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The Evolution and Challenges of Materials in Ancient Book Restoration: Which is More Important for Long-Term Preservation of Documents, Traditional or Modern Restoration Materials?

Yufei Shao

Abstract:

The restoration of ancient books plays a very important part of the preservation of cultural heritage. The main idea of it is to preserve historical authenticity, Long material life and cultural continuity. This article arranges the development of restoration materials of ancient books, mainly discussing the applications and evaluations of traditional and modern materials. Traditional materials like Chinese traditional paper, Japanese traditional paper, fish glue and starch paste. These materials have high reversibility, good compatibility, and culture consistency, so they have been used in preserving the original appearance of books and carrying the craft tradition for centuries. With the development of scientific technology, modern materials such as synthetic paper, acid-free paper, polymer adhesives, nanomaterials, and fiber-reinforced composites have gradually emerged. These materials are better at improving the stability of the structure and durability. This article will analyse the pros and cons of both traditional and modern materials across multiple dimensions, encompassing performance comparison, applicable scenarios, and ethical considerations, among others. Combining some real examples, this article will emphasize that choosing proper restoration materials should depend on some factors like the materials of the books, the aim of the restoration and the damage level. This article aim to provide an overall theoretical support and practical approach for culture heritage conservators. Also helps to promote the preservation work to me scientific, systematic and sustainable. This study proposes a "reversible base + local high-strength reinforcement" layered conservation strategy, emphasizing that material selection should be based on the document's condition and preservation goals, balancing structural durability with

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cultural authenticity under ethical restoration principles.

Keywords: Ancient Book Restoration; Restoration Materials; Reversibility and Durability; Cultural Heritage Preservation; Hybrid Conservation Strategies

1. Introdution

Ancient books regarded as a very essential part of the world culture heritage, it carries a rich history, culture and knowledge. They not only witness the evolution of human culture, but also is the carrier of the ideas and culture of the past era. However, as the time goes by, because of natural aging and the change of temperature and environment humidity, ancient books will face varying degrees of damage. These damage will not only show on the appearance, it may also lead to the loss of literature content. Therefore, the restoration of the books become a vital work for protecting the historical culture heritages. The main purpose is to restore the structure of the books and keep the initial appearance and its cultural connotations as much as possible at the same time. With the development of the restoration materials and techniques, the method of restoration is also improving. However, how to choose a suitable material to restore different books is still a problem that has long been urgently needed.

The choice of the restoration materials plays an important role in the restoration of ancient books. Traditional materials like rice paper, isinglass, etc, it has long been regarded as a type of material that is able to better maintain the historical authenticity of documents and the reversibility of the restoration. By contrast, modern materials is more likely to use synthetic materials or acid-free materials, they can improve the stability and durability. As a result, they can help to maintain the use ages of these ancient books more effectively. However, modern materials always have problems with poor reversibility and other aspects, these problems may have an impact on the ancient books themselves. Hence, how to balance the use of traditional and modern restoration materials has become a challenging and complex issue in the work of protecting cultural relics.

The aim of this paper is to discuss the evolution process of restoration materials in ancient books and try to analyze the importance of both traditional and modern materials in the long term protection of documents. We are going to discuss this topic in different aspects and analyze the advantages and disadvantages of each of these two types of materials in depth. At the same time, this paper will try to figure out how to choose the most suitable restoration materials by considering the damage condition and protection needs in different ancient books. This article will especially focus on “Which is more important for book’s long-term preservation? Traditional or modern restoration materials?” This core issue is discussed in order to provide scientific and practical guidance for restoration workers. Through the review of the evolution and application of ancient book restoration materials, the aim of this article is to give a beneficial reference for the field of the protection of cultural heritage, helping ancient book restorers to give a more proper and scientific decision when faced with different material options.

The structure of this article is as follows: The second part: In the thesis review, we will firstly review the basic principle and development of ancient books restoration. Introduce the main types and the applications of traditional materials and modern materials in details. We will pay more attention on analyzing the properties, advantages and disadvantages of these materials. The thirds part: In the discussion, we will have a deep discussion about the reversibility, durability and restoration effectiveness and trying to find how to combine the application of traditional and modern materials in order to achieve the goal of long term sustainability. The past part: In conclusion, we will conclude the main ideas in this article and give some specific suggestions for the process of ancient books restoration. Also, we will talk about the trend of development and challenges about restoration arterial in the future.

