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CONCEPTUAL PAPER

Smart FabLabs: The Role of Artificial Intelligence in FabLabs for Heritage Preservation

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ABSTRACT

This article examines how artificial intelligence (AI) and digital fabrication could support the safeguarding of tangible and intangible cultural heritage through FabLabs. It presents a conceptual discussion based on selected publications and institutional project descriptions, rather than an empirical evaluation of integrated AI-FabLab systems. The analysis considers laboratory organisation, possible technical workflows and public participation. HeritageWatch.AI illustrates the use of digital information for monitoring heritage risks; the Aromatic FabLab and Odeuropa provide distinct examples of craft transmission and AI-supported olfactory heritage research. The Notre-Dame restoration illustrates the value of 3D documentation and multidisciplinary data sharing. These examples inform a proposed workflow linking documentation, expert interpretation and the fabrication of educational objects. Potential benefits depend on reliable evidence, specialist oversight, community participation and sustained funding. Digital models and physical facsimiles can support interpretation, but generated reconstructions require clear provenance and validation. The discussion identifies conditions for responsible implementation without claiming universal accessibility or demonstrated conservation gains from AI-FabLab integration.

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1. Introduction

Digital fabrication connects computer-based design with the production of physical objects. The FabLab movement developed from work on personal and digital fabrication at the Massachusetts Institute of Technology (MIT), particularly its Center for Bits and Atoms. Gershenfeld (2007) describes how access to fabrication tools can help people develop practical responses to local needs. Anderson (2012) situates desktop manufacturing and shared design within the broader maker movement.

FabLabs offer a setting in which researchers, craftspeople, students and other participants can design and make objects together. In this article, a smart FabLab means a fabrication laboratory that uses AI for a defined task within such work. This is a proposed direction for practice, rather than a claim that all FabLabs already operate integrated AI systems. In heritage projects, relevant tasks could include organising documentation, assisting interpretation and producing educational models.

The central question is how AI could contribute to heritage work in FabLabs while respecting the evidence, the physical integrity of objects and the communities associated with them. Technical possibilities must be considered alongside funding, staff expertise, data quality and the long-term maintenance of project outputs.

Four questions organise the discussion:

Q1: How can researchers, craftspeople and community contributors participate in defining a heritage project and assessing its outputs?

Q2: Under what conditions could AI-assisted interpretation and fabricated objects improve access to heritage information?

Q3: How might shared laboratory networks support the continuity of projects, skills and documentation?

Q4: What data practices and forms of oversight are needed for community participation in digital heritage work?

The article first examines FabLab organisation, then considers AI applications in heritage documentation and interpretation. It uses selected examples to develop a possible workflow for FabLabs and discusses its technical, financial and ethical limits.

1.1. *Scope and approach*

The article is a conceptual narrative discussion of selected publications, institutional accounts and project websites. It examines the purposes, technical functions and organisational requirements described by these sources, then proposes a workflow for FabLabs. It does not report fieldwork, a systematic search, a tested prototype or measurements of conservation outcomes. The four questions guide interpretation; they are not hypotheses tested on a common dataset. Project websites document how initiatives describe their activities and are considered separately from research evaluations.

2. FabLab organisation and practice

2.1. *Definition and origins*

A FabLab is a workshop for digital fabrication and learning that connects local activity with a wider network. Its users may include entrepreneurs developing prototypes, artists exploring materials, students learning design and electronics, and community groups addressing practical needs. The Fab Foundation (n.d.) describes shared tools, processes and knowledge exchange as features of the network. The equipment and services available at individual sites vary.

Common equipment includes laser cutters, vinyl cutters, computer-controlled milling machines, 3D printers and tools for electronics and microcontroller programming (Fab Foundation, n.d.). These serve different purposes: cutting sheet material, machining parts, building objects layer by layer and assembling electronic prototypes. A heritage project must select equipment according to the required material, size and level of detail, as well as the laboratory's capabilities.

