

Article

HBIM as a Tool for the Conservation of Vernacular Heritage: Exploring Its Potential for the Preservation of Traditional Hórreos in Northern Spain

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Abstract

Traditional “hórreos”, vernacular granaries widely distributed across northern Spain, constitute a highly valuable form of cultural heritage due to their historical, architectural, and ethnographic significance. However, their progressive deterioration, dispersion in rural contexts, and limited maintenance resources pose significant challenges for their long-term conservation. This research article explores the potential of the Historic/Heritage Building Information Modelling (HBIM) methodology as an innovative and effective tool for the documentation, analysis, conservation, and management of “hórreos” as cultural heritage assets. The study proposes an HBIM-based workflow adapted to the specific characteristics of “hórreos”, integrating data acquisition techniques such as laser scanning, photogrammetry, and historical archival research with parametric modelling of traditional construction elements. The resulting HBIM models are conceived not only as geometric representations, but as comprehensive digital repositories that store historical data, construction techniques, materials, conservation states, and recorded pathologies. The research analyses how HBIM supports decision-making in restoration planning and enables preventive maintenance strategies over time. Furthermore, the article discusses the role of HBIM in improving heritage management at a territorial scale, enabling standardised inventories and supporting institutional protection policies. The potential of HBIM for heritage dissemination, education, and digital preservation is also examined. The results highlight HBIM as a powerful and adaptable methodology that contributes to a more sustainable, informed, and holistic approach to the conservation of “hórreos”, enhancing both their physical preservation and their transmission as living cultural heritage.



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1. Introduction

The conservation of vernacular architecture is based on protecting not only the buildings themselves, but also the culture, traditional techniques and the relationship between them and their environment that they represent [1]. This involves intervening as little as possible, maintaining their use and functionality, and prioritising repair over replacement to preserve their authenticity [2]. It is also essential to use local materials and traditional knowledge to integrate these elements into their territorial context and to promote sustain-

able management that considers both social and environmental factors, thereby ensuring their transmission to future generations [3,4].

The “hórreo” is one of the most characteristic buildings of the vernacular architecture of Asturias (Spain) [5] and of other areas in the north-west of the Iberian Peninsula [6,7]. It is an auxiliary structure for agricultural and livestock farming and rural dwellings, and its main function was to dry and store harvested produce, protecting it from damp, rodents and other animals [8]. In the past, their use was widespread throughout the humid regions of the Iberian Peninsula, from northern Portugal to the inland valleys of Navarre, but today they are found only in the regions of Asturias and Galicia in northern Spain. It is currently estimated that there are approximately 10,000 “hórreos” in Asturias and 35,000 in Galicia, although they are gradually disappearing due to abandonment and a lack of maintenance. “Hórreos” are threatened by the lack of training in traditional trades linked to “hórreo” culture, as well as by the lack of documentation regarding both construction and restoration techniques, and the uses, functions, values and significance of the “hórreo” [9]. Some authors also point out that another problem regarding the conservation of these structures lies in the absence of a comprehensive register covering all “hórreos”, the lack of detailed information on each one, poor regulation in terms of legislation, rural depopulation and limited understanding of the significance of these structures [5].

In recent years, the Government of the Principality of Asturias has implemented various measures to protect the “hórreo”, most notably the “Hórreo Plan” [10], which seeks to reconcile heritage conservation with their current use by regulating new uses, simplifying administrative procedures and providing grants for their restoration. This plan also provides for the amendment of current regulations to facilitate controlled interventions and promote the economic viability of these properties without compromising their cultural values. At the same time, at national level, the process has begun to designate the “hórreos” of the north of the Iberian Peninsula as a Representative Manifestation of Intangible Cultural Heritage [11], thereby strengthening the protection not only of their physical form but also of the associated knowledge, traditional techniques and symbolic values [12,13]. Added to this are initiatives by other public and private bodies, such as cultural associations and grant schemes for restoration, as well as research, cataloguing and inventory projects that contribute to their documentation and active conservation. Taken together, these actions reflect a shift towards a more comprehensive model of protection, combining regulation, active management and the cultural enhancement of the “hórreo”.

In this regard, the application of new techniques such as the HBIM (Heritage Building Information Modelling) methodology can assist in the conservation of hórreos in various ways:

- Many “hórreos” in Asturias are at risk due to neglect; therefore, the use of HBIM would enable the creation of a digital archive of rural heritage, generating accurate 3D models that record their geometry, materials, construction techniques and ornamental elements, thereby preserving this information even if the “hórreo” itself disappears.
- “Hórreos” are not merely simple structures, but a building system based on traditional knowledge, such as nail-free timber joinery or other specific construction techniques, which in many cases have been passed down solely through oral tradition. The application of HBIM would enable these techniques to be documented, organised into databases and integrated into parametric models, thereby preserving traditional building knowledge.
- HBIM can also facilitate a detailed study of the granary’s condition, identifying deterioration (damp, deformation, rot), detecting structural failures and enabling long-term monitoring, which is particularly important in Asturias, given that its damp and rainy climate accelerates the degradation of the timber.

- A good HBIM model would also serve to improve the planning and execution of conservation interventions by enabling the prior simulation of construction solutions, the assessment of the impact of interventions, and the documentation of the restoration phases of the “hórreos”, where it is essential to respect traditional techniques and avoid aggressive interventions.
- As mentioned above, Asturias has thousands of “hórreos” scattered across the region, which makes their management difficult. The creation of structured digital inventories and the integration of information into territorial databases using HBIM would enable each case to be classified according to its type, condition and level of protection. This would facilitate the design of public conservation policies, the prioritisation of interventions and the monitoring of heritage, making it a key tool for management at a regional level. HBIM can be directly linked to the definition of the level of protection and restrictions on use and intervention. The model serves as a tool for verifying regulatory compliance, managing authorisations and documenting legal interventions.
- Finally, HBIM can also facilitate cultural dissemination through 3D visualisation, virtual or augmented reality, and the production of educational material, transforming a rural feature into an active cultural resource.

