

Original Paper

Digital Communication Strategies for Atlas Silk Heritage: An NFC-Enabled Cultural Product Case Study

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Abstract

Atlas silk is a traditional silk-based intangible cultural heritage (ICH). Its digital communication faces challenges such as limited public awareness, fragmented cultural information, and the separation of cultural products from their cultural narratives. This study explores how external near-field communication (NFC) smart hangtags can connect physical cultural products with digital heritage content. A preliminary survey (n = 237) informed the development of three NFC-enabled product prototypes. An initial user evaluation (n = 32; 28 valid paired questionnaires) showed higher post-experience ratings of participants' self-reported understanding of production techniques, patterns, and cultural origins, as well as their willingness to purchase or recommend the products. Technical testing showed that the external NFC tags could be read under the tested conditions, although nearby metal components may reduce reading stability. This study considers the external NFC entry point as a "situated interpretive layer" connecting physical product encounters with digital cultural narratives and proposes four design principles: optimizing access points, organizing digital content in layers, improving technical compatibility, and establishing mechanisms for long-term content maintenance and cultural review. The findings should be interpreted as exploratory and require further examination with larger samples and long-term field studies.

Keywords

Atlas silk; intangible cultural heritage, digital heritage, near-field communication (NFC), physical-digital interaction, cultural products

1. Introduction

Intangible cultural heritage (ICH) includes not only craft processes and material outcomes, but also knowledge, memory and values in specific communities and cultural contexts. With the development of

digital images, mobile Internet and interactive media, the digitization of ICH has gradually shifted from data preservation to public interpretation and interactive experience. However, digital technology does not necessarily lead to effective communication. Visual representation and fragmented information separated from cultural contexts may simplify ICH into consumable cultural symbols. Therefore, how to improve the accessibility of cultural content while maintaining the accuracy of cultural interpretation and narrative continuity remains an important issue in the digital communication of ICH.

Atlas Silk is a national intangible cultural heritage of China, handwoven in Hotan with the ancient warp tie-dyeing technique. Its warp-resist dyeing process produces abstract patterns with naturally blurred edges and a sense of flow, and its colors and patterns are closely related to local lifestyles, dress customs and aesthetic traditions (Zhang & Huang, 2021). However, for the public without relevant knowledge, information about its history, crafts, pattern meanings and artisan experience remains fragmented. Although some cultural and creative products use the colors and patterns of Atlas silk, they provide limited explanations of their craft origins and cultural meanings, resulting in visual recognition without sufficient cultural interpretation.

In recent years, the digitization of Atlas silk has involved digital pattern translation, AIGC visual design, mobile communication and multimedia display (Li & Pan, 2025; Xu, 2025; Yang et al., 2024; Zhao, 2026). These studies have expanded the forms and channels of traditional cultural communication, but existing practices mainly focus on visual presentation or independent online platforms. The connection between physical cultural products and digital cultural content remains limited. How users can access information about crafts, patterns and cultural backgrounds while interacting with physical products therefore requires further exploration.

Near-field communication (NFC) provides a lightweight way to establish such a physical – digital connection. Users can access craft videos, pattern explanations and cultural stories by bringing compatible smartphones close to NFC tags attached to product hangtags or packaging. Previous studies have shown the potential of NFC in cultural and creative products, information display and textile heritage (Wei & Wang, 2025; Yan et al., 2026; Zhu et al., 2024). However, existing studies mainly focus on conceptual design, information display or technical performance, with limited attention to how NFC connects physical products with digital narratives in everyday contexts, including entry-point recognition, device compatibility, content organization and long-term maintenance.

Based on these gaps, this study uses NFC-enabled Atlas silk cultural products as a case and combines a preliminary user survey, prototype development, technical testing and user evaluation to explore the connection between physical products and digital cultural content. The study addresses the following research questions:

RQ1: What are the gaps in public understanding of Atlas silk, and what cultural content needs and design requirements can be identified?

RQ2: How do users access and experience digital cultural content through NFC-enabled physical products, and what changes occur in their self-reported cultural understanding after the experience?

RQ3: What design principles can balance technical usability, narrative coherence and sustainability in NFC-enabled heritage communication?

Through a specific design case and exploratory user evaluation, this study examines how an external NFC smart hangtag connects Atlas silk cultural products with digital cultural content and derives practical principles for entry design, content organization, device compatibility, long-term maintenance and cultural review. Conceptually, NFC is regarded as a “situated interpretive layer” connecting physical product encounters with digital cultural narratives, providing a case reference for the digital communication of Atlas silk and other traditional textile heritage.