2. literature review

2.1 The basic principles of ancient book restoration

The core purpose of the restorations of ancient books is to ensure the preservation of the informational and cultural baggage carried in the documents and to prolong their physical life. Being carriers of cultural heritage, ancient books do not just include written and visual information but reflect the values of society, artistic accomplishments,

and historical background of that period; the preservation of cultural memory and continuity can be seen as the primary and primary goal of restoring damaged book(Bainbridge, 2023a; Zervos & Alexopoulou, 2015). The first goal is to preserve as much cultural knowledge as possible, particularly in documents that detail philosophies, political systems, social life, and scientific achievements of earlier times; the second goal is to increase the material stability by reducing structural decay due to aging materials such as paper and leather(Zervos & Alexopoulou, 2015). Moreover, most ancient books have undergone a long-term storage or overuse, which leads to poor readability or destruction, so the recovery of readability and visual conditions is an important step in the conservation process(Wang et al., 2024).

Three fundamental concepts—reversibility, minimal intervention, and historical authenticity—guide scientific and ethical restoration. These principles underpin contemporary conservation ethics and aim to ensure that treatment choices do not compromise an artifact's long-term integrity; in practice, they favor targeted, limited interventions and thorough documentation to maintain cultural context and transparency (American Institute for Conservation [AIC], 2024; International Council of Museums—Committee for Conservation [ICOM-CC], 2008; International Council on Monuments and Sites [ICOMOS], 1994). Developing a restoration strategy also requires assessing material composition, damage extent, treatment goals, and environmental conditions; for example, paper artifacts often employ breathable Japanese tissues and wheat starch paste for localized mends, whereas leather-bound volumes require compatible, like-for-like approaches (Northeast Document Conservation Center [NEDCC], n.d.; British Library, 2019). Finally, material performance and risk profiles are highly sensitive to temperature and relative humidity; therefore, storage and treatment environments should be designed and evaluated using sector standards and quantitative metrics for chemical and mechanical risks (ASHRAE, 2019; International Organization for Standardization [ISO], 2024; Nishimura, 2011).

2.2 The characteristics and the applications of traditional materials

2.2.1 Paper materials

Paper is one of the most common materials in the ancient books. Therefore, choking a suitable paper material for books in really essential. Traditional paper like rice paper, Japanese paper etc are widely used in restoration because they have good breathability, moisture absorption, and repair performance. These paper are usually made by plans' fiber, so they can perfectly combine with the raw materials that exist in ancient books. This results in effective hole filling and reinforcement(Keya et al., 2019). Rice paper, as a type of traditional Chinese paper, known for its good flexibility and hygroscopicity, always used to restore the damaged paper books, especially has a strong result in hole filling and reinforcement(Luo et al., 2021). Japanese paper is a type of traditional paper in Japan. It contains good adaptation and durability, and is especially suitable to fix the books with thin paper and severe ageing(Han et al., 2023).

The restorative properties of rice paper are not only reflected in its physical properties, but also closely related to its cultural background. Due to the complex production process of rice paper and its high degree of craftsmanship, the selection of rice paper in the restoration process not only protects ancient books, but also reflects respect for traditional skills(Luo et al., 2021). As a natural paper, washi paper can play a role in reinforcing and supplementing ancient book restoration, especially on the edges and severely damaged parts of books. In addition, the fine surface of washi paper is suitable for providing a texture consistent with the original writing during the restoration process, so that the restored ancient books not only maintain their original appearance, but also have new use value(Han et al., 2023).

2.2.2 Adhesives

Adhesives play an important role in the restoration. Traditional adhesives like fish glue, starch paste, and rice paste, etc are commonly used in restoration due to their good adhesion and reversibility(Borges et al., 2018; Bridarolli et al., 2022; Luo et al., 2023). Among them, fish glue is the natural gum extracted from the swim bladder. It has strong adhesion and will not cause excessive pressure on the ancient book material during the restoration process, so it is widely used in the restoration of paper ancient books. The reversibility of the fish glue makes it safer to use during the restoration. Because it can be removed from the paper in the further processes and will not permanently influence the original state of the cultural relics(Mosleh et al., 2023).