Despite the growing adoption of Heritage Building Information Modelling (HBIM) for the documentation and management of cultural heritage assets, most existing applications have focused on monuments, religious buildings, archaeological sites, and architecturally significant historic structures. In contrast, vernacular architecture, particularly traditional timber granaries such as the Asturian hórreo, has received comparatively limited attention within the HBIM field. This represents a significant research gap, especially considering the cultural, historical, and ethnographic value of these structures and the increasing threats posed by abandonment, lack of maintenance, and the gradual disappearance of traditional construction knowledge.

Furthermore, the morphological diversity of “hórreos”, together with their distinctive constructive solutions based on timber assembly systems and reversible joints, presents specific challenges for digital documentation and information modelling that are not commonly addressed in existing HBIM studies. Consequently, there is a need to evaluate the suitability of HBIM methodologies for documenting, managing, and preserving this type of vernacular heritage.

Consequently, the aim of this study is to adapt HBIM to the specific characteristics and needs of the “hórreo”. The following chapter describes the state of the art of the HBIM methodology and the standard stages of its application. The stages of this methodology are then examined, adapting its application to the characteristics of this type of building through a specific case study. The results are then discussed in relation to other relevant research studies. Finally, the key conclusions of this study are drawn, whilst also proposing possible avenues for future development.

2. State of the Art

Building Information Modelling (BIM) has become an established approach to design, analysis and documentation processes within the architecture, engineering and construction industry [14]. A Building Information Model (BIM) is a set of information structured in such a way that data can be shared. These models provide a three-dimensional, parametric representation of the building's components and should be understood as a virtual representation of the building prior to construction. One of the main advantages of BIM is that it facilitates understanding of the construction sequence, whilst enabling the correction of design issues identified in the plans based on construction logic, thereby preventing design errors from reaching the construction phase. Although BIM and HBIM share many of their

characteristics and possibilities, BIM is based on the design of new buildings, whilst HBIM takes existing buildings as its starting point.

The concept of HBIM was first used in the work of Murphy et al. [15] at the Dublin Institute of Technology. HBIM aims to model and document architectural elements according to artistic, historical and constructional typologies [16]. Following numerous studies carried out in recent years in the fields of historical and archaeological heritage—often with varying scopes, HBIM is becoming an established practice [17,18] for documenting the condition of artefacts [19,20], analysing the phenomena to which they are subject, studying their construction processes diachronically [21], managing restoration sites [22], and monitoring the evolution of artefacts over time.

The HBIM methodology has been applied in different stages depending on the specific case or objective of each study [23–28]. Despite these differences, all authors agree on three basic stages:

1. Data capture: This is the starting point of the process, and various technologies and methods may be used, such as laser scanning, photogrammetry and the compilation of available historical documentation. The main difficulties at this stage are limited access, complex geometries and the high cost of some of the techniques employed.
2. Data processing: Dependent on the preceding capture stage, this involves cleaning, aligning and refining point clouds and other information obtained. Depending on the subject under study, the volume of data, as well as acquisition errors within it, it can complicate this stage.
3. Modelling: This involves converting the previously acquired information into a parametric BIM. The lack of specific component libraries and irregular geometry are the main challenges in carrying out this stage.

Differences between models arise as the scope of HBIM is expanded; in some cases, historical analysis [25], which examines the building's evolution, or stratigraphic analysis is included. The level of detail in the technical process is also significant, leading some authors to establish preliminary planning stages or specific processing phases [24]. It is also possible to integrate the life cycle, that is, the management, maintenance and monitoring of the building under study [27]. The current trend is towards more integrated, interoperable models geared towards heritage management [29].

The HBIM methodology has been applied in various studies to vernacular architecture, small-scale buildings or timber structures, some of which share characteristics comparable to the “hórreo”. For instance, it has been used in the preservation and renovation of traditional timber dwellings in China [30,31]. In these cases, the complex timber-framed structures primarily involve the use of posts and beams as the main structural components; that is, components that are more regular and, therefore, more easily parameterised than those used in “hórreos”. Although the “hórreo” is functionally simpler, it is highly distinctive from a constructional perspective. It is a modular, demountable and highly rationalised system, which requires a modelling approach focused more on individual components and places greater emphasis on joints. Consequently, it is necessary to model construction details with greater relative precision, as well as to develop highly specific libraries. Unlike other cases studied in the literature, which generally focus on monumental or larger-scale buildings, the “hórreo” is a unique example due to its small size, its modular and demountable nature, and its widespread geographical distribution, which poses specific methodological challenges in terms of scalability, efficiency and standardisation of modelling.

3. HBIM Methodology Applied to Hórreos

The application of the HBIM methodology to an Asturian “hórreo” presents several challenges, including:

- The limited availability of historical documentation for individual “hórreos”.
- High variability between “hórreos” (there is no single standard).
- Difficulties in modelling caused by timber deformation and traditional joinery.
- The cost of developing an HBIM model can be high relative to the individual value of a “hórreo”.

In this case, the HBIM methodology has been applied to the modelling of the “hórreo” shown in Figure 1, located in Argüero, Villaviciosa, Asturias (Spain). This recently constructed “hórreo” replaced an earlier one built on the same site but which had to be dismantled due to structural safety issues. The selection of this particular hórreo was also influenced by practical considerations related to accessibility. Most hórreos are privately owned structures and access for detailed surveying, inspection, and data acquisition is frequently restricted. The selected case study offered the necessary level of access to perform comprehensive documentation and modelling activities while remaining representative of the traditional typology.



Figure 1. Modelled “hórreo” located in Argüero, Villaviciosa, Asturias (Spain).

