

RESEARCH DESIGN AND EVALUATION OF AN INTEGRATIVE ARTEFACT FOR HBIM AND THE ABC METHOD WITHIN DESIGN SCIENCE PARADIGM

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Abstract

This article presents the research design process and validation of a scientific artefact developed under the Design Science Research (DSR) paradigm. The study addresses a problem in cultural heritage management related to data integration and visualisation to support preventive conservation through interoperable digital systems. The research is structured as a research cycle that includes problem identification and motivation, definition of solution objectives, artefact design and development, demonstration of its operation, performance evaluation, and communication of results. The artefact was validated using qualitative and quantitative methods with experts to assess its conceptual coherence, usefulness, and applicability in real contexts. The results confirm the suitability of the DSR approach for the construction and evaluation of technological solutions applied to cultural heritage.

Keywords

Design Science Research (DSR), Artifact evaluation, Interoperability, Risk management, Preventive conservation, Environmental Sensors

1. Introduction

Advances in digital technologies have transformed documenting, analysing and managing cultural heritage, giving rise to new opportunities for preventive conservation and the adoption of data-driven measures. However, this technological progress also poses methodological challenges, such as the design of research that produces technically sound, theoretically coherent and empirically validated artefacts.

In this context, Design Science Research (DSR) has established itself as a methodological paradigm aimed at solving problems through the application of knowledge to create artefacts that respond to real-world needs (Hevner, March, Park, & Ram, 2004). The process begins with the need to design an artefact or with the observation of a problematic situation that justifies the creation of a formalised solution (Dresch, 2013).

The aim of this paper is to describe the design of the research and the evaluation of an artefact in accordance with the Design Science Research paradigm and to demonstrate how its principles can be applied in the field of the preventive conservation management of cultural heritage.

The main objective of the artefact is to optimise the processes of collecting, analysing and visualising data on environmental conditions, conservation state and potential damage to a heritage asset, and to convert this data into useful information for risk decision-making.

The result is an interoperable workflow that integrates data from environmental sensors (Bergomi, Comite, Guglielmi, Borelli, Bonomi, Ciprandi, Mariani, Faggiano, Ricciardi, Proto, & Fermo, 2022; Moretti, Scurpi, Proietti, & Fiore, 2024; Tringa, Kavrouidakis, & Tolika, 2024), HBIM models (Cursi, Martinelli, Calcerano, Clavano, & Gigliarelli, 2025; Ippolito, Attenni, & Darwa, 2023; Martinelli, Calvano, Calcerano, & Gigliarelli, 2025; Sbrogiò, 2024; Valentini, Battini, & Vecchiattini, 2023) and the ABC risk management system (Coelho, Amorim, Silva, Karsten, Perdesoli Jr., Michalski, & Feltmann, 2022).

The evaluation process uses the artefact's implementation results in a pilot case: the heritage site of the Real Colegio-Seminario de Corpus Christi (Colegio del Patriarca) in Valencia, Spain.

The structure of the paper is organised as follows. The introduction section outlines the research context and objectives. The Methods

section describes the research design process based on the theoretical foundations of the Design Science Research (DSR) paradigm, presenting the main methodological references applied. The Results section presents the application of the proposed methodological framework, including evaluation and validation strategies, and the obtained results. The Discussion section analyses the results, reflecting on the artefact's functionality, the achievement of the research objectives and the feasibility of its implementation. Finally, the Conclusions section summarises the study's main evaluation within the Design Science Research paradigm.

Due to the breadth and complexity of the research, a detailed description of the workflow and its technical implementation, as well as the full experimental results, are beyond the scope of this paper and are presented in the author's doctoral thesis (Rolim, 2026). The article focuses on the research design process and evaluation of the artefact within the Design Science Research paradigm.

2. Methods

2.1 Design Science Research paradigm

This research is based on the design sciences paradigm, also referred to as the artificial sciences (Simon, 1996). The objective of design sciences is to solve problems by applying knowledge systematically to create artefacts that address real-world needs (Hevner et al., 2004). Unlike the natural sciences, which focus on explaining existing phenomena, the design sciences seek to determine 'what is effective' by creating and evaluating solutions for specific problems (Gregor & Hevner, 2014; Hevner et al., 2004).

This approach has been selected due to its ability to integrate scientific rigour with practical relevance. This allows the construction of the artefact (the HBIM-ABC workflow) to be more than just a technical exercise; it becomes a formalised response to a problematic situation observed in the management of the preventive conservation of heritage assets. The activities of this research therefore focus on constructing and evaluating the artefact, integrating technical, methodological and contextual knowledge to generate tangible results and measure its usefulness and effectiveness.

Design sciences are based on the integration of three key elements: the environment, the

knowledge base, and the research process. These elements are articulated through three interrelated cycles: the cycle of rigour, the cycle of relevance, and the cycle of design (Hevner et al., 2004). The cycle of rigour connects research with existing scientific knowledge, the cycle of relevance links the process to the needs of the environment in which the problem originates, and the cycle of design constitutes the core of the process of constructing and evaluating the proposed artefact. This framework enables the connection of existing scientific knowledge with the needs of the context, facilitating the development of applicable solutions (Fig. 1).

According to Hevner and Chatterjee (2010), a checklist is proposed to validate that design science research complies with these principles and ensure the presence and correct articulation of the three cycles in the research process.

2.2 Design Science Research guidelines

This research follows the seven guidelines of Hevner and Chatterjee (2010), which evaluate the methodological and practical soundness of design science research, ensuring that relevant problems are addressed and useful, theoretically well-founded solutions are generated:

- **Guideline 1: Design as an Artifact.**
Produce a viable artifact as a construct, model, method or instantiation.
- **Guideline 2: Problem relevance.**
Develop solutions for important and relevant problems.
- **Guideline 3: Design evaluation.**
Demonstrate the utility, quality and efficacy of the artifact.
- **Guideline 4: Research Contributions.**
Provide clear and verifiable contributions in the areas of the design artifact, foundations, and/or design methodology.
- **Guideline 5: Research Rigour.**
Apply rigorous methods in the construction and evaluation of the design artifact.
- **Guideline 6: Design as a Search Process.**
Systematically search for effective solutions using available means.
- **Guideline 7: Communication.**
Present results clearly to both technical and management audiences.

These guidelines emphasise the importance of transparency in the construction, evaluation, and dissemination of designed artefacts.