Starch pulp and rice milk are natural adhesives made by mixing starch or rice flour with water(Yu et al., 2024). The adhesive properties of these materials are relatively mild. That makes them suitable for the restoration of ancient books that are not too fragile. The starch paste has little impact on ancient books during the restoration process, and its transparency is high, which can maintain the original appearance as much as possible after restoration and will not have a negative impact on the visual effect of ancient books(Wang et al., 2024). The restoration effect of rice milk is relatively mild, and it will not cause much

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pressure on ancient books during the restoration process, making it suitable for light restoration of books(Yang et al., 2010). This reversible behaviour is further illustrated in Fig. 1, which shows how starch/rice paste bonds swell slightly under moisture, reinforcing the need for careful humidity control during restoration.

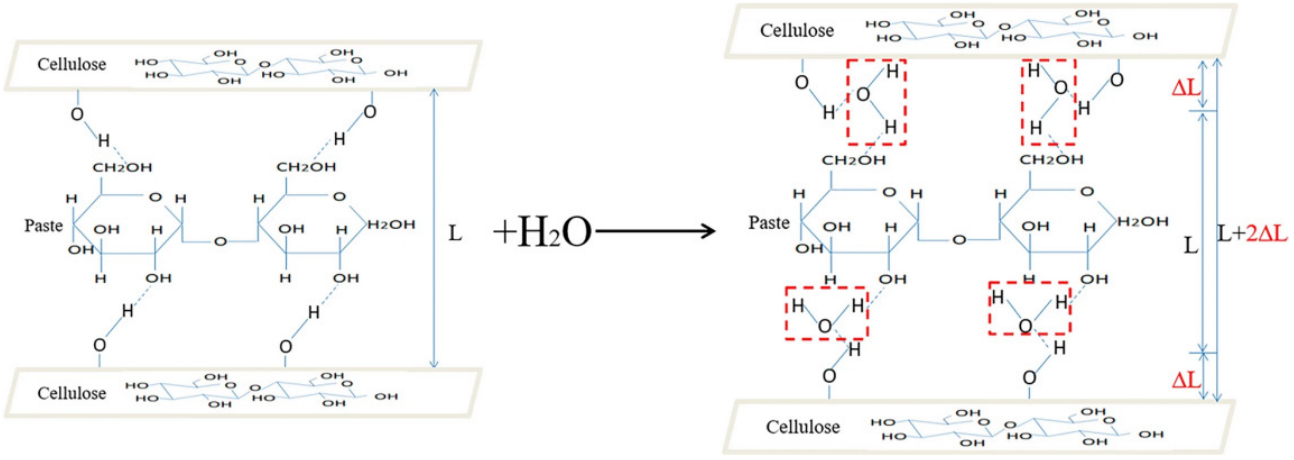

Figure 1 Schematic illustration of hydrogen bonding between starch/rice paste and paper fibers.

The advantages of traditional adhesives are their reversibility and gentleness. These makes them can maximize the protection of the structure and the materials in books during the restoration. However, natural adhesives are really sensitive to the humidity of the environment, we need to pay more attention in controlling the environment. For example, fish glue and rice milk are really sensitive the change in humidity, too low or too high of the humidity can all leading the decrease of the adhesive. Therefore, during the restoration, we need to pay special attention in the control of humidity(Bridarolli et al., 2022).

2.2.3 Restoration process

Traditional restoration techniques are an integral part of the restoration of ancient books, and techniques such as manual repair, hole repair, and lining have been passed down for hundreds of years and have important cultural and historical value. The manual mending technique involves reattaching broken paper, leather, or fabric sections through delicate stitching and repair. During the repair process, conservators need to consider the historical and cultural background of the ancient book, use suitable materials and techniques, and ensure that the restoration effect does not affect the original appearance of the ancient book as much as possible(Szczepanowska, 2013).