It was built from chestnut wood (*Castanea sativa*), which is widely used in Asturias due to its resistance to damp, fungi and rot, as well as its dimensional stability and availability, as it is abundant in Asturian forests. Its construction can be dated to 1999, and it is used by its owner more as an ornamental feature on the plot than as a traditional granary. This “hórreo” is considered a representative case study for the application of the HBIM methodology because it incorporates all the essential architectural, structural, and constructive elements that define this vernacular building typology. The building preserves the characteristic configuration of the Asturian “hórreo”, including its elevated structure, support system, chamber, roof, and traditional timber assembly principles,

thereby accurately reflecting the spatial and constructive logic of these granaries. While some of its timber components were manufactured using modern industrial processes rather than traditional handcrafting techniques, this circumstance does not diminish its validity as a case study for HBIM development. From this perspective, the geometric, functional, and constructive characteristics that are relevant for HBIM implementation remain fully represented in the selected example. Furthermore, given the considerable variability that exists among “hórreos” in terms of dimensions, details, and decorative or functional elements, the chosen case provides a suitable and realistic representation of the typology while allowing the proposed methodology to be tested and validated under real conditions.

3.1. Project Objectives and Planning

The first phase of the HBIM project consists of defining the specific objectives of the model to be developed, as well as planning the subsequent stages. In the case of structures such as the “hórreo”, this primarily involves heritage documentation, assessment of the state of conservation, and the planning of future interventions. It is therefore necessary to establish the required level of detail (LOD) for the modelling and to select the most appropriate tools, such as photogrammetry and BIM software. In this context, a specific challenge is striking a balance between the level of detail and the effort required, as the “hórreo” is a relatively small structure with considerable architectural complexity; this means that an excessively detailed model may not be proportionate to the practical value of the project.

Several HBIM studies have highlighted that the appropriate level of development should be selected according to the intended use of the model rather than pursuing the highest possible geometric detail [32,33]. Table 1 compares the characteristics of each LOD, highlighting their advantages and disadvantages according to their intended purpose and their applicability to the Asturian hórreo. For documentation, conservation assessment and intervention planning purposes, a medium-to-high level of detail combined with enriched semantic information is often considered more effective than highly detailed geometric modelling, providing an appropriate balance between modelling effort and practical usefulness.

In this case, the most appropriate level of detail is around LOD 300, accompanied by a high level of information (LOI). This level allows for the sufficiently accurate representation of both the general geometry and the main structural elements, whilst also including certain relevant details of traditional joints (basic assemblies, structural connections, arrangement of components). Furthermore, it is sufficiently accurate to reflect significant deformations, identify defects and analyse structural behaviour, whilst also allowing for the incorporation of non-geometric information on materials, construction techniques and state of repair, which are fundamental to decision-making. A higher level, such as LOD 400 or above, would prove inefficient in terms of time and cost for this type of heritage.

The next step involves planning the data capture and processing stages, as well as the HBIM itself, for which it is necessary to select the appropriate tools based on the objectives and characteristics of the proposed project. This selection must consider not only the modelling itself, but also the requirements of the subsequent stage involving the analysis, management and monitoring of the “hórreo”.

Table 1. LOD comparison.

Level	Main Characteristics	Advantages	Disadvantages	Application to Asturian Hórreos
LOD 200	Simplified geometry, approximate dimensions, and a limited amount of associated information.	Reduced modelling time; lower costs; suitable for general inventories and cataloguing activities.	Limited ability to represent construction details, deformations, and pathologies; reduced usefulness for conservation studies.	Territorial inventories or preliminary surveys involving a large number of hórreos.
LOD 300	Model closely aligned with reality, including an accurate definition of the main construction elements and a medium-to-high level of information.	Good balance between accuracy, modelling effort, and practical usefulness; supports construction analysis, heritage documentation, and condition assessment.	Does not fully reproduce all geometric irregularities and unique details; some complex elements may require simplification.	Generally, the most appropriate level for heritage documentation, conservation assessment, and intervention planning.
LOD 400	Highly detailed model reproducing geometric irregularities and containing the maximum amount of available information.	Highest geometric fidelity; suitable for detailed studies of joints, traditional construction systems, and advanced structural analysis.	High data acquisition and modelling costs; time-consuming; may include more detail than required for specific objectives.	Advanced research projects, complex restoration works, or detailed analysis of traditional construction techniques.

3.2. Data Capture and Processing

At this stage, data are collected using photographs, manual measurements and, where possible, photogrammetry or laser scanning; however, given the general characteristics of “hórreos”, namely, that they are small structures, in many cases it is not cost-effective to use high-cost technologies:

- Direct measurement and conventional photographic documentation can provide adequate results more quickly and, in a manner, proportionate to the scope of the project.
- Photogrammetry is particularly useful for “hórreos” when precision and detailed analysis are required. Its main advantage is its ability to capture actual geometry, including deformations and complex details. It may be unnecessary or inefficient when the project’s objectives are basic, such as simple documentation or cataloguing; when the geometry is straightforward and does not require the capture of actual deformations; or when there are budget and time constraints.
- Given the high cost, the need for specialised equipment and the time involved in processing large point clouds, 3D laser scanning is generally excessive for HBIM of a “hórreo”, unless the project’s objective requires very high geometric accuracy for a detailed analysis of deformations or structural defects.

Based on the data collected, all elements of the “hórreo” are documented, such as the “pegollos”, the timber body, the roof and the assembly details. In the specific case of “hórreos”, the main difficulties stem from accessibility issues, due to the presence of vegetation, the proximity of other nearby structures or the height of the body itself, which makes it difficult to capture details of the lower section and the roof that are difficult to document. Furthermore, in many cases, various elements have irregular geometry, with non-orthogonal features and deformations caused by ageing and other problems.

In this case, the measurements were taken manually and are shown in Figure 2, which also identifies some of the characteristic elements of this type of building.

