35–41.
9. 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]
10. Penjor, T.; Banihashemi, S.; Hajirasouli, A.; Golzad, H. Heritage Building Information Modeling (HBIM) for Heritage Conservation: Framework of Challenges, Gaps, and Existing Limitations of HBIM. *Digit. Appl. Archaeol. Cult. Herit.* **2024**, *35*, e00366. [CrossRef]
11. Liu, J.; Li, B. Heritage Building Information Modelling (HBIM): A Review of Published Case Studies. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2024**, *XLVIII-1-2024*, 387–393. [CrossRef]
12. Checkland, P.; Holwell, S. *Information, Systems and Information Systems: Making Sense of the Field*; John Wiley & Sons: Chichester, UK, 1998.
13. The Forum on Information Standards in Heritage (FISH). *MIDAS Heritage—The UK Historic Environment Data Standard*, v1.1; Historic England: Swindon, UK, 2012.
14. National Institute of Standards and Technology Information System. Available online: https://csrc.nist.gov/glossary/term/information_system (accessed on 10 April 2024).
15. The Royal Academy of Engineering. Creating Systems That Work: Principles of Engineering Systems for the 21st Century. 2007. Available online: https://raeng.org.uk/media/o3cnzjvw/rae_systems_report.pdf (accessed on 21 August 2023).
16. Bolton, A.; Butler, L.; Dabson, I.; Enzer, M.; Evans, M.; Fenemore, T.; Harradence, F.; Keaney, E.; Kemp, A.; Luck, A.; et al. Gemini Principles. 2018. Available online: https://www.cdbb.cam.ac.uk/DFTG/GeminiPrinciples#:~:text=The%20Gemini%20Principles%20report%20was,share%20data%20in%20the%20future (accessed on 21 August 2023).
17. INCOSE UK Z5: Lean Systems Engineering. 2020. Available online: https://incoseuk.org/Documents/zGuides/Z5_Lean_rebrand_issue1.2_pdf_web.pdf (accessed on 21 August 2023).
18. Connor, D. *Information System Specification & Design Roadmap*; Prentice Hall: Hoboken, NJ, USA, 1985.
19. Council of Europe. *Convention on the Value of Cultural Heritage for Society (Faro Convention)*; Council of Europe: Faro, Portugal, 2005.
20. INCOSE, UK. Systems Thinking. Available online: https://incoseuk.org/Normal_Files/WhatIs/Systems_Thinking (accessed on 10 April 2024).
21. Gemini Council; Lamb, K. Gemini Papers: What Are Connected Digital Twins. 2022. Available online: https://www.cdbb.cam.ac.uk/files/gemini_papers_-_what_are_connected_digital_twins.pdf (accessed on 21 August 2023).
22. Centre for Digital Built Britain. About the Centre for Digital Built Britain. Available online: https://www.cdbb.cam.ac.uk/AboutCDBB (accessed on 10 April 2024).
23. Gemini Council; Lamb, K. Gemini Papers: How to Enable an Ecosystem of Connected Digital Twins. 2022. Available online: https://www.cdbb.cam.ac.uk/files/gemini_how.pdf (accessed on 21 August 2023).
24. Albert, M.-T.; Bernecker, R.; Cave, C.; Prodan, A.C.; Ripp, M. *50 Years World Heritage Convention: Shared Responsibility—Conflict & Reconciliation*; Albert, M.-T., Bernecker, R., Cave, C., Prodan, A.C., Ripp, M., Eds.; Springer International Publishing: Cham, Switzerland, 2022; ISBN 978-3-031-05659-8.

25. Historic England Historic Environment Records (HERs). Available online: https://historicengland.org.uk/advice/technical-advice/information-management/hers/ (accessed on 20 April 2024).
26. Know Your Place About the Project. Available online: https://www.kypwest.org.uk/about-the-project/ (accessed on 20 April 2024).
27. Arches Arches for HERs. Available online: https://www.archesproject.org/arches-for-hers/ (accessed on 15 December 2024).