The technology of hole repair is mainly used for fixing the part that is damaged badly. Repair staffs will usually use materials like rice paper and Japanese paper to fill the holes especially those between the page number or on the edges of the books. Workers can use this technology to recover the wholeness of the texts efficiently. It can prevent to influence the use of the books in the further(Letnar et al., 2006). Lining is to add a layer of restoration paper or cloth on the back of the books to strengthen its stability of the structure, especially for those books which have already been fixed for many times. Use lined fabric can improve the durability and the usability of ancient books.

These traditional repairing technology only pay attention to recovering the original outlook of ancient books, but also emphasis the sustainability of those books after restoration. Although these traditional methods are really complicated, its finesse and craftsmanship can effectively pass on historical skills and culture during the restoration process(Letnar & Vodopivec, 2004). Traditional restoration skills are still using the many restoration progresses though the modern technology are developing fast. These traditional methods will be especially used in those fixing works that need to restore historical and cultural identity.

2.3 The characteristics and the applications of modern materials

2.3.1 Synthetic paper and acid-free paper

As technology upgrades, synthetic paper and acid-free paper have become two of the most luxurious materials to be fixed on antiquarian books, which also effectively answers the obsolescence of the tradition paper that is easily aged and acidified and thus increasingly abandoned by the modern conservation demands. Both these two new restoration papers are closers in the micro-environmental and mechanophysical properties of the wood. They extend the durability of the areas repaired to a great extent, while at the same time, these papers, as the newly restored, keep the documents visually unchanged, greatly slowing down the subsequent deterioration and thus also the secondary

interventions become less prevalent. Hence, they more adequately correspond to modern conservation criteria such as reversibility, minimal intervention, and material compatibility(Kelly et al., 2022).

In detail, synthetic paper consists of man-made polymer substrates (for instance, polypropylene or polyester fibres) and is a product without wood pulp. It is a product of excellent ageing, excellent tensile strength, excellent structural support, and 100% waterproof, tear-resistant, chemical-resistant, and highly resistant to the ageing process(Mendanha et al., 2024). The part most affected by the treatment and the one to be thus most stressed shall be made of this material so as to later be able to be handled without overpressure and therefore have the merit of both extending the lifespan of the ancient books and returning the stability and the readability of the post-treatment state(Letnar et al., 2006). Acid-free paper, on the other hand, removes acidic components during pulping and sizing and has a neutral to slightly alkaline pH, so that acidification and embrittlement progress slowly, it is a combination of durability and high transparency, which allows the use of the lining, infilling, and strengthening techniques without the obvious change of the layout and the reading. Thus, it provides a more trustworthy way for the restoration of first and foremost works(Vibert et al., 2023).

2.3.2 Modern adhesives

As an important material for ancient books restoration, modern adhesives are widely used in resent years. These adhesives usually use polymer-based materials such as polyvinyl alcohol, polyester adhesives, etc., to provide stronger adhesion and stability. The characteristics of modern adhesives are high durability, sustainability and strong adhesion. These characteristics can help modern adhesives to endure the influence made by environment better. However, compared with traditional adhesive, the reversibility of modern adhesive is poor. Hence, we should be careful when making a choice(Borges et al., 2018; Liu et al., 2022).

Polyvinyl alcohol (PVA) is a synthetic polymer widely used in the restoration of ancient books. PVA glue has a good solubility, transparency and adhesion. It can be used in the restoration of paper-made and leather-made books. Its strong adhesion allows it to provide an everlasting structure stability, able to recover the structure of ancient books especially during the restoration (Li & Chen, 2020) However, PVA glue has a poor reversibility because its chemical properties are really stable. As a result, we need to think twice when choosing it as a material of restoration and ensure that the result after restoration can fit the need of long-tern conservation.

Polymer-based adhesives, such as polyester glue, have also been used in the restoration of ancient books in recent years. These adhesives not only have a strong anti-ageing property and sustainability, utility can also provide a stronger adhesion during the restoration. Polyester flue as a high-performance adhesive, it is often used to restore more complex or special ancient books(Lazzari & López-Morán, 2024). However, the main disadvantage of polyester glue is its poor reversibility. Once you use this glue, it will be really difficult to remove it. Therefore, when using this material, special attention needs to be paid to the details and operation techniques in the restoration process to ensure that the restoration effect does not affect the original appearance of the ancient books.