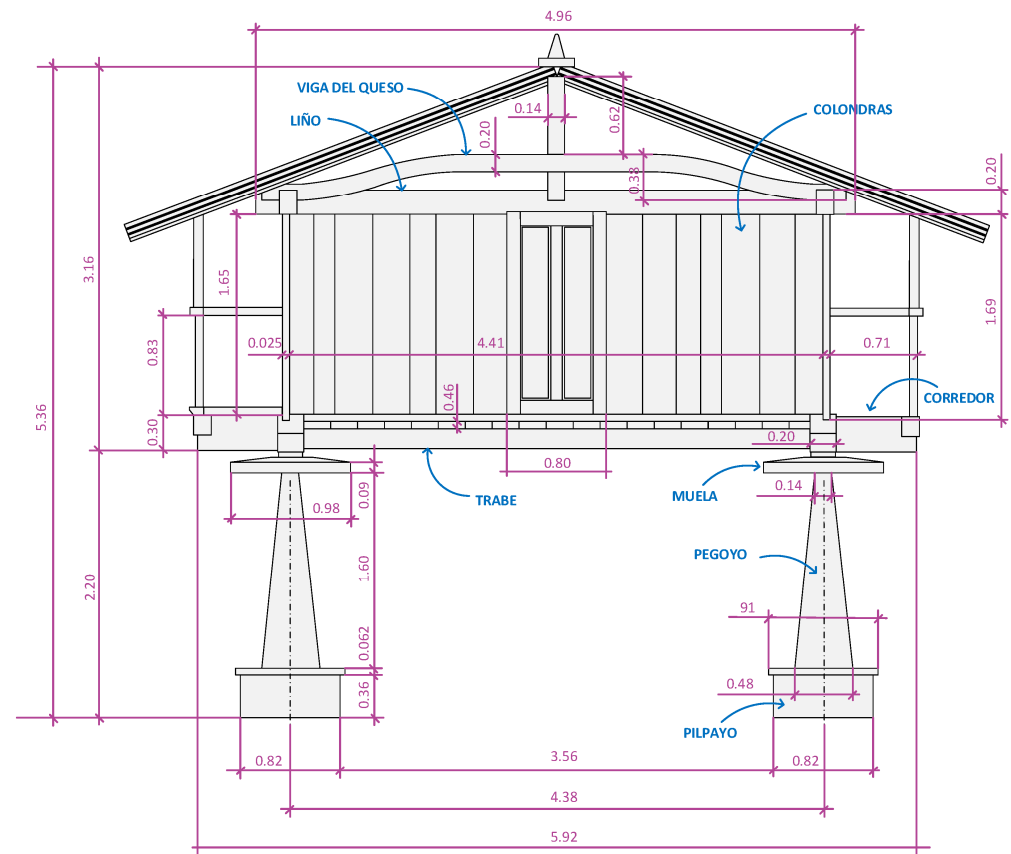


Figure 2. Dimensions of the modelled “hórreo” (metres).

In addition to the dimensions of the elements, in the case of Asturian “hórreos”, it is useful at this stage of the project to compare their specific construction characteristics with those of the reference “hórreo” in Asturias. This “hórreo”, located at the Museo del Pueblo de Asturias in Gijón, is technically known as the “hórreo patron” [34]. It can be typologically dated to the 18th–19th centuries, although it does not correspond to a specific date but rather represents a reconstruction or synthesis of the traditional Asturian model based on historical examples from that period. It embodies the classical structural canon, with a strictly square floor plan and constructed entirely of timber (oak or chestnut), a hipped roof, stable proportions and clean joints. Any variation observed when studying another “hórreo”, such as a different joinery method or a thinner type of “colondra” (the vertical plank forming the walls), helps to classify it within a specific geographical school or to identify whether it is a more archaic or evolved model. It is therefore regarded as the benchmark for research into traditional Asturian architecture and serves as a technical basis and architectural model for guiding restoration and conservation projects for other “hórreos”:

- It provides the geometric and assembly model, enabling traditional carpenters and restorers to measure its exact proportions, the angles of the timber cuts and the nail-free interlocking systems (tongue-and-groove joints) to replicate them faithfully in damaged “hórreos” across the region.
- As it is monitored by researchers, this “hórreo” provides data on how oak or chestnut timber responds to weight and weather conditions over the years, establishing a baseline for ageing that helps technicians predict when and where the structure of other “hórreos” will fail, depending on their exposure to the elements.
- Official restoration projects use the components of this model (such as the pegs, millstones and “colondras”) to determine which materials and techniques are acceptable

when applying for public heritage conservation funding, thereby avoiding the use of cement, metals or unsuitable timbers.

The differences between this “model hórreo” and the one used as a case study are notable:

1. In terms of its external appearance, the “hórreo” that is the subject of this study features an element uncommon in “hórreos” dating from before the 19th century: an external perimeter walkway that runs around the “hórreo”, increasing its size. The walkway is attached to the beams by means of cantilevered pieces known as “almanques”. This walkway was first developed for a structure like the “hórreo”, known as a “panera”, with the aim of increasing the surface area required for drying maize cobs and, at the same time, facilitating air circulation to speed up the process. From the 19th century onwards, “hórreos” featuring this additional structure began to appear. The “hórreo patron”, on the other hand, is simpler and lacks this external corridor; consequently, its dimensions appear smaller. Instead, it features four elements—one at each corner of the base, which brace the eaves of the roof and are known as “tentemozos”.
2. The presence of this corridor necessitated increasing the height of the hórreo’s body, thereby facilitating the passage of people; consequently, this difference in height can also be observed in the images (Figures 1 and 3).
3. Another difference, which has implications for the BIM process, is that the “hórreo” under consideration in this study is of relatively recent construction, as indicated above. Consequently, the timber used in its structural elements has been industrially processed to a greater or lesser extent. Thus, a large proportion of the structural elements can be treated as “primitives” that are easily represented using BIM software (beams, columns, walls, etc.). In contrast, the “standard hórreo”, although also built of timber, is in this case made of very minimally processed timber and, in any case, hand-crafted; consequently, the curvature, knots and imperfections make it very difficult to treat these elements as BIM primitives.



Figure 3. “Model hórreo”, Museum of the Asturian People in Gijón, Asturias (Spain).