28. Floros, G.S.; Ellul, C. Loss of Information during Design & Construction for Highways Asset Management: A GeoBIM Perspective. *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.* **2021**, *VIII-4/W2-2021*, 83–90. [CrossRef]
29. Moretti, N.; Ellul, C.; Re Cecconi, F.; Papapesios, N.; Dejaco, M.C. GeoBIM for Built Environment Condition Assessment Supporting Asset Management Decision Making. *Autom. Constr.* **2021**, *130*, 103859. [CrossRef]
30. Colucci, E.; de Ruvo, V.; Lingua, A.; Matrone, F.; Rizzo, G. HBIM-GIS Integration: From IFC to CityGML Standard for Damaged Cultural Heritage in a Multiscale 3D GIS. *Appl. Sci.* **2020**, *10*, 1356. [CrossRef]
31. Matrone, F.; Colucci, E.; De Ruvo, V.; Lingua, A.; Spanò, A. HBIM in a Semantic 3D GIS Database. *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.* **2019**, *42*, 857–865. [CrossRef]
32. Ramage, M.; Shipp, K. *Systems Thinkers*; Springer: London, UK, 2020; ISBN 978-1-4471-7474-5.
33. Checkland, P.; Scholes, J. *Soft Systems Methodology in Action*; John Wiley & Sons Ltd.: Hoboken, NJ, USA, 1990; ISBN 0-471-92768-6.
34. INCOSE Systems and SE Definitions. Available online: https://www.incose.org/about-systems-engineering/system-and-se-definitions (accessed on 10 April 2024).
35. Checkland, P.B. The systems movement and the "failure" of management science. *Cybern. Syst.* **1980**, *11*, 317–324. [CrossRef]
36. Checkland, P. *Systems Thinking, Systems Practice: Includes a 30-Year Retrospective*; Wiley: Hoboken, NJ, USA, 1999; ISBN 978-0-471-98606-5.
37. INCOSE. *INCOSE Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities*, 4th ed.; John Wiley & Sons: Hoboken, NJ, USA, 2015.
38. Checkland, P.; Poulter, J. *Learning for Action: A Short Definitive Account of Soft Systems Methodology, and Its Use for Practitioner, Teachers and Students*; John Wiley & Sons Ltd.: Hoboken, NJ, USA, 2006.
39. Checkland, P. From Optimizing to Learning: A Development of Systems Thinking for the 1990s. *J. Oper. Res. Soc.* **1985**, *36*, 757–767. [CrossRef]
40. Liu, J.; Foreman, G.; Sattineni, A.; Li, B. Integrating Stakeholders' Priorities into Level of Development Supplemental Guidelines for HBIM Implementation. *Buildings* **2023**, *13*, 530. [CrossRef]
41. *ISO 19650-3:2018*; Organization and Digitization of Information about Buildings and Civil Engineering Works, Including Building Information Modelling (BIM). Information Management Using Building Information Modelling. Operational Phase of the Assets. The British Standards Institute: London, UK, 2018.
42. Global Forum on Maintenance and Asset Management. *The Asset Management Landscape*, 2nd ed.; Global Forum on Maintenance and Asset Management, 2014; Available online: https://gfmam.org/sites/default/files/2019-05/GFMAMLandscape_SecondEdition_English.pdf (accessed on 1 November 2023).
43. Lovell, L.J.; Davies, R.J.; Hunt, D.V.L. Building Information Modelling Facility Management (BIM-FM). *Appl. Sci.* **2024**, *14*, 3977. [CrossRef]
44. Lovell, L.; Davies, R.J.; Hunt, D.V.L. Theoretical Information Requirements for Historic Building Information Modelling. In Proceedings of the FCIC'24 Faro Convention International Conference, Porto, Portugal, 29 January 2024. in publication.
45. Goodman, L.A. Snowball Sampling. *Ann. Math. Stat.* **1961**, *32*, 148–170. [CrossRef]
46. *BS ISO 55000:2014*; Asset Management. Overview, Principles and Terminology. The International Standards Organisation: Geneva, Switzerland, 2014.
47. Historic England. *Practical Building Conservation: Conservation Basics*; Martin, B., Wood, C., McCaig, I., Eds.; Routledge: Oxford, UK, 2024; Volume 3.
48. McDonald, D.; Barter, M.; Shepherd, A.; Joynt, A. *RIBA Conservation Guide*, 1st ed.; Routledge: Oxford, UK, 2024; ISBN 9781914124877.
49. Heesom, D.; Boden, P.; Hatfield, A.; De Los Santos Melo, A.; Czarska-Chukwurah, F. Implementing a HBIM Approach to Manage the Translocation of Heritage Buildings. *Eng. Constr. Archit. Manag.* **2021**, *28*, 2948–2966. [CrossRef]
50. Gates, E.F. Rich Pictures: A Visual Method for Sensemaking Amid Complexity. *Am. J. Eval.* **2024**, *45*, 238–257. [CrossRef]
51. The Open University Rich Pictures. Available online: https://www.open.edu/openlearn/science-maths-technology/engineering-technology/rich-pictures (accessed on 13 December 2024).