2. Related Research and Research Gap

2.1 Digital Communication of Intangible Cultural Heritage and Physical Interaction

Digital technology has been widely used in the recording, display and communication of intangible cultural heritage, gradually shifting from digital preservation to interactive experience and cultural interpretation. Vert et al. (2021) pointed out that mobile technologies and digital platforms can expand access to cultural heritage information and provide a flexible environment for public participation. Hulusic et al. (2023) further showed that digital cultural heritage experiences depend not only on information presentation, but also on user interaction, content organization and cultural context.

Physical–digital integration provides another perspective on this issue. Duranti et al. (2024) noted that digital heritage displays may create “material detachment,” where digital content becomes separated from physical objects and their particular contexts. Reconnecting digital content to physical objects and their contexts may help maintain the relationship between material experiences and digital interpretations. Rizvic et al. (2024) also argued that interactive digital narratives need to balance user autonomy and narrative integrity to avoid excessive fragmentation of cultural information.

These studies suggest that digital heritage communication concerns not only the content provided, but also the context and entry points through which users access it. For traditional textile heritage with strong material and craft characteristics, linking digital interpretation to physical-product experience remains an important issue.

2.2 Digitization and Cultural Product Communication of Atlas Silk

Existing research on the digitization of Atlas silk mainly focuses on pattern digitization, visual design and new-media communication. Zhao (2026) examined its pattern composition and digital expression from the perspective of pattern types and visual characteristics, while Li and Pan (2025) explored AIGC and H5 for the visual translation and dynamic presentation of traditional patterns. Yang et al. (2024) also examined the role of digital technologies in Atlas silk communication and innovative design, while Xu (2025) explored communication through short videos, live streaming and other new-media scenarios. These studies have expanded Atlas silk from traditional display to digital expression and online communication.

However, existing research still focuses mainly on visual translation, digital content production and online communication, with relatively limited attention to the connection between physical cultural products and digital cultural interpretation. In cultural products, the colors and patterns of Atlas silk can be directly perceived, but their production techniques, pattern origins and cultural backgrounds are not naturally communicated through the products themselves. How to provide a convenient and sustainable cultural interpretation entry point without altering the textile itself therefore remains underexplored.

2.3 NFC-Enabled Cultural Products and Research Gap

NFC is a short-range wireless communication technology that provides a relatively simple way to connect physical products with digital content. Previous studies have applied NFC to cultural and creative products, cultural information display, and traditional textile identification and anti-counterfeiting (Wei & Wang, 2025; Yan et al., 2026; Zhu et al., 2024). Muangasame and Tan (2023) also showed that integrating digital technologies with physical cultural experiences can expand access to cultural content and provide new interactive entry points for heritage experiences.

Existing NFC-related research mainly focuses on tag identification, information linking, technical performance or conceptual product design. Less attention has been paid to how users discover and understand NFC entry points, how devices and use environments affect reading experiences, and how digital content can form a continuous narrative with the cultural attributes of physical products. For heritage cultural products, simply linking an NFC tag to a webpage does not necessarily create effective cultural communication; entry-point location, discoverability, operation prompts, content hierarchy and subsequent maintenance may also affect the physical–digital experience.

Therefore, existing research still lacks case studies combining physical product design, NFC interaction, digital cultural content, technical adaptability and user evaluation. This study addresses this gap through an external NFC smart-hangtag prototype for Atlas silk and examines its use through a preliminary survey, prototype iteration, technical testing and user evaluation, from which design principles for traditional textile heritage communication are derived.

3. Research Methods

3.1 Research Design

This study uses a mixed-method case study supported by design practice to explore how NFC connects physical Atlas silk cultural products with digital cultural content. The research includes four stages: first, literature analysis and a preliminary user survey to identify public knowledge gaps and cultural content needs; second, development of NFC-enabled cultural product prototypes and mobile digital content; third, internal and device testing to optimize the NFC hangtag and page structure; and finally, a small-scale user evaluation of the optimized V2.0 prototype to examine user operation, digital content access, and changes in self-reported cultural understanding. The research process follows the path of “requirement identification–prototype development–technical optimization–user evaluation.”

3.2 Preliminary User Survey

The research team conducted an online questionnaire survey through WeChat, campus groups and social media platforms from March to April 2026. A total of 240 questionnaires were collected, of which 237 were retained after excluding responses with missing core items, abnormal completion times or obvious duplication. The survey covered respondents' existing knowledge of Atlas silk, information channels, interest in interactive cultural products, product preferences and digital content needs. Frequencies and percentages were used to analyze closed-ended questions, while open-ended responses were used to summarize knowledge gaps and content needs.