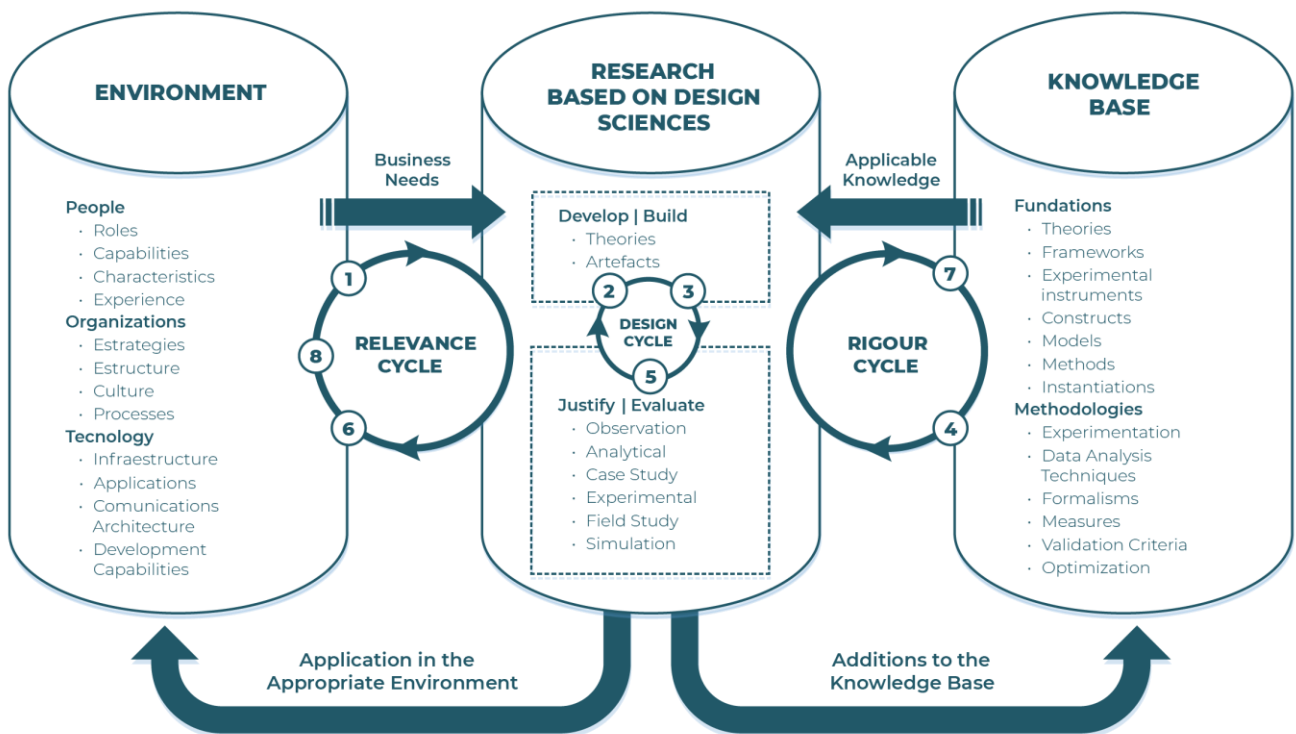


Fig. 1: Cycles in design science research according to Hevner (2004) and their correlation with the checklist proposed by Hevner and Chatterjee (2010). Source: Adapted from Reyes-Burgos and Aquino-Trujillo (2022).

2.3 Design Science Research Methodology (DSRM)

The Design Science Research Methodology (DSRM) proposed by Peffers, Tuunanen, Rothenberger and Chatterjee (2007) was adopted to structure the research process. This methodology structures the development of the research into six fundamental stages:

- Identification of the problem and its motivations: Definition of the research problem and justification of its relevance.
- Definition of the objectives of the solution: Specify the artefact's objectives based on the identified problem.
- Design and development: Create the artefact that responds to the identified problem.
- Demonstration: Implementing the artefact in a controlled or realistic environment to show that it can solve the problem.
- Evaluation: A systematic evaluation of the artefact is carried out, observing its performance in relation to the previously defined objectives.
- Communication: Disseminating the findings and results in academic and professional circles.

2.4 Methodological tools

The Knowledge Innovation Matrix (KIM) developed by Gregor and Hevner (2014) was used to classify the innovation and contribution of the research to knowledge. This tool classifies types of innovation according to the maturity of knowledge surrounding the problem and its solution. It identifies four types of contribution:

- Invention: High knowledge of both the problem and its solution. This leads to highly innovative developments.
- Improvement: High knowledge of both the problem and its solution. This allows existing technologies or processes to be optimised.
- Exaptation: Reuse of known solutions in new problem contexts.
- Exploitation: The problem is well known, but the available solutions are limited. This drives the exploration of new alternatives.

The proposals of Dresch, Lacerda, and Antunes (2015), Ngwenyama (2014) and Peirce (1878) were used to define the reasoning mode. According to Peirce, scientific thought mainly operates through three forms of inference:

- Deductive reasoning: Deriving conclusions from general principles to specific cases.
- Inductive reasoning: Deriving generalisations from empirical observations.
- Abductive reasoning: Proposing plausible explanations or hypothesis based on observed data, often serving as the origin of innovative ideas.

The classification proposed by March and Smith (1995) was used to define the products generated by the research. Within the framework of design sciences, research results take the form of artefacts that contribute to knowledge in a tangible way. These artefacts can be classified into four categories:

- Constructs: conceptual elements used to describe problems and solutions.
- Models: representations that describe relationships between constructs.
- Methods: systematic procedures for solving problems.
- Instantiations: practical implementations that demonstrate the applicability of the artefact.

To structure the evaluation phases, the artefact evaluation process proposed by Sonnenberg and Brocke (2012), was applied (Fig. 2). This method divides the evaluation process into two phases: ex ante, conducted before artefact construction, evaluating justification (Eval1) and conceptual design (Eval2); and ex post, conducted after construction, evaluating the artefact's utility, effectiveness, and efficiency through organizational interactions (Eval3), as well as its practical application (Eval4).

To identify the appropriate evaluation criteria, we consulted the works of March and Smith (1995) and Sonnenberg and Brocke (2012), where these criteria are defined according to the type of artefact. During the criteria definition phase, other studies on the evaluation of artefacts using the DSR paradigm were also analysed (Mijač, 2019; Prat, Comyn-Wattiau, & Akoka, 2014). Among these, it is worth highlighting the research carried out by Prat et al. (2014), which defines a hierarchy of criteria for evaluating information system artefacts (IS artefacts). This hierarchy is divided into five dimensions:

- Goal: assesses the extent to which the artefact fulfils the purpose for which it was designed.
- Environment: assesses the consistency and suitability of the artefact in its context of application.

- Structure: evaluates the internal and formal quality of the artefact in terms of its design, organisation and correspondence with the modelled reality.
- Activity: evaluates the dynamic and functional behaviour of the artefact during its use or execution.
- Evolution: evaluates the artefact's ability to adapt, resist change and improve over time.

In turn, each dimension is subdivided into evaluation criteria and sub-criteria.

To define the evaluation methods, the classification proposed by Hevner et al. (2004) was followed, which includes observational, analytical, experimental, testing, and descriptive approaches. The selection of the method depends on the characteristics of the artefact and the context in which the research is conducted.

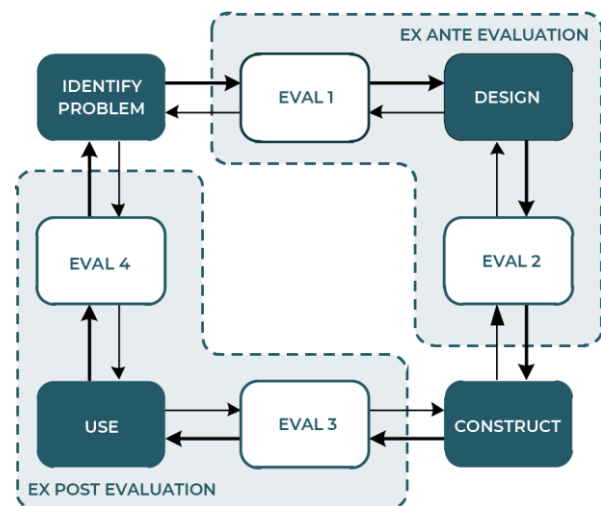


Fig. 2: Phases of evaluation within a DSR process. Source: Adapted from Sonnenberg and Brocke (2012).

3. Results

3.1 Application of the Design Science Research guidelines

This section explains how the research aligns with the Design Science Research (DSR) guidelines proposed by Hevner and Chatterjee (2010).

Guideline 1: Design as an artefact.

In this research, an artefact was developed to integrate environmental data collected by sensors and data on heritage assets in an HBIM environment, focusing on interoperability with the ABC System to optimise the preventive conservation management of cultural assets.