2.3.3 New restoration materials

In recent years, advances in science and technology have increased the use of new restoration materials—especially nanomaterials and fibre-reinforced media—in the conservation of ancient books. These options not only strengthen and extend durability but also broaden treatment choices. Nanomaterials can penetrate the microstructure of paper fibres, enhancing anti-ageing performance and tensile strength while preserving the book's original appearance; they also improve moisture and UV resistance, thereby prolonging service life(Gu, 2023).

Fibre-reinforced materials, notably cellulose nanofibres (CNFs), combine strong mechanical properties with good workability. Used as structural reinforcements, they stabilize weakened areas, raise overall durability, and help prevent further embrittlement of paper or leather—particularly valuable for fragile volumes(Raju & Shanmugaraja, 2021).

That said, long-term performance and reversibility still require further study. Some materials show excellent short-term results, but durability and true reversibility remain central research questions. In practice, conservators should select materials case-by-case, aligning them with specific objectives and conditions, and judiciously combine traditional techniques with modern innovations.

2.4 The factors that influence the choice of restoration materials

The selection of repair materials should not only be based on their nature, but also on the substrate and condition of the book, the objectives of the treatment, the environment, and the cultural-historical context. Since book conservation is complicated, each decision should be made by weighing up the functional and aesthetic aspects so that the materials and techniques not only improve the usability but also the visual integrity.

Substrate and condition matter first. Paper, leather, and

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silk have distinct physical and chemical behaviours and therefore call for different materials and skills. Paper artefacts, which often deteriorate through physical, chemical, and environmental stresses, benefit from breathable, hygroscopic supports—e.g., xuan or Japanese papers—for stabilization(Teygeler, 2018). Leather repairs typically use like-with-like approaches (vegetable-tanned leather, leather powder, compatible resins) to preserve flexibility and feel, while silk requires materials matched in hand and colour to avoid altering appearance(Bainbridge, 2023b). The extent and location of damage guide further choices: light damage may only need surface cleaning, local mends, and reinforcement; severe losses may require stronger supports such as synthetic or acid-free papers. Spines often need high-strength reinforcement, whereas edge tears or losses are better served by more pliable infill papers(Sovinski, 1999).

Treatment aims and environment refine the selection. For preventive goals, prioritize durability and stability—acid-free and synthetic papers and modern adhesives—to resist humidity swings and light over time(Lennartson, 2001). If restoring appearance and readability, transparency, flexibility, and compatibility with the original are crucial, so the result remains authentic in look and use (Zhou, 2020). Environmental factors—temperature, relative humidity, and air quality—strongly affect long-term stability: high humidity demands moisture-resistant materials; overly dry conditions call for humidity-buffering supports(Novak, 2023).

Last but not least, the cultural and historical contexts of the book ought to determine the materials as well as the methods used. Understanding of the scripts, the images, and the regional traditions not only preserves the cultural coherence but also provides the basis for the methods that are used in restoration- for example, the Chinese methods usually focus on minimal intervention and the preservation of historical traces, whereas most of the Western methods are predominantly centred on durability and functionality. Thorough knowledge of the context also helps in ensuring that modern conservation techniques do not interfere with the book's historical character(Ren & Cao, 2021).

3. Discussion

As the literature review has methodically detailed the changes in restoration materials and their performance features, it is clear that both traditional and modern materials have different benefits under different restoration conditions. Traditional materials have better compatibility and reversibility, thus they are usually in line with the principles of cultural authenticity and minimal intervention, while modern materials have commendable advantages in durability and structural reinforcement. Nevertheless, in reality, the choice of materials is not a binary one—it mostly comprises complex trade-offs between ethical standards, technical feasibility, and the specific conditions of the object. Hence, there is a need for a deeper discussion on how conservators can combine reversibility with durability, solve ethical issues when applying new materials, and use different strategies that take into account cross-cultural, environmental, and structural factors. The next chapter will delve into these issues with the support of actual cases and technical analyses to outline a more comprehensive model of ancient book conservation that is environmentally friendly and sustainable.