3.3. HBIM

In this phase, the parametric model of the “hórreo” is constructed using the information obtained in the previous phase, distinguishing between elements such as the *pegollos*, the *tornarratas*, the body and the roof. Simple parametric families are usually employed, which are then adjusted manually. The main difficulty in this case is that *hórreos* feature non-standard geometries and traditional construction systems (nail-free joints), which makes it difficult to represent them in conventional BIM software. Furthermore, the warping of the timber necessitates simplification choices that may affect the model’s accuracy.

To fulfil its function, regardless of its type and the materials used, any kind of “hórreo” consists, from the bottom upwards, of the following three elements:

1. The substructure, comprising supports known as “*pegollos*”, which are tall enough to insulate the structure from ground damp and prevent access by vermin. They rise from the foundation and are topped with small slabs known as “*muelas*” or “*tornaratas*”, which prevent rodents from entering.
2. The body, an intermediate granary with either permeable or solid walls, depending on whether its primary purpose is to dry the harvest or to store it once dried.
3. The roof, which protects the structure from the external environment and which, depending on the type of *hórreo*, may be gabled, hipped or hipped-gabled.

Figure 4 illustrates the phases of this modelling process, which correspond to the main stages of “hórreo” construction [35]. It begins with the placement of the supporting elements (“*pilpayo*”, “*pegollo*”, “*muela*”), upon which the base of the body is placed, consisting of the “*trabes*” and the “*pontas*” (Figure 4a). Next, the side walls are constructed from “*colondras*”, that is, the vertical planks that form the enclosure of the body (Figure 4b). Once the square body is complete, the parts forming the base of the roof are placed, upon which the roof rests (Figure 4c). Finally, the roofing material is laid (Figure 4d), in this case roof tiles.

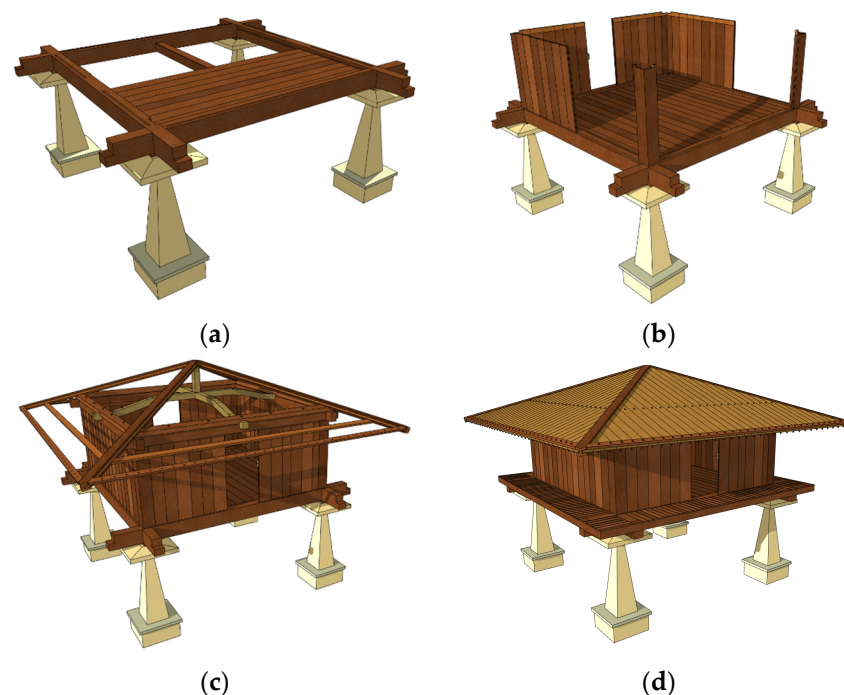


Figure 4. “Hórreo” modelling stages. (a) Installation of support elements; (b) Construction of walls; (c) Installation of the roof base; (d) Roofing with tiles.

Modelling the construction details in an HBIM model of an Asturian “hórreo” is essential, as it allows for the accurate representation not only of the building’s overall geometry, but also of the traditional timber joinery systems that define its structural behaviour and heritage value. These elements contain key information on historical construction techniques, which cannot be captured through the simplifications inherent in conventional BIM. Including these details in the HBIM model enables a more accurate analysis of the state of conservation, facilitates interventions that respect the original construction logic, and contributes to the preservation of traditional technical knowledge. Furthermore, these detailed models serve as a tool for documentation, research and dissemination, enabling the complexity and uniqueness of this vernacular heritage to be conveyed with rigour.

In this regard, in the Asturian hórreo, the “colondras” are joined together by auxiliary pieces called “almillas”, which act as interlocking elements without the need for nails or metal fittings, as can be seen in Figure 5, which includes real-life images alongside the corresponding model. Each “colondra” features longitudinal grooves along its side edges into which the “almillas”, which are generally thinner, are inserted, functioning as connecting tongues between two adjacent boards. This system allows for the formation of a continuous, flexible and perfectly assembled structure, capable of adapting to the expansion and deformation of the wood over time. Furthermore, the connection using “almillas” facilitates the assembly and partial dismantling of the “hórreo” and contributes to internal ventilation, as it maintains subtle gaps that allow air to circulate—an essential condition for the drying and preservation of the stored produce.

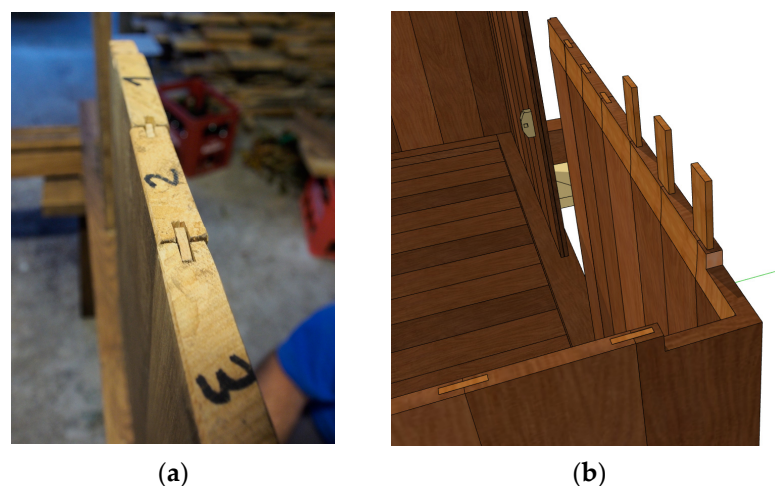


Figure 5. Construction detail of the “hórreo” storage chamber enclosure: (a) real image, (b) model.