Guideline 2: Relevance of the problem.

The problem that motivated this research is the current decentralisation of the data feeding the ABC System, as well as its lack of interoperability with unified digital models, such as HBIM. This situation the system's effectiveness as a support tool for preventive conservation management.

Guideline 3: Design evaluation.

The platform was evaluated through a pilot study on a real heritage building. The evaluation included an analysis of how it functions, verification that the defined objectives have been achieved, and assessment by experts in conservation, heritage management, and HBIM methodology.

Guideline 4: Contributions.

From a practical perspective, it proposes the development of an interoperable workflow that can be implemented and adapted in cultural institutions and by heritage professionals. From a Theoretical perspective, it proposes a conceptual model for the integration of heritage and environmental data in HBIM environments geared towards risk management. Finally, from a methodological perspective, it documents a case study of the application of the DSR method in the field of preventive conservation.

Guideline 5: Research rigour.

The development of the artefact is based on a detailed study of a pilot case focused on the interoperability of sensors, HBIM models and the ABC System.

Guideline 6: Design as a search process.

Throughout the research, different configurations, tools and forms of data visualisation were tested to find a solution that is both viable and applicable in heritage management contexts.

Guideline 7: Communication.

The results have been disseminated through a doctoral thesis, publications in scientific journals and presentations at international conferences.

3.2 Application of the Design Science Research Methodology (DSRM)

This section describes the application of the Design Science Research Methodology (DSRM) proposed by Peffers et al. (2007) (Fig. 3).

Identification of the problem and its motivations: A state-of-the-art analysis was carried out, based on a systematic literature review and a bibliometric study, which revealed a

lack of research focused on applying the HBIM methodology in risk management contexts and integrating it with established systems, such as the ABC System. The lack of interoperability between the two methodologies was observed to limit their multidisciplinary potential and reduce their contribution to the preventive conservation of cultural heritage.

This diagnosis was complemented by consultations and technical discussions with various key stakeholders. These included the heritage managers of the Colegio del Patriarca, such as the rector and the administrator of the protocol archive, who helped to identify priority areas for sensors placement. Additionally, the sensor specialists from the University of Alicante provided guidance on the operation, limitations and applicability of environmental monitoring technologies.

Heritage and cultural tourism specialists also contributed broader insights into the potential benefits of the collected data for heritage management and valorisation. These interactions made it possible to pinpoint both the problems and the opportunities for innovation, thereby consolidating the relevance of the approach taken in this research.

Definition of the objectives of the solution:

The objective was defined as designing a workflow capable of integrating environmental data collected by sensors within a HBIM environment, ensuring interoperability with the ABC System and optimising its operational stages, bases on the identified problem. A critical review of applicable digital technologies in heritage contexts was carried out to achieve this objective, including BIM software, IoT systems, and data management platforms.

Design and development:

An interoperable workflow was developed based on the theoretical framework and requirements of the ABC System using tools such as Autodesk Revit, Dynamo, IoT systems, cloud storage services, and Excel spreadsheets.

The system architecture was designed to dynamically link the environmental data provided by the sensors, the heritage metadata from the HBIM model, and the deterioration parameters identified from specialised bibliographic sources.

Methodological tests were conducted during this phase to verify the technical feasibility of data integration, as well as preliminary compatibility tests between software and devices.

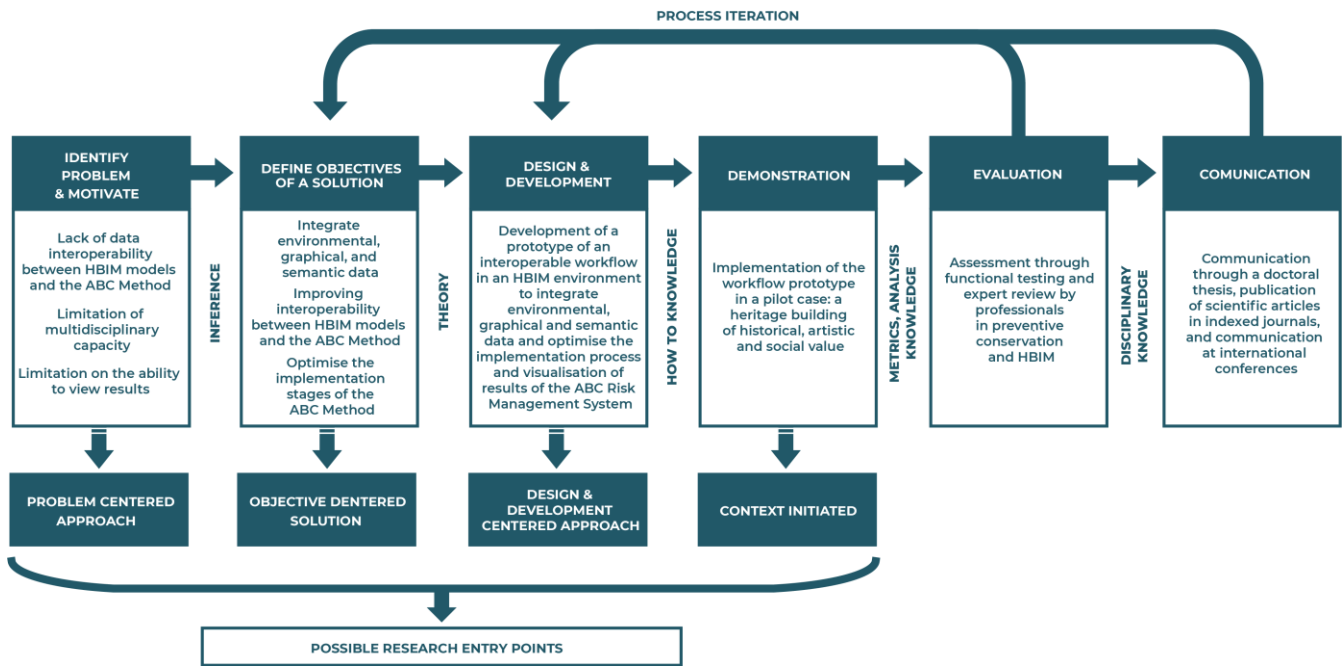


Fig. 3: Application of the DSRM in the research structure. Source: Prepared by the author based on Peffers et al. (2007).

Demonstration: The proposal was implemented in a real pilot case: The Colegio del Patriarca in Valencia, a heritage building of significant historical, artistic and social value. Fieldwork involved documenting the building’s geometry, construction materials, environmental conditions and potential risks, as well as collecting environmental data using sensors and developing the HBIM model.

Sensors were used to measure temperature, relative humidity and carbon dioxide concentration. These data flows were integrated into the HBIM model, allowing for visual and parametric evaluation of risk indicators, as well as their correlation with the stages of the ABC System (Coelho et al., 2022).

Evaluation: The artefact developed (the workflow) was evaluated and validated in two aspects: as a method and as an instantiation. From a methodological perspective, its effectiveness was assessed in relation to the research objectives was assessed. An instantiation, its efficiency, performance and accuracy were evaluated. This evaluation was based on functional tests carried out in the pilot case, as well as expert review by institutions specialising in heritage conservation and HBIM management.

Communication: The research results are being disseminated through a doctoral thesis, publications in scientific journals (Rolim, López-González & Viñals, 2024; Rolim & López-González,

2024) and presentations at international conferences specialising in the conservation of cultural heritage and the application of digital technologies in this field (Rolim, 2024; Orozco-Carpio & Rolim, 2024).