The preliminary survey sample was independent of the subsequent prototype evaluation sample. The questionnaire described interactive cultural products through a scenario of "scanning to view cultural stories or production videos," but participants did not actually use NFC. Therefore, the results were used only to inform prototype design and were not interpreted as evidence of NFC acceptance or communication effects. As complete demographic information was not collected, comparisons between audience groups were not conducted.

3.3 Prototype Development and Technical Testing

Based on the preliminary survey, long scarves, shoulder bags and cushions were selected as prototype carriers representing wearing, daily carrying and home-use contexts. Each prototype used an NTAG215 passive NFC tag enclosed in an external smart hangtag connected to the product without sewing, adhesive or perforation of the textile. The hangtag included a standardized NFC symbol and operation instructions, with a QR code linking to the same mobile page as a backup entry.

The mobile page included a short video of the warp-resist dyeing process, animated pattern interpretation and artisan audio narration. After V1.0 was completed, 10 internal members tested entry prompts, hangtag settings and page navigation, leading to the development of V2.0. This internal test was used only for design iteration and was not included in the formal user evaluation.

Huawei Mate 80, Apple iPhone 17 and Xiaomi 17 Pro smartphones were used to test the external NFC hangtag under unobstructed and metal-adjacent conditions. The tests examined basic reading performance and possible interference from nearby metal components. The results were used only for prototype-stage technical suitability assessment, not for comparisons between smartphone brands or models or for generalization to all devices and use environments.

3.4 User Evaluation

In May 2026, 32 participants were recruited through convenience sampling via campus bulletin boards, social media platforms and personal referrals for the V2.0 prototype evaluation. Participants were aged 18–42 years ($M = 26.4$, $SD = 5.1$), including 12 males and 20 females; two had design-related educational backgrounds and 30 had non-design backgrounds. None reported systematic prior knowledge of Atlas silk heritage.

Participants used their own smartphones to locate the NFC area on the product hangtag, read the tag and access the mobile page containing digital cultural content. Researchers recorded major usability problems during entry discovery, tag reading and page access, while the system recorded page dwell

time and content access. After the experience, participants completed a questionnaire and provided open-ended feedback on content understanding, operational difficulties and suggestions.

Of the 32 participants, 28 (87.5%) completed valid paired pre- and post-experience questionnaires; four were excluded due to incomplete responses. Three independent 5-point Likert-type items assessed self-reported understanding of warp-resist dyeing, the cultural and geographical origins of specific patterns, and different pattern types and craft characteristics. A separate 5-point item measured purchase or recommendation intention. Since these items measured different dimensions, they were not combined into a single scale, and no internal consistency coefficient was calculated.

This study explores user experience in realistic use scenarios rather than causal effects under strictly controlled conditions. As no control group was included, pre-post changes cannot be causally attributed to NFC and are therefore interpreted as within-subject perceptual changes rather than objective knowledge gains.

3.5 Data Analysis and Research Ethics

Preliminary survey, user operation and system access data were analyzed descriptively using frequencies, percentages, means and standard deviations. Paired-samples t-tests were conducted on the 28 valid paired questionnaires, reporting pre- and post-test means and standard deviations, mean differences with 95% confidence intervals, t values, degrees of freedom, two-sided p values, and Cohen's as the standardized effect size. Open-ended responses were analyzed descriptively and grouped into usability problems, content preferences and long-term use concerns. Page dwell time was measured from successful page loading until the page was closed or moved to the background; video completion was defined as the proportion of starts reaching 90% of the total video duration.

This study was conducted as minimal-risk anonymous user experience research. Participants in the preliminary survey and prototype evaluation were informed of the research purpose, procedures and data use before participation and voluntarily consented to participate. No personally identifiable information was collected, and workshop images, artisan voices and pattern interpretations were used with authorization from the relevant individuals.

4. Results

4.1 Preliminary Survey and Design Requirements

Among the 237 respondents, 123 (51.9%) had never heard of Atlas silk, only about 10.5% reported being relatively familiar with it, and 109 (46.0%) had not formed a clear impression of its visual characteristics. Regarding cultural content, 164 respondents (69.2%) wanted to learn about the production process, 143 (60.3%) were interested in its historical and cultural background, and 160 (67.5%) expressed interest in interactive cultural products. These results indicate limited overall awareness and a demand for explanatory content beyond product and pattern display.