52. *ISO 41011:2017(En)*; Facility Management—Vocabulary. The International Standards Organisation: Geneva, Switzerland, 2017.
53. Cohen, L.; Manion, L.; Morrison, K. *Research Methods in Education*, 5th ed.; Routledge: Oxford, UK, 2000; ISBN 0-415-19541-1.
54. RIBA. *RIBA Plan of Work 2020 Overview*; RIBA: London, UK, 2020.
55. Rathnasiri, P.; Jayasena, S. Green Building Information Modelling Technology Adoption for Existing Buildings in Sri Lanka. Facilities Management Perspective. *Intell. Build. Int.* **2022**, *14*, 23–44. [CrossRef]

56. Brunet, M.; Motamedi, A.; Guénette, L.M.; Forgues, D. Analysis of BIM Use for Asset Management in Three Public Organizations in Québec, Canada. *Built Environ. Proj. Asset Manag.* **2019**, *9*, 153–167. [CrossRef]
57. Government Data Quality Hub. Hidden Costs of Poor Data Quality. Available online: https://www.gov.uk/government/news/hidden-costs-of-poor-data-quality (accessed on 2 July 2024).
58. Haug, A.; Zachariassen, F.; Liempd, D. van The Costs of Poor Data Quality. *J. Ind. Eng. Manag.* **2011**, *4*, 168–193. [CrossRef]
59. McPartland, R. What Is the Common Data Environment (CDE)? Available online: https://www.thenbs.com/knowledge/what-is-the-common-data-environment-cde#:~:text=For%20example,%20a%20project%20might,out%20in%20Employer%E2%80%99s%20Information%20Requirements (accessed on 14 March 2024).
60. UNESCO; ICCROM; ICOMOS. IUCN Enhancing Our Heritage Toolkit 2.0: Assessing Management Effectiveness of World Heritage Properties and Other Heritage Places. 2023. Available online: https://whc.unesco.org/en/eoh20/ (accessed on 20 February 2024).
61. Mayouf, M.; Jones, J.; Elghaish, F.; Emam, H.; Ekanayake, E.M.A.C.; Ashayeri, I. Revolutionising the 4D BIM Process to Support Scheduling Requirements in Modular Construction. *Sustainability* **2024**, *16*, 476. [CrossRef]
62. Boton, C. Supporting Constructability Analysis Meetings with Immersive Virtual Reality-Based Collaborative BIM 4D Simulation. *Autom. Constr.* **2018**, *96*, 1–15. [CrossRef]
63. Xi, W.; Cong, W. Remote Practice Methods of Survey Education for HBIM in the Post-Pandemic Era: Case Study of Kuiwen Pavilion in the Temple of Confucius (Qufu, China). *Appl. Sci.* **2022**, *12*, 708. [CrossRef]
64. García, E.S.; García-Valldecabres, J.; Blasco, M.J.V. The Use of HBIM Models as a Tool for Dissemination and Public Use Management of Historical Architecture: A Review. *Int. J. Sustain. Dev. Plan.* **2018**, *13*, 96–107. [CrossRef]
65. Conti, A.; Fiorini, L.; Massaro, R.; Santoni, C.; Tucci, G. HBIM for the Preservation of a Historic Infrastructure: The Carlo III Bridge of the Carolino Aqueduct. *Appl. Geomat.* **2022**, *14*, 41–51. [CrossRef]
66. Cheng, Y.M.; Mou, C.C.; Lu, Y.C.; Yen, Y.N. HBIM in Cultural Heritage Conservation: Component Library for Woodwork in Historic Buildings in Taiwan. In *Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection*; Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics); Springer: Cham, Switzerland, 2018; Volume 11196.
67. English Heritage. *Sustainable Conservation Principles*; English Heritage: Swindon, UK, 2023.
68. UNESCO Institute for Statistics. Conservation of Cultural Heritage. Available online: https://uis.unesco.org/en/glossary-term/conservation-cultural-heritage (accessed on 24 April 2024).
69. Kołakowski, T. Translocation of Historic Monuments as an Economic Project. *J. Interdiscip. Res.* **2016**, *5*, 31–35.