3.3 Application of the Methodological tools

Applying the KIM matrix by Gregor and Hevner (2014) (Fig. 4) classified the proposed artefact within the exaptation quadrant, as it reuses existing technologies and concepts (the HBIM methodology and environmental monitoring sensors) in a new extension context (the risk management methodology). This adaptation constitutes an incremental innovation, integrating methodologies for documenting and monitoring heritage assets with a risk management system and prioritizing interoperability.

Based on reasoning modes (Dresch et al., 2015; Ngwenyama, 2014; Peirce, 1878), the research combined abductive, inductive and deductive approaches. Abductive reasoning was employed to generate new ideas from the analysis of scattered data and contextual needs. Inductive reasoning was employed to identify patterns in concrete data, and Deductive reasoning enabled the application of pre-existing theoretical models such as the ABC Method (ICCROM, 2016; ICCROM & Ibermuseos, 2017) and the HBIM methodology.

PROBLEM	HIGH	<p>Improvement: Develop new solutions for known problems.</p> <p><i>Research Opportunity</i></p>	<p>Exploitation: Applying known solutions to known problems.</p> <p><i>Limited Research Opportunity</i></p>
	LOW	<p>Invention: Inventing new solutions to new problems.</p> <p><i>Research Opportunity</i></p>	<p>Exaptation: Extending known solutions to new problems (adopting solutions from other fields).</p> <p><i>Research Opportunity</i></p>
		LOW	HIGH
		SOLUTION	

Fig. 4: Knowledge Innovation Matrix (KIM) with opportunities for research and external impact results. Source: Adapted from Gregor and Hevner (2014).

According to March and Smith (1995), this research produced three types of artefacts:

- Models, through the proposal of diagrams for integration between systems and information flow.
- Methods, through the design of a workflow to integrate environmental data with HBIM models and the ABC System
- Instantiation, through the implementation of the workflow in a pilot case.

3.4 Evaluation process

3.4.1. Application of the evaluation phases

Following the artefact evaluation phases by Sonnenberg and Brocke (2012), evaluation activities were carried out for the workflow during both the preliminary design phase and the prototype implementation phase of the artefact:

- First evaluation phase (EVAL 1) – ex ante: In this phase, referred to as justification, the relevance and novelty of the identified problem is demonstrated through a review of the literature.
- Second evaluation phase (EVAL 2) – ex ante: In this phase, the workflow design was evaluated using logical reasoning and the possible solution to the problem posed was demonstrated through the design of the artefact.
- Third evaluation phase (EVAL 3) – ex post: In this phase, it was verified that the artefact meets the objectives established in this

research (effectiveness). Additionally, its functioning was evaluated through the analysis of efficiency, accuracy and performance, as well as the feasibility of its implementation.

- Fourth evaluation phase (EVAL 4) – ex post: This phase involves proposing a future line of research derived from this study to verify the artefact’s applicability and usefulness of the artefact in practice contexts. This phase includes developing a case study and/or conducting field experiment to analyse and evaluate the artefact’s impact within its intended environment and among users of the ABC Method. It also involves validating the process through surveys and interviews with users and experts.

3.4.2. Application of the evaluation criteria

The artefact evaluated and validated in this research is, by definition, an instantiation, representing a practical materialisation of a method (March & Smith, 1995). The works of March and Smith (1995) and Sonnenberg and Brocke (2012), where consulted to identify the most appropriate evaluation criteria, which are defined according to the type of artefact. As the artefacts is an instantiation, the adopted criteria were effectiveness, efficiency and environment and user impact.

Efficiency was adopted to evaluate whether the artefact optimised the operational tasks of the ABC System, and effectiveness to evaluate whether the artefact met the objectives set out in the research, namely integration of environmental data taken by the sensors into the HBIM model, visualisation of data in the HBIM model using colour filters, and preparation of data for integration into the ABC System.

The criterion relating to the impact on the environment and users requires an extensive field study to be carried out in collaboration with users of the ABC Method in real contexts. Such a study would allow the optimisations introduced by the workflow to be evaluated in a comparative manner. However, due to time constraints, this study could not be conducted within the scope of this research and has therefore been postpone to a future research phase. Instead, this criterion was replaced by an analysis of the artefact’s implementation feasibility.

When comparing the evaluation criteria selected from Sonnenberg and Brocke (2012) with the hierarchy proposed by Prat et al. (2014), it was observed that the evaluation process adopted in this research mainly corresponds focus on analysing the extent to which the artefact fulfils its purpose and how its operations functions. This involves the criteria presented in Table 1.

Tab. 1: Evaluation criteria for goal and activity dimensions.

Dimension	Evaluation criteria
Goal	<p><i>Efficacy</i>: the degree to which the artefact achieves its objective.</p> <p>Validity: the degree of reliability.</p> <p><i>Generality</i>: the degree of breadth with which the artefact addresses the issue.</p>
Activity	<p><i>Completeness</i>: degree to which the artefact fulfils its function.</p> <p><i>Consistency</i>: applies to dynamic (activities) or static (structure) aspects.</p> <p><i>Accuracy</i>: demonstrated agreement with the results of experiments.</p> <p><i>Performance</i>: speed with which the activity is carried out.</p> <p><i>Efficiency</i>: relationship between the results and inputs of the activity.</p>

The remaining hierarchy dimensions — environment, structure, and evolution — were not considered as their application exceeds the scope of this research. The environment dimension was not included in this phase, as the workflow will not implemented directly by users of the ABC Method, but rather validated within a controlled experimental context. The structure dimension would require a thorough evaluation of the artefact's internal architecture, involving specialists in programming or script development in Dynamo. Finally, the evolution dimension could only be addressed through new applications or case studies conducted in different contexts.

Recent studies, such as those by Mdletshe, Motshweneng, Oliveira, and Twala (2023) and Mijač (2019), have applied the evaluation hierarchy developed by Prat et al. (2014) to

artefact evaluation processes, identifying the criteria most frequently used in scientific publications. Based on this identification, the initially selected criteria of efficiency, effectiveness, and feasibility of implementation were maintained, and accuracy and performance were incorporated.

3.4.3. Evaluation methods applied

To select the most appropriate evaluation methods for evaluating the artefact, the classification of methods defined by Hevner et al. (2004) was consulted. Based on this classification, the evaluation methods shown in Table 2 were selected.

3.4.4. Validation methods applied

The workflow was validated from two distinct perspectives: (a) fulfilment of the research objectives and the artefact functionality, and (b) the feasibility of implementing the workflow in practical contexts.

(a) HBIM expert team (focus group).

The artefact's evaluation and validation were conducted by a team of experts from the Department of Architecture and Design at the Politecnico di Torino (Italy).

The team consisted of: A professor with a PhD in Drawing and Surveying for the Conservation of Built and Territorial Heritage; a researcher with a PhD in Architecture and Master's degree in Digital Architecture; a researcher with a PhD in Architectural and Landscape Heritage, with expertise in geometric-informative modelling for developing digital twins for museum heritage; and a PhD candidate specialising in Architectural and Landscape Heritage, whose research focuses on the digital representation of heritage, the use of BIM/HBIM, and developing digital and immersive experiences applied to museography.

(b) An expert in the ABC Method (semi-structured interview).

The feasibility of implementing the workflow was evaluated and validated through a semi-structured interview with an ABC method expert at the International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM) in Rome, Italy.

The participating expert holds a degree in chemistry and a master's degree in polymer chemistry and has served as a conservation project

Tab. 2: Selected evaluation methods and their metrics.