The connection between the “toca”, the name given to the upper component that acts as the wall coping and roof support, and the “aguilones” (sloping elements that form the roof truss structure) is achieved through a traditional timber joinery system combining mortise-and-tenon joints and direct supports (Figure 6). The “toca” features notches on its upper surface or at its ends to accommodate the feet of the “aguilones”, ensuring their correct positioning and the transfer of loads to the walls. This connection is usually achieved using box-and-tenon joints or tailored recesses, which guarantee stability without the need for metal components, whilst also allowing for a certain degree of adjustment to accommodate movement in the timber. In this way, the “toca” functions as an intermediate structural distribution element, whilst the “aguilones” rest firmly upon it, forming the base of the roof and ensuring the correct transfer of loads from the roof to the “hórreo” as a whole.



Figure 6. Construction detail of the joint between the “toca” and the “aguilones”: (a) real image, (b) Model.

A characteristic element in the roof structure of the Asturian “hórreo” is the so-called “viga del queso”, which plays a fundamental role as a central supporting element, as the “pilarillo” rises from it—a small vertical piece situated at the keystone of the truss (Figure 7). This element acts as a meeting point and support for the four “aguilones”, which rise from the sides of the roof until they converge at the apex. The connection is achieved through traditional timber joints, in which the upper ends of the “aguilones” fit into the “pilarillo” via recesses or mortises, transferring the roof loads to the “viga del queso” and, from there, to the rest of the structure. This system allows for a balanced distribution of forces and ensures the stability of the roof, whilst maintaining the removable and flexible construction logic characteristic of the hórreo, adapting to dimensional variations in the timber without resorting to metal fixings.

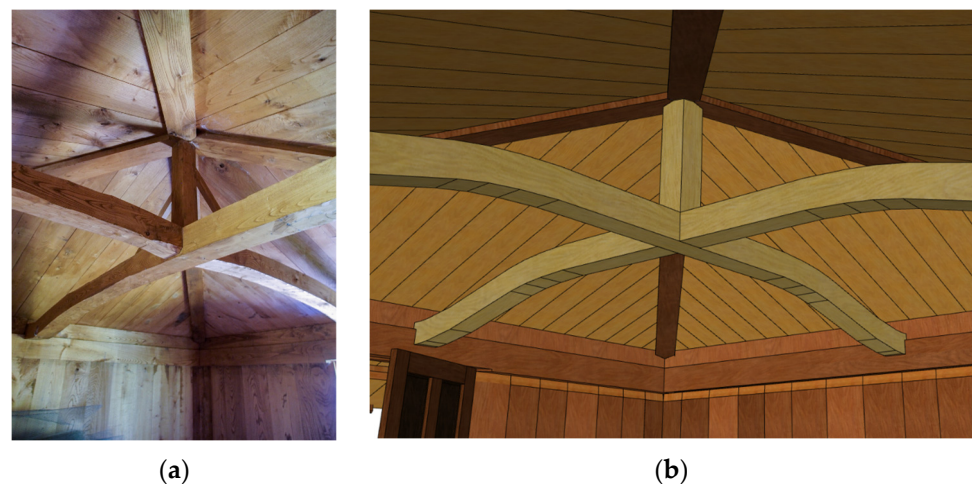


Figure 7. Construction detail of the “viga del queso” supporting the roof structure: (a) real image, (b) Model.

With the addition of the staircase, usually made of wood and situated between two “pegollos”, the “hórreo” enters its final stages of construction, which focus on ensuring accessibility, protection and the functional closure of the structure. In the case of the modelled “hórreo”, as shown in Figure 8, a stone staircase is included between the “pegollos”. This type of solution offers great durability and resistance to damp but partially breaks with the traditional construction logic of the “hórreo”, which is designed to be fully dismantlable. Once the staircase has been installed, which allows elevated access to the storage chamber and maintains protection against rodents thanks to the rodent-proof fittings, work proceeds to the finishing of the enclosures, ensuring the correct assembly of doors, walkways (if

any) and ventilation elements. Final adjustments are also made to the structural elements, checking the overall stability of the structure and the functionality of the traditional joints. Finally, any additional elements are added, such as railings, decorative features or specific solutions depending on the type of “hórreo”, resulting in a fully functional “hórreo” ready for its traditional use as a ventilated storage space. In this case, the “hórreo” features an external corridor made of timber, using the same species as the rest of the “hórreo” (mainly chestnut or oak).