Based on these findings, three design requirements were identified: selecting cultural products with daily-use or display functions as physical carriers; presenting craft, pattern and cultural information

through video, animation and audio; and establishing convenient physical–digital access through an external NFC smart hangtag.

4.2 Product Prototypes and Digital Content Design

Based on the preliminary survey, long scarves, shoulder bags and cushions were developed as prototypes representing wearing, daily carrying and home-use contexts. All three used typical Atlas silk colors and patterns and were equipped with external NFC smart hangtags.

The NTAG215 tags were enclosed in detachable hangtags without sewing, adhesive or perforation of the textile. Each hangtag included an NFC symbol, brief operation instructions and a backup QR code. Users could access the mobile page by bringing an NFC-enabled smartphone close to the tag, following the path: physical product → hangtag → NFC area → smartphone proximity → digital page → cultural content.

The mobile H5 page contained three core modules: a short video of the warp-resist dyeing process, animated pattern interpretation and artisan audio narration. The process video presented key production steps, the pattern module explained representative patterns and their cultural meanings, and the audio module provided artisan narratives. The interface and content structure of the mobile page are shown in Figure 1.

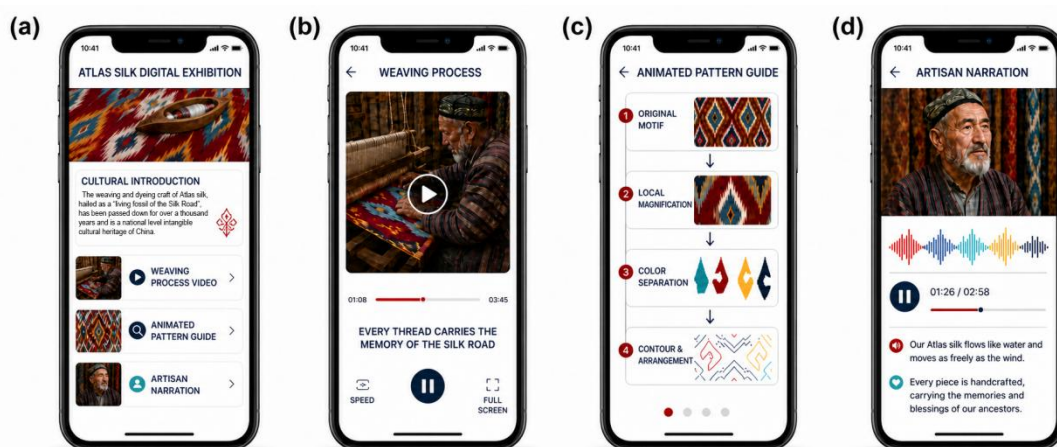


Figure 1. Mobile H5 interface and digital cultural content modules

4.3 NFC Performance Testing and Prototype Optimization

4.3.1 NFC Reading Performance

Table 1 presents the NFC reading performance of the three tested smartphones under unobstructed and metal-adjacent conditions.

Table 1. NFC Reading Performance across Tested Smartphones and Environmental Conditions

Smartphone model	Operating system	Unobstructed reading distance (cm)	Reading success rate under metal-adjacent conditions	Average first-response time (s)
Huawei Mate 80	HarmonyOS 6.0	3.2	8/10 (80%)	0.6
Apple iPhone 17	iOS 26.6.1	2.5	7/10 (70%)	0.8
Xiaomi 17 Pro	HyperOS 3	3.8	9/10 (90%)	0.5

Under unobstructed conditions, effective reading distances ranged from 2.5 to 3.8 cm, with average first-response times of 0.5–0.8 s. Under metal-adjacent conditions, reading success rates ranged from 70% to 90%, suggesting that nearby metal components may reduce reading stability. This result supports avoiding excessive proximity between NFC hangtags and metal zippers, buckles or decorative components and retaining a backup QR-code entry.

Given the limited number of devices and repeated readings, these results are used only as a prototype-stage technical check and should not be interpreted as comparisons between smartphone brands or generalized to other devices and use environments.

4.3.2 Prototype Optimization

V1.0 internal testing showed that some users could not immediately identify the NFC area and needed to adjust smartphone positioning, while the mobile page contained too many information levels and did not sufficiently highlight core content. In V2.0, NFC symbols and brief operation instructions were added, hangtag position and orientation were adjusted to reduce proximity to metal components, and page navigation was simplified to emphasize the craft video, animated pattern interpretation and artisan audio.