Evaluation criteria	Methods and metrics used
Efficiency	Method: Dynamic analysis – The flow is executed in real scenarios from the pilot case to observe its performance and measure the execution time of the main tasks. Metric: Percentage of scenarios solved correctly.
Accuracy	Method: Functional tests (black box) – To check whether the interfaces generate the expected results and the accuracy of these results. Metric: Percentage of parameters generated correctly.
Performance	Method: Scenarios – Construction of representative scenarios and validation of the correct response of the system. Metrics: Average execution time for each task.
Efficacy	Method: Static analysis – Evaluation of the relevance of the results. Metric: Result of the Likert scale applied in the HBIM expert focus group.
Feasibility	Method: Descriptive – Construction of a convincing argument about the usefulness of the artefact. Metric: Result of the interview with an expert in the ABC Method. Positive or negative evaluation.

manager at ICCROM. He has collaborated with the Canadian Conservation Institute (CCI) and the Casa de Oswaldo Cruz / Fiocruz on key initiatives for risk management in cultural heritage conservation, including the development of the ABC Method (ICCROM, 2016; ICCROM & Ibermuseos, 2017) and the ABC Risk Management System for Cultural Heritage (Coelho et al., 2022).

3.5 Evaluation results

3.5.1. Artefact functioning

The objective of this phase was to determine whether the workflow was operating correctly. To this end the artefact’s efficiency, accuracy and performance were evaluated. The procedures adopted in the evaluation process were presented to and subsequently validated by a focus group of experts.

To evaluate efficiency, nine scenarios were analysed to determine the percentage correctly resolved by the workflow. To this end, the workflow was executed in its entirety in three cycles, each corresponding to one of three spaces considered in the pilot case: the side chapel of San Vicente Ferrer, room 5 of the museum and space 1 of the protocol archive (Table 3).

Accuracy was assessed by analysing and comparing the data generated in the previous step with the environmental data tables collected by sensors, as well as with the tables containing material conservation standards and information on cultural assets included in the HBIM model. This analysis was conducted by sampling 30

parameters: ten from each cycle executed and three from each space, as well as one from the master view (Table 4).

To evaluate performance, the execution time of all scripts involved in the three workflow execution cycles was measured (Table 5).

3.5.2. Achievement of objectives

The evaluation process began with a presentation to all members of the focus group. This explained how the ABC Method/System works and the presented the proposed workflow, highlighting the objectives, operational logic and potential results.

Afterwards, each participant shared their initial impressions of the workflow briefly. This was followed by a discussion of its strengths and limitations, after which a survey based on Likert scale (Brooke, 1996). This survey included the following statements:

- The workflow optimises the process of compiling data on cultural assets.
- The workflow promotes interoperability between HBIM models and the ABC System.
- The workflow is capable of optimising the operational stages of the ABC System.
- The workflow encourages multidisciplinary collaboration between the agents involved in the preventive conservation of cultural assets.
- The workflow expands the analysis and evaluation capacity of the ABC System.
- The workflow allows for the optimisation of the management of the preventive conservation of cultural assets.

Tab. 3: Workflow efficiency analysis – correctly resolved scenarios.

Scenario	Description	Result
1	Date: 09/08/2024 1:00 p.m. Space: San Vicente Ferrer Chapel	Flawless execution
2	Date: 09/08/2024 1:00 p.m. Space: Museum	Flawless execution
3	Date: 09/08/2024 1:00 p.m. Space: Protocol Archive	Flawless execution
4	Date: 08/01/2024 4:00 p.m. Space: San Vicente Ferrer Chapel	Flawless execution
5	Date: 08/01/2024 4:00 p.m. Space: Museum	Flawless execution
6	Date: 08/01/2024 4:00 p.m. Space: Protocol Archive	Flawless execution
7	Date: 02/04/2025 10:00 a.m. Space: San Vicente Ferrer Chapel	Flawless execution
8	Date: 02/04/2025 10:00 a.m. Space: Museum	Flawless execution
9	Date: 02/04/2025 10:00 a.m. Space: Protocol Archive	Flawless execution
Total scenarios evaluated: 9 Total scenarios executed correctly: 9 Total scenarios that presented errors: 0 Percentage of scenarios resolved correctly: 100%		

The results of evaluating of these objectives are presented in Table 6, which summarises the responses obtained from surveys conducted with the HBIM expert focus group. They survey from also included a section where each participant could provide qualitative feedback.

Strengths: The artefact has several notable strengths. Its coherent and robust structure provides a solid foundation for analysis. Furthermore, it optimises data collection processes and improves interoperability between methodologies that would traditionally operate independently. The workflow was recognised as a useful methodological tool that aligns with research objectives. Additionally, the artefact strengthens the ABC System and supports preventive conservation processes in a more structured and collaborative manner.

Areas for improvement: Some aspects of the artefact could be further refined. For instance, incorporating an additional input stage for information provided by specialists in architectural history, conservation, curation and registration could enhance the documentation process. Maintaining successive versions or

records of information would also improve traceability and facilitate the comparison of results over time. Finally, exploring the multiscale nature of the ABC Method in more depth and its integration within the HBIM environment could enhance methodological consistency and clarify the practical implications of the ABC Method in digital environment.

3.5.3. Feasibility of implementation

The practical feasibility of implementing the workflow was assessed through a semi-structured interview with an ABC Method expert. The meeting lasted approximately two hours.

The session began with a presentation explaining the research objective, the workflow design process, how it functions, and the results it can produce. After the presentation, the artefact's positive and negative aspects were discussed, and several questions relating to the prototype's objectives and operation were clarified. The interview was subsequently conducted and recorded in audio, with the expert answering the questions presented in Table 7.

Tab. 4: Result of workflow accuracy analysis – data generated correctly.

Cycle	Parameters analysed	Results
Cycle 1	Date: 09/08/2024 1:00 p.m. Space: San Vicente Ferrer Chapel Parameter: Condition_HR_M1 – Altar railing Parameter: Condition_HR_Fluc_M1 – Altar Parameter: Damage_HR_Fluc_M1 – Talavera tiles	Correct (Optimal) Correct (Fluctuation) Correct (Microfractures)
	Date: 09/08/2024 1:00 p.m. Space: Museum Parameter: Condition_T_M1 – C. LLano’s Chant Book Parameter: Condition_T_Fluc_M1 – Recumbent image of Christ Parameter: Damage_HR_Fluc_M1 – Painting Dep. Sta. Catalina	Correct (High) Correct (Optimal) Correct (None)
	Date: 09/08/2024 1:00 p.m. Space: Protocol Archive Parameter: Damage_HR_max_M1 – Protocol Archive Collection Parameter: Damage_T_max_M1 – Protocol Archive Collection Parameter: Damage_T_min_M1 – Protocol Archive Collection	Correct (None) Correct (Oxidation) Correct (None)
	Date: 09/08/2024 1:00 p.m. Space: Master View Parameter: HR_Sensor_1	Correct (55)
Cycle 2	Date: 08/01/2024 4:00 p.m. Venue: San Vicente Ferrer Chapel Parameter: Condition_T_M1 – Altar Railing Parameter: Condition_T_Fluc_M1 – Altar Parameter: Damage_T_Fluc_M1 – Talavera Tiles	Correct (High) Correct (Optimal) Correct (None)
	Date: 08/01/2024 4:00 p.m. Space: Museum Parameter: Condition_HR_M1 – C. LLano’s Chant Book Parameter: Condition_HR_Fluc_M1 – Recumbent Image of Christ Parameter: Damage_HR_Fluc_M1 – Painting Dep. Sta. Catalina	Correct (High) Correct (Optimal) Correct (None)
	Date: 08/01/2024 4:00 p.m. Space: Protocol Archive Parameter: Damage_T_max_M1 – Protocol Archive Collection Parameter: Damage_HR_Fluc_M1 – Protocol Archive Collection Parameter: Damage_T_Fluc_M1 – Protocol Archive Collection	Correct (High) Correct (Optimal) Correct (None)
	Date: 08/01/2024 4:00 p.m. Space: Master View Parameter: T_Sensor_3	Correct (32.9)
Cycle 3	Date: 02/04/2025 10:00 a.m. Space: San Vicente Ferrer Chapel Parameter: Condition_HR_M1 – Altar Railing Parameter: Condition_HR_Fluc_M1 – Altar Parameter: Damage_T_max_M1 – Talavera Tiles	Correct (Optimal) Correct (Optimal) Correct (None)
	Date: 02/04/2025 10:00 a.m. Space: Museum Parameter: Condition_T_M1 – C. LLano’s Songbook Parameter: Condition_T_Fluc_M1 – Recumbent image of Christ Parameter: Damage_HR_max_M1 – Painting Dep. Sta. Catalina	Correct (Optimal) Correct (Optimal) Correct (None)
	Date: 02/04/2025 10:00 a.m. Space: Protocol Archive Parameter: Months_HR_Fluc_M1 – Protocol Archive Collection Parameter: Months_T_Fluc_M1 – Protocol Archive Collection Parameter: Damage_T_Fluc_M1 – Protocol Archive Collection	Correct (Optimal) Correct (Optimal) Correct (None)
	Date: 02/04/2025 10:00 a.m. Space: Master View Parameter: HR_Sensor_4	Correct (52.5)
Total parameters evaluated: 30 Total correct parameters: 30 Total parameters with errors: 0 Percentage of parameters generated correctly: 100%		