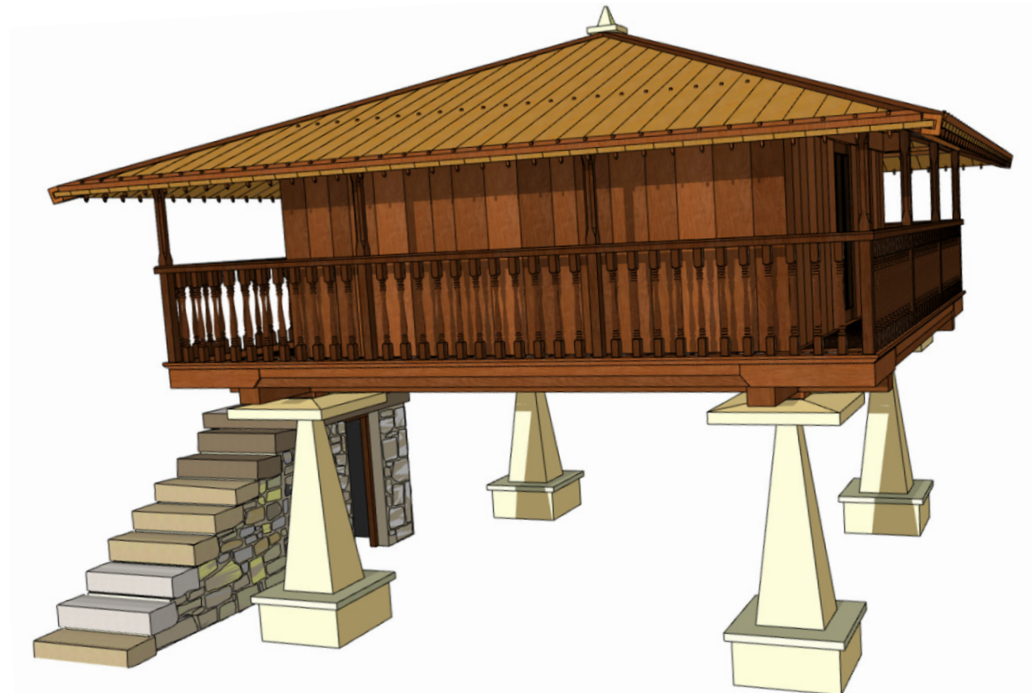


Figure 8. HBIM model of the study “hórreo”.

The model is supplemented with non-geometric information, such as materials, state of preservation, construction techniques and historical data. In the case of the hórreo, this includes the identification of the timber (chestnut or oak), the stone used for the “pegollos” and the construction type. The main difficulty is usually the lack of specific documentation for each hórreo, which means one has to rely on estimates or general knowledge of vernacular heritage, thereby reducing the reliability of the information included in some cases.

3.4. Analysis, Management and Life Cycle

The HBIM model of an Asturian “hórreo” can incorporate a wide range of information that goes far beyond mere geometry, integrating data that enables the heritage asset to be fully understood, analysed and managed. In addition to precise geometric information about the building (dimensions, deformations and spatial configuration) and construction details relating to structural systems and traditional joints—such as timber joinery or elements specific to the “hórreo” (pegollos, colondras, roof, etc.)—it can also include other relevant information. It is essential to incorporate information on materials, including the type of timber, stone or roofing, together with their physical properties. Added to this is information on the state of conservation, which may include issues such as damp, deterioration or structural deformations, enabling a detailed diagnosis. The HBIM model allows for the assessment of the hórreo’s structural and material condition, detecting deformations, defects (damp, rot) and potential risks. In this case, problems such as uneven

settlement or deterioration of the timber can be identified. However, a significant difficulty is the uncertainty surrounding the properties of the materials, particularly in old timber structures, which limits the accuracy of the analyses and the reliability of the simulations.

The model can also be supplemented with historical and heritage data (chronology, typology, evolution of the *hórreo*), as well as regulatory and conservation information (listing status, legal restrictions). It is also possible to integrate the history of interventions and maintenance, and finally spatial and management information, such as location, relationship with the “*quintana*” (farmstead) or future planning. Finally, the HBIM model can be used as a management tool, enabling the monitoring of the *hórreo*’s condition and the planning of future inspections or interventions. Taken together, this dataset makes the HBIM model a true digital twin of the *hórreo*, useful both for scientific analysis and for its long-term conservation and management. In this context, a common problem is the lack of continuity in the use of the models, as many HBIM projects are not updated over time due to resource constraints or the absence of clear digital maintenance protocols.

4. Discussion

The use of an HBIM model applied to an Asturian “*hórreo*” represents a significant advance over traditional documentation methods, both in terms of the volume of information and the capacity for analysis and management. Conventional procedures, based on plans, sketches, photographic documentation and textual descriptions, provide a necessarily partial and static representation of the building. In contrast, the HBIM methodology allows precise geometry to be integrated into a single digital environment alongside information on construction, materials, diagnostics and history, generating a more complete, coherent and dynamic representation. Furthermore, the HBIM model facilitates the continuous updating of data, the analysis of defects, the simulation of interventions and management throughout the asset’s life cycle, aspects that are difficult to achieve using traditional techniques. However, its implementation still presents certain challenges, such as the relatively high cost of development and the need for specialised resources, particularly in small-scale buildings such as “*hórreos*”, as well as the requirement for specific training in the methodology and associated tools [36].

The results obtained demonstrate that HBIM can be effectively applied to the documentation and management of Asturian *hórreos*, extending its scope beyond the monumental and architecturally complex heritage assets that have traditionally dominated HBIM research. Similar studies have demonstrated the usefulness of HBIM for the digital documentation of churches, palaces, archaeological sites, and other historic buildings, highlighting its ability to integrate geometric and semantic information within a single digital environment. However, applications focused on vernacular architecture remain comparatively limited. In this context, the present study confirms that HBIM can also be adapted to small-scale heritage structures while preserving the information management capabilities that have been reported in larger and more complex heritage assets.

Furthermore, although recent literature points to a general trend towards the use of laser scanning in the initial data capture phase, due to its high precision and ability to record complex geometries and construction details [26], this study proposes an alternative strategy based on the manual capture of information. This choice is driven both by the research objectives and the characteristics of the subject under study, a small-scale building, as well as the need to optimise the costs of the process, thereby demonstrating the viability of lighter methodological approaches in certain contexts. This finding is particularly relevant in the context of vernacular heritage, where financial and technical resources are often limited. The proposed workflow demonstrates that acceptable modelling results

can be achieved through less resource-intensive approaches, improving the feasibility of large-scale documentation initiatives.

The research also highlights the importance of selecting an appropriate level of development (LOD) according to the objectives of the project. Existing HBIM literature frequently emphasises the advantages of highly detailed models; however, several authors have also noted that increasing model complexity may significantly raise modelling costs and processing requirements without necessarily providing additional benefits for conservation management. The experience gained during this study supports this position. The use of LOD300 allowed the representation of the main constructive and geometric features of the *hórreo* while maintaining a reasonable balance between information content and modelling effort. This outcome suggests that intermediate levels of development may be particularly suitable for small vernacular buildings, where the primary objective is usually documentation, inventorying, and conservation planning rather than fabrication or structural simulation.