Staffing depends on the host organisation, resources and activities. Responsibilities may be divided among the following roles:

A director or project lead develops the laboratory's strategy, seeks funding and maintains relationships with partner organisations.

A FabManager coordinates daily activities, supports users, organises workshops and arranges equipment maintenance and safe operation.

Technicians, interns, students or volunteers may assist with projects and public activities according to their training. Specialist heritage work also requires access to conservators, curators or relevant craft practitioners; general machine competence does not establish conservation expertise.

The FabLab movement grew out of MIT's work on digital fabrication and its educational outreach. Its emphasis on practical experimentation links learning with the design and production of objects (Gershenfeld, 2007; Fab Foundation, n.d.).

The educational aim is to make design and fabrication more accessible, allowing users to explore how technologies work and how they can be adapted to local needs.

Gershenfeld's (2007) account of personal fabrication provides a basis for considering several possible contributions of FabLabs:

Helping users develop practical skills through the design and fabrication of their own projects.

Supporting learning through prototypes, testing, revision and collaboration across disciplines.

Connecting local problems with knowledge and experience shared through the wider network.

Providing space for ideas initiated by users and community groups.

Helping prospective enterprises explore designs before committing to larger production. These are possible functions; their achievement depends on each laboratory's activities and resources.

2.2. *Establishing a FabLab*

An institution-led laboratory may be hosted by a university, public authority or business that provides premises, equipment or staff. Funding can combine host support, grants, partnerships and income from services. A founding institution need not provide all of the laboratory's continuing resources.

A community-led laboratory may develop from a group of makers, artists, electronics enthusiasts or other participants who pool skills and equipment. Institution-led and community-led arrangements can also be combined. These are useful ways of considering project organisation, rather than mutually exclusive categories (Eychenne, 2012).

2.3. *Organisational models and public access*

The host organisation and funding arrangements influence whom a laboratory serves and how it operates. Drawing on Eychenne's (2012) discussion of FabLab organisation, three broad orientations can be distinguished for this analysis. Actual laboratories may combine them, and access conditions differ between sites.

Educational laboratories primarily support teaching, student projects and research. They may also offer activit-

ies for external participants. Fees, opening hours and staffing depend on the institution and its partners.

Business-oriented laboratories focus on prototyping for companies, start-ups and independent practitioners. Paid services may help fund their activities. Participation in the FabLab network involves more than adopting a name: the Fab Foundation (n.d.) identifies public access for free or in-kind exchange during part of each week, support for the Fab Charter, shared tools and processes, and engagement with the network.

Public and community-oriented laboratories place greater emphasis on workshops, training and locally defined projects. Their viability may depend on public support, partnerships, memberships or paid activities. The number of projects and public sessions must be planned around staffing, safety and available equipment.

3. AI in heritage documentation and interpretation

AI can assist selected tasks in heritage research and interpretation, including the analysis of digital collections and the development of virtual experiences. Münster et al. (2024) review opportunities, challenges and research priorities in this field. Their discussion supports examining particular applications and their requirements, rather than assuming that AI improves every conservation activity.

A useful distinction is between documenting observed features and proposing an interpretation of missing or uncertain features. Both may contribute to a heritage project, but their evidential status differs. A digital file also needs information about its source, processing history and uncertainty if it is to support subsequent research.

3.1. *Analysis and diagnosis*

For condition assessment, a trained image-analysis system could help identify patterns associated with visible damage or changes between surveys. Its usefulness depends on the observations available, the quality of the training data and validation for the intended setting. Alerts require specialist review before they guide an intervention.

Materials analysis requires appropriate observations and measurements. AI may assist the interpretation of analytical data, but an ordinary photograph alone does not establish an object's chemical composition. Any proposed conservation treatment must take account of material properties and the judgement of qualified specialists.

Generative models require particular caution. Altaweel et al. (2024) examine GAN-based enhancement of 2D images of Roman coins and report both improvements in appearance and limitations, including distortions and weaker results for severe damage. The study concerns image visualisation; it does not show that generated details recover the exact original appearance. In a FabLab, such output could be used for a labelled interpretive model after expert review, while the source record is retained.