70. Autodesk. Revolutionizing Facility Management for a Historic Educational Institution with Digital Twins. Available online: https://intandem.autodesk.com/resource/february-2024-webinar/?mktvar002=6254648004%7CEML%7C775937782&utm_medium=email&utm_source=follow-up&utm_campaign=6254648operationalfy-24-q4-tandem-product-update-webinar-january&utm_id=6254648004&mkt_tok=OTE4LUZPRC00MzMAAAGRQfiXpAMgGCZz9pIjZQAtB7dgl44iwfGr9y3cz9hPGpOlfrYpEf-0_7mgiDiakJOm2een7X0CZWApJInyagKQSMi12gZ9-de-pVp7bBCl6ETocxFBf_BH#recording (accessed on 24 April 2024).
71. Boesgaard, C.; Hansen, B.V.; Kejser, U.B.; Mollerup, S.H.; Ryhl-Svendsen, M.; Torp-Smith, N. Prediction of the Indoor Climate in Cultural Heritage Buildings through Machine Learning: First Results from Two Field Tests. *Herit. Sci.* **2022**, *10*, 176. [CrossRef]
72. Sudbury Gasworks Restoration Trust. The Gasworks in 3D. Available online: https://sudburygasworks.com/2023/01/19/the-gasworks-in-3d/ (accessed on 10 April 2024).
73. Akcamete, A.; Akinci, B.; Garrett, J.H. Potential Utilization of Building Information Models for Planning Maintenance Activities. In Proceedings of the EG-ICE 2010—17th International Workshop on Intelligent Computing in Engineering, Nottingham, UK, 30 June–2 July 2010.
74. Tsay, G.S.; Staub-French, S.; Poirier, É. BIM for Facilities Management: An Investigation into the Asset Information Delivery Process and the Associated Challenges. *Appl. Sci.* **2022**, *12*, 9542. [CrossRef]
75. Matarneh, S.; Danso-Amoako, M.; Al-Bizri, S.; Gaterell, M.; Matarneh, R. BIM-Based Facilities Information: Streamlining the Information Exchange Process. *J. Eng. Des. Technol.* **2019**, *17*, 1304–1322. [CrossRef]
76. Currà, E.; D'amico, A.; Angelosanti, M. HBIM between Antiquity and Industrial Archaeology: Former Segrè Papermill and Sanctuary of Hercules in Tivoli. *Sustainability* **2022**, *14*, 1329. [CrossRef]
77. Lin, G.; Giordano, A.; Sang, K. From site survey to HBIM model for the documentation of historic buildings: The case study of Hexinwu Village in China. *Conserv. Sci. Cult. Herit.* **2020**, *20*, 111–123.
78. Ermenyi, T.; Enegbuma, W.I.; Isaacs, N.; Potangaroa, R. Building Information Modelling Workflow for Heritage Maintenance. In Proceedings of the International Conference of the Architectural Science Association, Auckland, New Zealand, 26–27 November 2020.
79. Barrile, V.; Fotia, A. A Proposal of a 3D Segmentation Tool for HBIM Management. *Appl. Geomat.* **2022**, *14*, 197–209. [CrossRef]

80. Ruffino, P.A.; Permadi, D.; Gandino, E.; Haron, A.; Osello, A.; Wong, C.O. Digital Technologies for Inclusive Cultural Heritage: The Case Study of Serralunga d'alba Castle. *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.* **2019**, *4*, 141–147. [CrossRef]
81. Banfi, F.; Bolognesi, C.M.; Bonini, J.A.; Mandelli, A. The Virtual Historical Reconstruction of the Cerchia Dei Navigli of Milan: From Historical Archives, 3D Survey and HBIM to the Virtual Visual Storytelling. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2021**, *46*, 39–46. [CrossRef]
82. Gaspari, F.; Barbieri, F.; Fascia, R.; Ioli, F.; Pinto, L. An Open-Source Web Platform for 3D Documentation and Storytelling of Hidden Cultural Heritage. *Heritage* **2024**, *7*, 517–536. [CrossRef]
83. *ISO/IEC 30173:2023*; Digital Twin—Concepts and Terminology. The International Standards Organisation: Geneva, Switzerland, 2023.
84. Health and Safety Executive. *Managing Health and Safety in Construction Construction (Design and Management) Regulations 2015*; Health and Safety Executive: London, UK, 2015.
85. Salzano, A.; Cascone, S.; Zitiello, E.P.; Nicolella, M. Construction Safety and Efficiency: Integrating Building Information Modeling into Risk Management and Project Execution. *Sustainability* **2024**, *16*, 4094. [CrossRef]
86. Weick, K.E.; Sutcliffe, K.M.; Obstfeld, D. Organizing and the Process of Sensemaking. *Organ. Sci.* **2005**, *16*, 409–421. [CrossRef]