Tab. 5: Script execution time for each cycle executed (in minutes)

Script	Cycle 1	Cycle 2	Cycle 3
F0_DISTRIBUTION_DATE_TIME_MASTER_VIEW	00:14	00:16	00:15
F1_INTEGRATION_ENVIRONMENTAL_DATA_SENSORS	01:23	01:20	01:07
F2_INTEGRATION_DATA_CONSERVATION_MATERIALS	01:04	01:10	01:27
F3_ENVIRONMENTAL_CONDITIONS_MATERIALS_SENSOR_1	00:39	00:42	00:44
F3_ENVIRONMENTAL_CONDITIONS_MATERIALS_SENSOR_3	00:38	00:44	00:48
F3_ENVIRONMENTAL_CONDITIONS_MATERIALS_SENSOR_4	00:43	00:47	00:45
F4_POTENTIAL_DAMAGE_MATERIALS_SENSOR_1	00:23	00:15	00:16
F4_POTENTIAL_DAMAGE_MATERIALS_SENSOR_3	00:17	00:19	00:17
F4_POTENTIAL_DAMAGE_MATERIALS_SENSOR_4	00:17	00:20	00:17
F5_ANNUAL_COUNT_POSSIBLE_DAMAGE_SENSOR_1	01:02	01:02	01:17
F5_ANNUAL_COUNT_POSSIBLE_DAMAGE_SENSOR_3	01:08	01:16	01:28
F5_ANNUAL_COUNT_POSSIBLE_DAMAGE_SENSOR_4	01:16	01:19	01:30
F6_MONTHLY_COUNT_POSSIBLE_DAMAGE_SENSOR_1	01:03	01:12	01:16
F6_MONTHLY_COUNT_POSSIBLE_DAMAGE_SENSOR_3	01:06	01:21	01:31
F6_MONTHLY_COUNT_POSSIBLE_DAMAGE_SENSOR_4	01:11	01:22	01:37
F7_DAILY_COUNT_POSSIBLE_DAMAGE_SENSOR_1	01:02	01:15	01:21
F7_DAILY_COUNT_POSSIBLE_DAMAGE_SENSOR_3	01:06	01:20	01:34
F7_DAILY_COUNT_POSSIBLE_DAMAGE_SENSOR_4	01:11	01:22	01:37

Tab. 6: Result of workflow efficiency analysis.

The workflow optimises the process of compiling data on cultural assets.						
	TOTAL	SD	D	N	A	SA
No of responses	4	-	-	-	3	1
Percentage	100 %	-	-	-	75 %	25 %
The workflow promotes interoperability between HBIM models and the ABC System.						
	TOTAL	SD	D	N	A	SA
No of responses	4	-	-	-	-	4
Percentage	100 %	-	-	-	-	100 %
The workflow is capable of optimising the operational stages of the ABC System.						
	TOTAL	SD	D	N	A	SA
No of responses	4	-	-	1	3	-
Percentage	100 %	-	-	25 %	75 %	-
The workflow encourages multidisciplinary collaboration among those involved in the preventive conservation of cultural property.						
	TOTAL	SD	D	N	A	SA
No of responses	4	-	-	1	1	2
Percentage	100 %	-	-	25 %	25 %	50 %
The workflow expands the analysis and evaluation capabilities of the ABC System.						
	TOTAL	SD	D	N	A	SA
No of responses	4	-	-	-	1	3
Percentage	100 %	-	-	-	25 %	75 %
The workflow enables the optimisation of preventive conservation management for cultural assets.						
	TOTAL	SD	D	N	A	SA
No of responses	4	-	-	-	3	1
Percentage	100 %	-	-	-	75 %	25 %

SD: Strongly Disagree; D: Disagree; N: Neutral; A: Agree; SA: Strongly Agree.

Strengths: The tool has several important strengths. It enhances the analytical process of the ABC System by incorporating a spatial dimension, enabling a deeper understanding of the spatial distribution of heritage value, vulnerabilities, and exposure to deterioration agents, such as inappropriate humidity and temperatures conditions. It also improves risk communication and automates the process of compiling environmental data within the ABC Method, thereby making risk analysis more efficient. The visualisation of data in a 3D model enables risks to be communicated more clearly and comprehensively.

Furthermore, the tool supports the risk treatment and reduction phase, particularly when integrated with environmental simulation models, enabling the design and testing of solutions prior to implementation. The possibility of combining relative value, vulnerability and exposure within a

visual risk map also represent a significant potential for further development.

Areas for improvement: Some aspects require refinement. Representative models often simplify material behaviour in order to facilitate analysis, which may produce inaccurate or inadequate results. Introducing additional layers related to material vulnerability could reduce these simplifications and improve model quality. Adjustments are also necessary in the recording and analysis of certain risks, particularly those related to cumulative deterioration processes.

It is also important to involve a broader range of stakeholders, including communities or individuals connected to heritage assets, and to conduct practical tests and case studies to assess the integration of data in real-world applications. These measures would help to ensure that the tool is effective, accurate and applicable in practical conservation contexts.

Tab. 7: Questions asked in the interview with the expert on the ABC Method

Consent and Data Privacy
- Do you authorise the publication of the responses?
Strategic Value and Usefulness
- Where in the system would this proposal be most useful?
- What part of the proposal do you find most positive?
- What additional benefits could this workflow bring to the management of preventive conservation of cultural property?
Technical Integration
- Could the workflow help to apply the ABC Method?
- Would it also complement the analysis process?
- How feasible would it be to implement this workflow within the ABC System?
Implementation Feasibility
- Do you think it is feasible to test this workflow in a real risk management project?
- How much acceptance do you think this proposal would have among individuals and teams already working with the ABC Method and the ABC System?
Operational Design
- Do you think it would be better for the system to be operated by one person who centralises data from various agents in different areas and interacts with them, or a system in which each agent in each area could operate and feed into a central model?
Limitations and Improvements
- What limitations might it have?
- What improvements do you think are necessary to adapt the workflow to the ABC System?