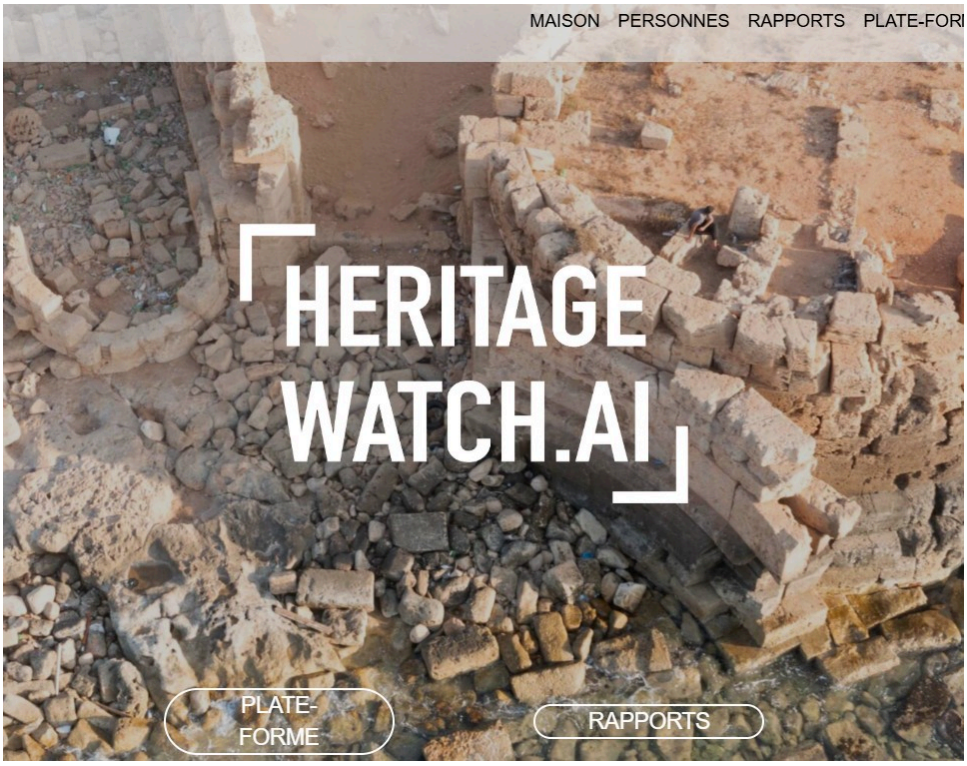


Fig. 1. The HeritageWatch.AI website

Source: HeritageWatch.AI (n.d.), https://heritagewatch.ai/

HeritageWatch.AI (n.d.) describes the use of automated change detection and pattern recognition to assess threats to heritage. Its website identifies sources such as satellite observations, 3D documentation, geospatial data, image

archives and crowdsourced contributions. The project illustrates an approach to information collection and risk monitoring. Its public description is not a comparative evaluation of conservation outcomes or evidence of a FabLab implementation. Figure 1 shows its website.

4. Possible applications in FabLabs

FabLabs could connect digital heritage information with the design of physical objects and public activities. A possible collaboration would bring together heritage specialists, machine operators and community participants, with clearly defined responsibility for the accuracy of information and the purpose of the object being made. The applications below are proposals informed by the selected examples.

4.1. *Workshops and public interpretation*

Collaborative workshops could involve participants in documenting objects, preparing 3D models or designing educational games based on historical sources. Tasks should match participants' skills and the permissions attached to the material. The value of participation would need to be assessed through the quality of the work and participants' experience, rather than inferred from attendance alone.

Tactile models and interactive exhibits could provide additional ways to explore heritage. For example, a fabricated model might help visitors examine a form that cannot be handled in the original collection. An AI-generated conversation with a historical figure would be an interpretive device whose content requires source checking and clear labelling. Accessibility also depends on the interface, language and needs of the intended audience.