3.1 Which is More Important for Long-Term Preservation of Documents, Traditional or Modern Restoration Materials

When ancient books are preserved for a long time, we need to follow the principle of"Reversibility first, durability up to standard"while choosing the restoration materials. In the field of paper literature restoration, reversible binders such as starch pulp and methyl cellulose are widely used due to their good compatibility with paper fibres and gentle treatment. This kind of material can be easily removed under certain temperature and humidity condition. It is conducive to the adjustment of future restoration work and the continuous advancement of academic study (Northeast Document Conservation Center [NEDCC], 2012; Canadian Conservation Institute [CCI], 2024).

Take the restoration of Buddhist scripture scrolls in British libraries for example, restoration team use Japanese paper and wheat starch pulp reinforces and resets the spine, reached the balance between the smallest intervene and reversible operation(Kralka & Muzart, 2022). Similarly, when dealing with the ageing and shedding of the spine, the Cornell University Library uses wheat starch paste to "paste" to soften the old layer, and combines it with Japanese or Korean paper for structural reinforcement, a process that ensures strength while retaining repair reversibility(Kirk, 2001)(Cornell University Library Conservation, 2017). During the real example of restoration, restoration team can use new materials such as nanocellulose as reinforcing layers when restoring some areas that are damaged seriously or areas with a lot of stress. Researches already showed that nanocellulose can improve the mechanical properties of papers. It contains a certain degree of removability, but its long-term ageing behaviour and reversibility still need to be continuously evaluated(Gmelch et al., 2024; Operamolla et al., 2021).

What's more, some scientists practitioners advocate giving priority to synthetic binders such as polyvinyl acetate

(PVAc) and acrylic acid in high-frequency viewing or extremely brittle collections. In order to obtain higher initial strength and environmental stability. The relevant binders perform well in some accelerated ageing and performance evaluations(Down, 2015) . However, synthetic binders have a very complicated ingredient so in long-term use, there is great uncertainty about its chemical stability and reversibility. A systematic study by the Canadian Institute of Preservation found that the properties of some products that are made by different PVAc or acrylic products may vary significantly over time. This result suggesting that short-term test results should not be directly extrapolated to long-term storage scenarios (Tétreault, 2018).

As a result, the proper choice of restoration materials need to follow the layered mode of "reversible base + local high-strength reinforcement" : The main body is spliced and lined with Japanese paper and rice milk/methyl cellulose, and replaceable reinforcement materials are added to the local high-stress areas. This program can not only balance the requirement of strength and reversibility, but also suit the main restoration guide and real examples of main international preservation institution.

3.2 Restoration ethical issues and preservation of culture heritage

The ethical foundation of restoration is based on four core principles: authenticity, minimal interaction, reversibility and documentation. These principles not only show on the ethical standards of AIC and ICOM, but also be extended in "The Nara Document on Authenticity". It emphasise that there is a different understanding of "original" in different traditional cultures (AIC, n.d.; Appelbaum, 1987). This means that in the west, they pay more attention on material and workmanship authenticity while in East Asia or Islamic tradition, they may switch the attention to "Continuity" and "Availability".

In the aesthetic and practice guideline of AIC requires that every management should not hinder future processing and need to provide complete record in order to make sure the transparency and traceability (AIC, n.d.). Appelbaum (1987) point out that reversibility is not an absolute, proposing that "reprocessability" is the operational goal, which provides a framework for the use of non-traditional materials such as nanomaterials, polymers, etc. today. For example, when paper is deacidified, the literature recommends using a bicarbonate system with a controllable solution concentration, leaving a moderate alkali reserve and ensuring future reprocessing (Guild et al., 2012).

However, some restoration theorist emphasize that modern materials may destroy the "authenticity" of history. Critics point out that large-scale deacidification processes deposit particles on the paper surface, altering the gloss and tactile feel(Malešič et al., 2022); Some gel cleaning techniques may remain in the fibre gaps, making it difficult to remove completely, impeding the possibility of future interventions.