4. Discussion

4.1. Reflective Validation

This section provides a reflective validation of the artefact, using the evaluation checklist proposed by Hevner and Chatterjee (2010). This checklist is commonly used within the Design Science Research framework to evaluate the rigour and relevance of the artefacts. The following points address the key aspects of the research design and validation of the proposed solution.

What is the research question (design requirements)? The main research question is: How can interoperability between HBIM models and the ABC Method optimise the management of preventive conservation of cultural assets?

What is the artefact? How is the artefact represented? The artefact developed is an interoperable workflow between HBIM models and the ABC Method, which aims to optimise the stages of implementation of the method in the ABC System, facilitate interdisciplinary collaboration and optimise the management of preventive conservation of cultural assets. It is presented as a functional prototype implemented in a pilot case.

What design processes (search heuristics) will be used to build the artefact? The design of the artefact is based on an interactive and heuristic process guided by the six steps of the DSRM: problem identification, objective definition, design and development, demonstration, evaluation and communication.

How are the artefact and the design processes grounded by the knowledge base? What, if any, theories support the artefact design and the design process? The artefact is based on an interdisciplinary knowledge base: preventive conservation theories and risk management principles applied to cultural heritage, the ABC risk management method and system, the HBIM methodology as a support for graphic and semantic integration, and the DSR framework as a research methodology. These theories underpin the design of the artefact and its practical application, ensuring scientific rigour and practical relevance.

What evaluations are performed during the internal design cycles? What design improvements are identified during the design cycle? During the design cycle, technical tests of the prototype and qualitative assessments are carried out with experts in heritage conservation and HBIM

methodology. These evaluations allow for the identification of improvements such as the simplification of data flow from sensors with HBIM models and the optimisation of environmental data visualisation and risk analysis in HBIM models.

How is the artefact introduced into the application environment and how is it field tested? What metrics are used to demonstrate artefact and utility and improvement over previous artefacts? The artefact is presented in an operational environment applied to a pilot case, in which real data is integrated into the HBIM model. The evaluation is carried out through a technical-functional analysis, interviews with experts, and a comparative analysis with traditional methods. The following indicators are used: improvement in risk management processes, integrated visualisation capacity, and data interoperability.

What new knowledge is added to the knowledge base and in what form (e.g., peer-reviewed literature, meta-artefacts, new theory, new methods)? The research provides a meta-artefact applicable to other heritage contexts for preventive conservation purposes and empirical evidence of its effectiveness. These results are integrated into the knowledge base through the documentation of the pilot case, the replicable design of the prototype, and its dissemination through academic publications, contributing to the field of design and heritage sciences.

Has the research question been satisfactorily addressed? Yes, the problem is addressed in the design and development, implementation and validation of the artefact. The workflow is useful for integrating complex data, improving the operability of the ABC System and facilitating more informed and coordinated decisions, thus fulfilling the main objective of the research and validating the hypothesis put forward.

The following subsections discuss the results obtained from the evaluation of the artefact in terms of its functionality, achievement of the research objectives and feasibility of implementation, based on this reflective validation.

4.2. Artefact functioning

The analysis of the artefact's functionality focused on three main criteria: efficiency, accuracy and performance.

In terms of efficiency, all nine scenarios tested were executed flawlessly, demonstrating the proper integration between workflow stages and consistent results in different environments. Notably, the artefact demonstrated the ability to consistently produce stable results under different operational scenarios.

In terms of accuracy, a comparison of the data generated by the workflow with the measurements obtained from sensors revealed a perfect alignment between the conservation standards and the parameters represented within the HBIM model. These results confirm the reliability of the modelling process and the implemented algorithms.

Performance was evaluated by calculating script execution times across three operational cycles. The results showed stable and efficient performance, with adequate response times for a test environment and good scalability for more complex environments. However, there are opportunities for improvement, particularly in automating certain intermediate processes to further reduce total execution time.

Overall, the results demonstrate that the artefacts meet the defined objectives in terms of efficiency, accuracy and performance. The observations collected during the focus group confirmed the validity of the evaluation process, as the applied methods, used indicators and obtained results are consistent, reproducible and verifiable. Therefore, the evaluation process is considered valid and provides a solid basis for applying the workflow in real heritage management context.

4.3. Achievement of objectives

In summary, the opinions expressed during the focus group reflected a very positive assessment of the artefact, accompanied by constructive suggestions for future improvements relating to optimisation, implementation and scalability.

The results confirm the workflow's effectiveness and its potential to enhance interoperability and collaboration in the field of preventive conservation of cultural assets.

4.4. Feasibility of implementation

In summary, the interview confirmed the importance of implementing the workflow. The observations revealed that incorporating spatial and visual dimension would significantly improve communication and risk management processes.

However, technical limitations relating to the representation of heritage asset vulnerabilities and system interoperability were identified. Future research should address these aspects through the development of more accurate vulnerability layers and the implementation of additional pilot cases in real-world environments.

Finally, the requirement for multidisciplinary teams and decentralised management structures emphasises that the effectiveness of the system depends on both its technological design and the coordination between the various stakeholders involved in preventive conservation process.

5. Conclusions

The starting point for this research was the recognition of the need to modernise conservation strategies using interoperable digital tools that could link data from different sources — sensory, graphic and analytical — in a unified, data-based heritage management model. Scientific and methodological knowledge has been generated, and a practical and applicable tool has been designed to optimise the management of preventive conservation of heritage assets.

The Design Science Research Methodology framework allowed the workflow to be conceived as a scientific artefact with theoretical and practical validity, designed to solve a real problem of a complex and multidimensional nature. In this way, the research has combined technological innovation with methodological rigour.

The evaluation focused on the functional dimensions and the fulfilment of the intended objectives, giving priority to efficiency, effectiveness, accuracy, performance and feasibility of application. In later stages, this evaluation may be extended to the environmental, structural and evolutionary dimensions proposed by Prat et al. (2014), in order to reinforce the comprehensive analysis of the artefact.

The validation was mainly conceptual and based on interviews and focus groups, which confirmed the theoretical coherence and practical feasibility of the model.

However, it is considered appropriate to extend this validation through empirical studies in real scenarios with users of the ABC System, which will confirm its practical effectiveness and strengthen its applicability.

This research reinforces the relationship between Design Sciences, preventive conservation and heritage digitisation, and demonstrates that

the DSRM is an effective framework for addressing complex heritage management problems from an action-oriented scientific perspective. In this sense, HBIM approach emerges not only as technical tools, but as cultural infrastructures that support collaboration, interoperability, and knowledge co-creation. Their integration within complex workflows reinforces the shift toward a holistic, data-informed and multidisciplinary approach, enhancing the effectiveness and communicability of preventive conservation strategies.

6. *Funding sources*

This research was conducted within the framework of the research project 'Analysis and development of HBIM integration in GIS for the creation of a protocol for cultural heritage tourism planning' (ref. PID2020-119088RB-I00), as well as the FPU grant (ref. FPU21/06469), both funded by the Ministry of Science, Innovation and Universities (MICIU), Government of Spain.