4.2. *Perfume skills and olfactory heritage*

The Aromatic FabLab illustrates a local initiative for the cultivation of perfume plants, experimentation and the transmission of related skills. Grasse Expertise (2020) describes a nursery and training activities associated with Les Fleurs d'Exception du Pays de Grasse. The UNESCO inscription concerns the skills related to perfume in Pays de Grasse, including cultivation, processing and perfume composition (UNESCO, 2018). The laboratory supports this field of practice; the cited account does not establish the use of AI in its activities.



Fig. 2. Grasse Expertise page about the Aromatic FabLab

Source: Grasse Expertise (2020), https://grasse-expertise.com/plantes-a-parfum-et-savoir-faire-rendez-vous-a-laromatic-fablab/

Odeuropa is a separate research project. Europa Nostra (2025) describes its use of AI to identify and analyse references to smells in European historical texts and images dating from 1600 to 1920. Its resources support the study and presentation of olfactory heritage, including work with perfumers and heritage specialists. Historically informed scent recreations are interpretations based on evidence and expertise, rather than the recovery of every original smell. The project offers ideas for collaboration, but its achievements do not establish that the Aromatic FabLab uses its methods.

4.3. *A proposed workflow for heritage projects*

The following workflow brings together the article's organisational and technical discussion. It is a proposal for implementation and evaluation in a FabLab.

The first stage is to define the heritage question with the relevant institution and community, establish permissions and document the available evidence. Photogrammetry or laser scanning may then be used where appropriate to record an object or site. AI-assisted analysis should address a specified task, with results checked against observations and expert interpretation. Selected models can subsequently be prepared for educational fabrication or digital presentation.

Workshops and demonstrations could involve participants in reviewing models, testing exhibits and explaining the local significance of objects. A project should record who contributed, what decisions were made and which outputs are suitable for public release.

Before an output is published or fabricated, the team should distinguish measured features from inferred ones and record the sources of any reconstruction. The project

also needs a plan for storage, maintenance and reuse, including access arrangements for the community and the institution responsible for the collection.

4.4. *Digital models and the Notre-Dame example*

A 3D model records selected features of an object or site at a particular time. A digital twin links a digital representation with observations of its physical counterpart and may be updated as new data become available. The scope and frequency of those updates depend on the sensors, surveys and processes in place. A model does not capture every material property or become a digital twin simply because it was produced by laser scanning.

Simulation can help explore possible interventions or structural behaviour, but its conclusions depend on the model's assumptions, input data and validation. Changes in a monument must first be observed reliably before they can inform an update. Recording interventions and preserving earlier model versions can make a digital archive more useful for later conservation work.

Notre-Dame de Paris illustrates the importance of documentation before and after a major loss.

Tallon (2012) describes the use of laser scanning to investigate the cathedral's geometry before the April 2019 fire. Hertz (2024) reports that Tallon's scans contained more than a billion data points and contributed to the restoration. These records provided valuable evidence about parts of the building before the damage.

Dargemont and Heidmann's (2025) CNRS report describes the collection of pre-fire records, including Tallon's data, and new post-fire surveys using laser scanning, photogrammetry and drones. The Aïoli platform helped centralise and annotate documentation for multidisciplinary work. This example demonstrates the contribution of geometric records, shared data and specialist analysis. Laser scanning, photogrammetry and building information modelling (BIM) are distinct from AI, even though AI can be incorporated into some workflows. The Notre-Dame case is therefore informative for planning documentation and collaboration, while the performance of an integrated AI-FabLab process remains a separate question.

4.5. *Governance resources and limits*

The safeguarding of intangible heritage includes the continued practice and transmission of knowledge within communities (UNESCO, 2003). A digital archive can assist this work, but it cannot by itself sustain the relationships, learning and settings through which a practice is passed on. Project priorities and public interpretations should therefore be developed with the people concerned.