4.4 User Evaluation Results

4.4.1 Evaluation Sample

All 32 participants completed the V2.0 experience and operation tasks, while 28 provided valid paired pre- and post-experience questionnaires; four were excluded because of incomplete items. Therefore, operation and page-access results are based on 32 participants, whereas pre–post comparisons are based on 28 paired questionnaires.

4.4.2 Self-Reported Cultural Understanding and Product Acceptance

Table 2 compares the pre- and post-experience scores of the 28 participants with valid paired questionnaires. Higher scores indicate greater self-reported understanding or stronger purchase/recommendation intention.

Table 2. Pre-post Comparisons of Self-reported Cultural Understanding and Product Acceptance (n = 28)

Evaluation dimension	Pretest M ± SD	Post-test M ± SD	Mean difference (post – pre)	95% CI	t (27)	p	Cohen's d _{av}
Understanding of the warp-resist dyeing process	3.5±0.8	4.2±0.7	0.7	(0.47, 0.93)	6.17	<0.001	0.93
Understanding of specific patterns' cultural and geographical origins	3.2±0.9	4.0±0.8	0.8	(0.55, 1.05)	6.51	<0.001	0.94
Understanding of different pattern types and craft characteristics	3.0±0.85	3.8±0.75	0.8	(0.56, 1.04)	6.83	<0.001	1.00
Purchase or recommendation intention	3.3±0.95	4.1±0.85	0.8	(0.54, 1.06)	6.23	<0.001	0.89

Paired-samples t-tests showed higher post-experience scores for all three self-reported cultural understanding indicators, including the warp-resist dyeing process, cultural and geographical origins of specific patterns, and different pattern types and craft characteristics (all $p < 0.001$). Purchase or recommendation intention was also higher after the experience ($p < 0.001$) (Table 2).

The first three indicators reflect participants' subjective assessments of their cultural understanding rather than objective knowledge. These results should therefore be interpreted as short-term within-subject perceptual shifts rather than objective knowledge gains or causal effects of NFC.

4.4.3 Page Usage and User Feedback

The average page dwell time was approximately 2 minutes and 17 seconds. The craft video was started 62 times, of which 38 plays reached at least 90% of its duration (a completion rate of 61.3%). Animated pattern content was accessed 55 times, and artisan audio was accessed 18 times. As repeated

accesses by the same participant were counted separately, these figures describe content access rather than statistical differences between modules.

Open-ended feedback indicated that participants generally found videos and animated illustrations easier to understand than long text. They also appreciated the colors, patterns and tactile qualities of the physical textiles alongside the digital information. Some suggested adding bookmarking, sharing, bilingual content and revisit functions, while others reported difficulty locating their smartphones' NFC sensing areas or expressed concerns about devices without NFC support. These comments support the use of clear entry instructions and a backup QR code.

5. Design Principles for NFC-Enabled Atlas Silk Cultural Products

Based on the prototype development, technical testing and user evaluation, four design principles are summarized for NFC-enabled Atlas silk cultural products.

5.1 Optimize Physical–Digital Access Entry

NFC access points should be visible, understandable and easy to operate. For textile cultural products, external detachable hangtags can reduce intervention in the textile while allowing flexible positioning and replacement. Clear NFC symbols, concise operation instructions and appropriate tag positioning can improve entry-point discoverability, while a QR code linking to the same digital content should be retained as a backup for devices or users unable to complete NFC access.

5.2 Establish a Layered Digital Content Structure

Digital cultural content can be organized in layers rather than presented at the same level. Short videos and animations may serve as entry-level content, as they offer straightforward explanations of production processes and pattern characteristics. Historical context, cultural significance, and artisan stories can provide further information for users who wish to explore these topics. The content structure should maintain continuity across different media modules rather than presenting fragmented information.

5.3 Improve Technical Compatibility and Reading Stability

NFC interaction needs to take product materials, tag placement and device differences into consideration. For products with metal zippers, buckles or other metal components, NFC tags should be positioned away from these parts to reduce potential reading interference. Since NFC sensing positions and support vary across smartphones, clear operating instructions and alternative access methods, such as QR codes, can improve accessibility across different use situations.

5.4 Establish Content Maintenance and Cultural Review Mechanisms

The long-term value of NFC-enabled cultural products depends not only on tag readability but also on whether the associated digital content remains accessible and accurate. Links and mobile pages need to be regularly maintained, while craft descriptions, pattern interpretations and cultural narratives should be reviewed to avoid misrepresentation or loss of context. When artisan narratives, images or other

cultural materials are used, the authorization and participation of relevant cultural holders should also be considered.