REFERENCES

- Bergomi, A., Comite, V., Guglielmi, V., Borelli, M., Bonomi, R., Ciprandi, C., Mariani, C., Faggiano, A., Ricciardi, M., Proto, A., & Fermo, P. (2022). Evaluation of indoor environmental conditions in the Sanctuary of the Beata Vergine dei Miracoli. *2022 IMEKO TC-4 International Conference on Metrology for Archaeology and Cultural Heritage, MetroArchaeo 2022*, 74–79. <https://doi.org/10.21014/tc4-arc-2022.015>
- Brooke, J. (1996). SUS: A “quick and dirty” usability scale. In P. W. Jordan, B. Thomas, B. A. Weerdmeester, & I. L. McClelland (Eds.), *Usability evaluation in industry* (pp. 207–212). London, England: Taylor & Francis.
- Coelho, C. M. T., Amorim, V. R. de, Silva, W. N., Karsten, I., Perdesoli Jr, J. L., Michalski, S., & Feltmann, C. dos S. (2022). *Sistema ABC de gestão de riscos para o patrimônio cultural: Manual do usuário*. Rio de Janeiro, Brasil: Canadian Conservation Institute/ICCROM/Fiocruz.
- Cursi, S., Martinelli, L., Calcerano, F., Calvano, M., & Gigliarelli, E. (2025). Digital twin and HBIM-to-IoT for smart museum management – the case of the DART Museum Chiostro del Bramante. *SCIRES-IT - SCientific RESearch and Information Technology*, 15(2), 71–84. <https://doi.org/10.2423/i22394303v15n2p71>
- Dresch, A. (2013). *Design science e design science research como artefatos metodológicos para engenharia de produção* (Master’s thesis). Recuperato da Repositório Digital della Unisinos (jesuita.org.br).
- Dresch, A., Lacerda, D. P., & Antunes, J. A. V. (2015). *Design science research: A method for science and technology advancement*. Cham, Switzerland: Springer. <https://doi.org/10.1007/978-3-319-07374-3>
- Gregor, S., & Hevner, A. R. (2014). The knowledge innovation matrix (KIM): A clarifying lens for innovation. *Informing Science: The International Journal of an Emerging Transdiscipline*, 17, 217–239. <http://www.inform.nu/Articles/Vol17/ISJv17p217-239Gregor0700.pdf>
- Hevner, A. R., & Chatterjee, S. (2010). *Design research in information systems* (Vol. 22). Springer US. <https://doi.org/10.1007/978-1-4419-5653-8>
- Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design science in information systems research. *MIS Quarterly*, 28(1), 75–105.
- ICCROM, & Canadian Conservation Institute. (2016). *The ABC method: A risk management approach to the preservation of cultural heritage*. Rome, Italy: Author.
- ICCROM, & Ibermuseos. (2017). *Guía de gestión de riesgos para el patrimonio museológico*. Rome, Italy.
- Ippolito, A., Attenni, M., & Darwa, R. (2023). HBIM as a tool for heritage presentation of Santa Maria in Trastevere. *SCIRES-IT - SCientific RESearch and Information Technology*, 13(1), 53–66. <https://doi.org/10.2423/i22394303v13n1p53>
- March, S. T., & Smith, G. F. (1995). Design and natural science research on information technology. *Decision Support Systems*, 15, 251–266. [https://doi.org/10.1016/0167-9236\(94\)00041-2](https://doi.org/10.1016/0167-9236(94)00041-2)
- Martinelli, L., Calvano, M., Calcerano, F., & Gigliarelli, E. (2025). Visual programming language to support interoperability of geometric and data modelling in HBIM processes. *SCIRES-IT - SCientific RESearch and Information Technology*, 15(1), 85–96. <https://doi.org/10.2423/i22394303v15n1p85>
- Mdletshe, S., Motshweneng, O. S., Oliveira, M., & Twala, B. (2023). Design science research application in medical radiation science education: A case study on the evaluation of a developed artifact. *Journal of Medical Imaging and Radiation Sciences*, 54, 206–214. <https://doi.org/10.1016/j.jmir.2022.11.007>
- Mijač, M. (2019). Evaluation of design science instantiation artifacts in software engineering research. In *Proceedings of the 30th Central European Conference on Information and Intelligent Systems* (pp. 313–321). Varaždin, Croatia: Faculty of Organization and Informatics.

- Moretti, E., Scurpi, F., Proietti, M. G., & Fiore, M. (2024). A multidisciplinary approach to the evaluation of air quality and thermo-hygrometric conditions for the conservation of heritage manuscripts and printed materials in historic buildings: A case study of the Sala del Dottorato of the University of Perugia. *Applied Sciences*, 14(12), 5356. <https://doi.org/10.3390/app14125356>
- Ngwenyama, O. (2014). Logical foundations of social science research. In I. Yazidi (Ed.), *Social and professional applications of actor-network theory for technology development* (pp. 7–13). Hershey, PA: IGI Global. <https://doi.org/10.4018/978-1-4666-6126-4.ch002>
- Orozco Carpio, P. R., & Rolim, R. (2024). GIS and HBIM for tourism management: A multiscale challenge. In *Proceedings Heritage Digital Technologies and Tourism Management - HEDIT2024* (pp. 208–216). Valencia, Spain: Editorial Universitat Politècnica de València. <https://doi.org/10.4995/HEDIT2024.2024.17751>
- Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A design science research methodology for information systems research. *Journal of Management Information Systems*, 24(3), 45–77. <https://doi.org/10.2753/MIS0742-1222240302>
- Peirce, C. S. (1878). Deduction, induction, and hypothesis. *The Popular Science Monthly*, 13, 470–482.
- Prat, N., Comyn-Wattiau, I., & Akoka, J. (2014). Artifact evaluation in information systems design-science research: A holistic view. In *Proceedings of the Pacific Asia Conference on Information Systems (PACIS)*. Chengdu, China: AIS.
- Reyes-Burgos, K., & Aquino-Trujillo, J. (2022). *Investigación en las ciencias del diseño: Aplicación en los contextos de computación y tecnología*. Chiclayo, Perú: Editorial USAT.
- Rolim, R. (2026). *Integración del Método ABC en HBIM para optimizar la Gestión de la Conservación Preventiva de Bienes Patrimoniales* (Tesis doctoral). Universitat Politècnica de València, Valencia, España.
- Rolim, R. (2024). Complex spaces in HBIM models: Volumetric visualization for data insertion. In *Proceedings Heritage Digital Technologies and Tourism Management - HEDIT2024* (pp. 198–207). <https://doi.org/10.4995/HEDIT2024.2024.17775>
- Rolim, R., & López-González, C. (2024). Materialisation of complex interior spaces for the insertion and visualisation of environmental data in HBIM models. *Applied System Innovation*, 7(6), 111. <https://doi.org/10.3390/asi7060111>
- Rolim, R., López-González, C., & Viñals, M. J. (2024). Analysis of the current status of sensors and HBIM integration: A review based on bibliometric analysis. *Heritage*, 7(4), 2071–2087. <https://doi.org/10.3390/heritage7040098>
- Sbrogiò, L. (2024). Open HBIM: IFC-based virtualization of architectural heritage. *SCIRES-IT - SCientific RESearch and Information Technology*, 14(2), 91–106. <https://doi.org/10.2423/i22394303v14n2p91>
- Simon, H. A. (1996). *The sciences of the artificial*. MIT Press.
- Sonnenberg, C., & vom Brocke, J. (2012). Evaluation patterns for design science research artefacts. In M. Helfert & B. Donnellan (Eds.), *Practical aspects of design science* (pp. 71–83). Springer. https://doi.org/10.1007/978-3-642-33681-2_7
- Tringa, E., Kavrouidakis, D., & Tolika, K. (2024). Microclimate-monitoring: Examining the indoor environment of Greek museums and historical buildings in the face of climate change. *Heritage*, 7(3), 1400–1418. <https://doi.org/10.3390/heritage7030067>
- Valentini, M., Battini, C., & Vecchiattini, R. (2023). HBIM to support the executive design of a restoration: Critical issues related to geometric and semantic modelling. *SCIRES-IT - SCientific RESearch and Information Technology*, 13(2), 125–136. <https://doi.org/10.2423/i22394303v13n2p125>