Furthermore, one of the aspects repeatedly highlighted in the literature is the lack of a standardised HBIM methodology [37], which reinforces the value of studies applied to specific cases. In this regard, this paper analyses and adapts the HBIM methodology to the specific context of small vernacular buildings, such as Asturian *hórreos*, whose formal and structural characteristics present difficulties in being directly translated into conventional three-dimensional modelling primitives. This adaptation may contribute to the definition of methodological criteria applicable to future developments in HBIM. In this regard, various authors have highlighted the need to develop specific parametric libraries [24], given that many of the characteristic elements of this type of architecture have no equivalent in standard BIM catalogues. The case of the Asturian *hórreo* further confirms this limitation, since characteristic elements such as *pegollos*, *colondras*, traditional timber joints, and roof components are not available in standard BIM catalogues. Modelling these components is often time-consuming due to their geometric complexity and the level of parameterisation required, which, in certain cases, necessitates the adoption of simplification strategies in line with the objectives of the HBIM project.

The diversity and complexity of traditional timber architectural heritage pose numerous challenges for the establishment of HBIM, both from a theoretical perspective and in its practical applications [38]. In this context, “*hórreos*” present a unique constructional feature that sets them apart from other vernacular buildings: their design as demountable and relocatable structures. This feature not only defines their construction logic but also confers upon them a specific heritage value, linked to traditional assembly techniques and their ability to adapt to the local environment. Consequently, the preservation of this construction knowledge is particularly important, and the HBIM methodology presents itself as an ideal tool for its documentation and accurate representation.

Furthermore, as various authors have pointed out, a significant proportion of the work carried out using HBIM has focused primarily on generating high-precision geometric representations of historic buildings [39]. However, to fully harness the potential of this methodology, the model must incorporate information relating to maintenance, conservation and restoration activities throughout the building’s entire life cycle, from the initial design through to its use and management. In this regard, HBIM should not be viewed merely as a documentation tool, but as a comprehensive heritage management system capable of supporting decision-making and the planning of long-term interventions.

5. Conclusions

The application of the HBIM methodology to an Asturian *hórreo* demonstrates that this digital approach can be successfully extended beyond the monumental and architecturally

prominent heritage assets that have traditionally dominated HBIM research. The main scientific contribution of this study lies not in the development of a new HBIM methodology, but in its adaptation to a vernacular timber structure characterised by small dimensions, high typological variability, modular construction systems, and strong links to traditional building knowledge. The results confirm that HBIM can effectively accommodate the specific geometric, constructive, and semantic requirements of this heritage typology, providing a structured framework for its documentation and management.

A key methodological contribution of the research is the adaptation of standard HBIM workflows to the particular characteristics of Asturian *hórreos*. This includes the definition of an appropriate level of development (LOD300) for balancing modelling effort and information requirements, the generation of specific parametric families for elements not represented in conventional BIM libraries, and the incorporation of heritage-related information associated with traditional construction techniques, assembly systems, materials, and conservation aspects. These adaptations demonstrate that HBIM workflows can be tailored to the needs of vernacular architecture while maintaining consistency with internationally recognised information modelling practices.

From a practical perspective, the generated HBIM model provides a centralised digital environment capable of integrating geometric, constructive, historical, and conservation-related information. This facilitates documentation, data management, condition assessment, and future intervention planning. The model also constitutes a valuable support tool for heritage professionals, public authorities, researchers, and owners by enabling the systematic recording of information and creating a digital basis for future monitoring and maintenance activities. In addition, the availability of interoperable IFC models promotes data sharing and long-term accessibility, enhancing the potential use of the information in different conservation and management contexts.

The proposed approach also contributes to the sustainable management of cultural heritage. The digitalization and structured documentation of *hórreos* support more informed decision-making processes, improve the planning of conservation actions, and facilitate the preservation of traditional knowledge associated with these buildings. By providing accurate and accessible information throughout the asset lifecycle, HBIM can help optimise available resources, prioritise interventions, reduce information loss, and support long-term conservation strategies. In this sense, the methodology contributes not only to heritage documentation but also to the sustainable management and safeguarding of a vernacular architectural typology that is currently threatened by abandonment, deterioration, and the gradual disappearance of traditional construction practices.

The study also presents several limitations that should be acknowledged. The methodology was tested on a single case study and therefore does not encompass the full diversity of *hórreo* typologies present across Asturias and neighbouring regions. Furthermore, the research focused primarily on the development of the HBIM model and the organisation of heritage information, without addressing advanced applications such as long-term monitoring systems, maintenance databases, environmental performance analyses, structural assessments, or repair simulation procedures. Future research should also establish objective indicators related to modelling efficiency, geometric accuracy, information completeness, interoperability, and conservation management capabilities, allowing comparisons between different workflows and levels of development. These aspects, while compatible with the proposed HBIM framework, remain beyond the scope of the present work.

Future research should expand the methodology to a broader range of *hórreo* typologies and other vernacular structures in order to assess its scalability and adaptability. Additional work could also focus on the development of standardised information protocols for conservation management, the integration of monitoring and inspection data,

the implementation of predictive maintenance strategies, and the connection of HBIM models with Geographic Information Systems (GISs) and regional heritage inventories. Such developments would further strengthen the role of HBIM as a comprehensive tool for the preservation, sustainable management, and long-term planning of vernacular cultural heritage.

Overall, this study represents a first step toward the systematic digital documentation and management of Asturian hórreos. The results demonstrate that HBIM provides a robust and adaptable framework for preserving both the tangible and intangible values of these unique buildings, while opening new opportunities for research, conservation, dissemination, and sustainable heritage management.

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Abbreviations

The following abbreviations are used in this manuscript:

BIM	Building Information Modelling
GISs	Geographic Information Systems
HBIM	Heritage Building Information Modelling

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