6. Discussion

6.1 Interpretation of the Main Findings

The findings suggest that the digital communication of Atlas silk involves not only limited public awareness, but also a gap between visual recognition and cultural interpretation. Although colors and patterns can be directly perceived through physical products, production techniques, pattern meanings and cultural backgrounds require additional explanation. In this case, the external NFC smart hangtag provided a lightweight entry point connecting physical products with digital cultural content without altering the textile itself.

The higher post-experience ratings of self-reported cultural understanding and purchase or recommendation intention suggest positive perceptual shifts after the combined physical–digital experience. However, these changes cannot be attributed to NFC alone. Participants experienced the physical products, NFC access and digital content as a combined process, and no control group was included. The results therefore reflect the overall experience rather than the isolated effect of NFC technology.

6.2 NFC as a Situated Interpretive Layer

The case also offers a perspective on the relationship between physical cultural products and digital heritage interpretation. Duranti et al. (2024) described “material detachment,” in which digital heritage content becomes separated from physical objects and their contexts. In this case, digital content was not provided as an independent online resource but was accessed through an NFC entry point attached to a specific Atlas silk product. This connection may help link digital interpretation to the physical object and its context of encounter.

Based on this case study, the concept of a “situated interpretive layer” is used to describe the role of the external NFC entry point. The term does not mean that NFC itself performs cultural interpretation. Rather, NFC provides an access layer through which digital narratives about crafts, patterns and cultural backgrounds are connected to a specific physical product and the situation in which users encounter it. In this sense, the interpretive value lies in the relationship among the physical product, digital content and context of use, rather than in the NFC technology alone.

Compared with direct access to an ordinary webpage, NFC introduces an active sequence of locating the tag, approaching the sensing area and completing the read, placing digital access and physical-product contact within the same encounter. The craft video reached at least 90% of its duration in 38 of 62 starts, while open-ended feedback frequently indicated that video and animation were easier to understand than long text. These observations suggest that visual craft content may be suitable as an initial form of interpretation after physical–digital access, although the present study does not establish comparative effects between content formats.

The situated interpretive layer should therefore be regarded as a case-derived conceptual lens rather than a validated theoretical model.

6.3 Research Limitations and Future Directions

This study has several limitations. First, both the preliminary survey and user evaluation used convenience sampling, and complete demographic information was not collected in the preliminary survey, limiting subgroup analysis and generalizability. Second, the prototype evaluation involved only 32 participants, with 28 valid paired questionnaires, and no control group or objective knowledge test was included. The observed changes therefore represent short-term self-reported perceptual shifts rather than verified knowledge gains or causal effects of NFC. Third, technical testing involved only three smartphone models and limited use conditions, so the results cannot represent broader device compatibility or long-term field performance. Finally, video completion was measured by playback events rather than unique participants, and repeated plays were counted separately.

Future research should expand participant diversity and sample size, collect more systematic demographic information, and conduct longer-term field evaluations in museums, cultural-product retail settings or heritage workshops. Controlled comparisons among NFC, QR-code and non-digital conditions could help distinguish the contribution of the access technology from that of the digital content itself. Objective knowledge measures and longitudinal follow-up could also be introduced to examine cultural understanding, retention and repeated use over time.

7. Conclusion

This study explored the use of external NFC smart hangtags in the digital communication of Atlas silk heritage through a preliminary user survey, prototype development, technical testing and user evaluation. The results show that external NFC hangtags can establish a physical–digital connection without altering the textile itself and provide access to digital content on production techniques, patterns and cultural backgrounds. Participants reported higher post-experience ratings of cultural understanding and purchase or recommendation intention, while technical testing indicated that nearby metal components may affect reading stability.

Based on the case, four design principles were identified: optimizing physical–digital access, establishing a layered digital content structure, improving technical compatibility and reading stability, and establishing content maintenance and cultural review mechanisms. Conceptually, the study uses the notion of a “situated interpretive layer” to describe how an NFC entry point can anchor digital cultural interpretation to a physical product and its context of encounter. The value of NFC therefore lies in connection rather than substitution: it connects material cultural experience with digital interpretation rather than replacing the physical heritage experience.

Given the small convenience sample, absence of a control group, reliance on self-reported measures and limited device testing, the findings should be interpreted as exploratory rather than causal or broadly generalizable. Future research should use larger and more diverse samples, objective

knowledge measures, longer-term field evaluation and controlled comparisons among NFC, QR-code and non-digital conditions.

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