For FabLabs, a workable budget needs to include skilled staff, maintenance, consumables, storage and the preservation of digital files. Open sharing can facilitate reuse, while permissions may limit the publication of sensitive cultural information or identifiable contributions. Responsibility for access, corrections and long-term stewardship should be agreed before the project begins.

The environmental costs of digital equipment also belong in project planning. Flipo et al. (2012) examine the environmental implications of information and communication technologies. For a heritage laboratory, the relevant assessment includes equipment manufacture and lifetime, energy use and material consumption, alongside any benefits from reuse or reduced travel.

The analysis is limited by the variety of the sources and the absence of a common evaluation framework. It does not estimate the prevalence of AI adoption in FabLabs, establish causal effects on preservation or compare the full costs of alternative methods. Claims about improved accuracy, engagement or accessibility require evaluation in the intended setting.

5. Conclusion

FabLabs offer a possible setting for connecting heritage documentation, digital interpretation and the fabrication of educational objects. AI could assist defined tasks within these activities, provided that its outputs can be checked and that the laboratory has the necessary technical and heritage expertise.

The selected examples have different purposes. HeritageWatch.AI describes digital monitoring of heritage risks; the Aromatic FabLab supports plant cultivation and skill transmission; Odeuropa uses AI in historical olfactory research; and the Notre-Dame restoration illustrates the value of detailed documentation and data sharing. Together they suggest useful components for future collaborations, rather than a demonstrated model of integrated AI-FabLab conservation.

Public participation can contribute local knowledge and help shape the design of educational objects. Its value depends on meaningful involvement, accessible activities and respect for the communities whose heritage is represented. Digital access and physical replicas can extend opportunities for interpretation without replacing the original object or the practice of a living tradition.

Sustained implementation requires funding for staff, equipment, data stewardship and training. It also requires a record of the evidence underlying reconstructions and a clear distinction between observed features and generated interpretations.

The proposed workflow provides a basis for practical evaluation. Further work could examine costs, the accuracy and usefulness of outputs, accessibility and community experience in specific laboratory settings. Such evidence would be needed to assess whether AI adds value to a heritage activity compared with the alternatives available.

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Appendices

Appendix A Glossary of AI and FabLabs

BIM (building information modelling): A process for organising digital information about a building, including geometry and associated attributes. A BIM model may support coordination and analysis without using AI.

CAD/CAM (computer-aided design and computer-aided manufacturing): Tools and processes used to design objects digitally and prepare instructions for fabrication. CFAO is the corresponding French abbreviation.

GANs (generative adversarial networks): Generative models trained through the interaction of a generator and a discriminator. In heritage applications they may produce plausible visual reconstructions, which require validation and must be distinguished from documentary evidence.

LiDAR (light detection and ranging): A measurement technique using laser light to estimate distances and produce spatial data such as 3D point clouds. A point cloud is a record of measured geometry, rather than an automatically updating digital twin.

3D printing: Additive manufacture of a physical object from a digital model. The detail and dimensional accuracy of a facsimile depend on the source data, preparation, equipment and material.

Appendix B Illustrative heritage initiatives

These initiatives illustrate different aspects of documentation, interpretation and skill transmission. They are not presented as equivalent implementations of AI in FabLabs.

HeritageWatch.AI: A project describing automated analysis and multiple data sources for monitoring changes and risks affecting heritage sites (HeritageWatch.AI, n.d.).

Aromatic FabLab: A plant-cultivation and training initiative associated with perfume skills in Pays de Grasse. The UNESCO inscription concerns the skills themselves (Grasse Expertise, 2020; UNESCO, 2018).

Odeuropa: A research project using AI to identify smell-related evidence in European historical texts and images from 1600 to 1920, with resources for olfactory interpretation (Europa Nostra, 2025).

Notre-Dame documentation: Pre-fire laser records and post-fire surveys supported multidisciplinary analysis and restoration documentation. The example concerns digital heritage work beyond the FabLab setting (Tallon, 2012; Hertz, 2024; Dargemont & Heidmann, 2025).