Within the ethical framework, the key is not to reject modern technology but to ensure an evidence-driven approach with minimal intervention. For documents that are already acidified or in which iron-gall ink is actively corroding the paper substrate, when traditional slurry mending and moisture control alone cannot halt deterioration, targeted modern materials may be judiciously introduced under strict ethical oversight and complete documentation. Hydro-alcoholic dispersions of nano-$Ca(OH)_2$ can deliver an alkaline reserve into the paper fibre network while minimizing risks such as tidelines and dimensional instability; studies have shown that such nanoparticle-based deacidification raises pH and slows cellulose chain scission in aged papers(Poggi et al., 2014). For iron-gall ink manuscripts, it is advisable to begin with the established calcium phytate–calcium hydrogencarbonate sequential stabilization to complex free Fe(II/III) and neutralize acidity; a thin, adhesive-free nanocellulose reinforcement layer may then be applied to mechanically stabilize fissured ink lines and brittle substrates without obscuring text, with multiple studies reporting reduced hydrolytic/oxidative degradation alongside strength gains . When considering mass deacidification, practitioners should weigh reports that some MgO-based processes may leave particulate residues on paper surfaces and alter appearance, and therefore favour carefully dosed treatments validated by local testing(Völkel et al., 2020). Throughout, an evidence-driven, minimal-intervention approach—supported by pilot tests and complete treatment records—preserves transparency, traceability, and future re-treatability, in keeping with AIC guidance and Appelbaum's advocacy of "retreatability" rather than absolute reversibility (AIC, n.d.; Appelbaum, 1987).

3.3 Material Selection and Regionalized Strategies in Cross-Cultural Conservation

When working across cultures in conservation, the compatibility of materials, the degradation of mechanisms, and the treatment process should be the main things that matter rather than giving preference to either traditional or modern materials just on an ideological basis. According to the ethical principles of minimal intervention and reversibility, the use of traditional and modern materials in a complementary way not only supports the visual and structural aspects of heritage objects but also ensures the technical possibility of re-treatment from the future.

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This closed conservation approach is carried out through a closed-loop workflow—pre-testing, pilot samples, monitoring, post-treatment analysis, retesting, and documentation. At the same time, intervention is differentiated according to functional zones, which is both the scientific rigour and safety of treatment decisions as well as the respect for authenticity (ISO, 2025a; ISO, 2025b). For example, highly reversible materials like Japanese paper and wheat starch paste are done to be used for text-bearing areas, and structurally demanding areas, on the other hand, may be allowed to have stronger synthetic polymers or nano-reinforcement materials but under strict condition control to attain both ethical and structural integrity.

Many conservation practices and scientific studies have proved that a combined material strategy is feasible and effective. A case in point is the East Asian stitched books restoration; the Bodleian Libraries chose ultrathin Japanese papers (for example mino-gami) and wheat starch paste as the main treatment materials. Adhesion flexibility was used to stabilize covers and spines. The method not only retained the look and the feel of the original materials but also showed good reversibility and humidity responsiveness (The British Library, 2019). To quiet the corrosion that is metal gall ink, restorers followed a two-step treatment phytic acid complexation followed by calcium bicarbonate precipitation that stabilizes iron ions, promotes acidity, and thus, retards further ink degradation. The steps are proven to be safe and effective in different international studies(Mahony & Pearlstein; Teixeira et al., 2025). In the paper cleaning field, gellan gum microgels have been chosen as they release the solvent according to the program, thus, the surface gets the cleaning treatment while the rest of the paper remains untouched and is not weakened by the fibres (Di Napoli et al., 2020). The Bookkeeper® method that implements dispersed MgO particles is used for large-scale deacidification of m collections and thus has been mostly instrumental in national libraries in North America and Eastern Europe. It's a fast process of pH elevation with the addition of alkaline reserve, which thus, provides a good example of large-scale stabilization against m degradation(Buchanan et al.). Moreover, modern materials and techniques in the conservation world prove to be effective and offer minimal impact as exemplified in the ongoing research of nanocellulose that is a future promising agent in the revitalization of weakened paper substrates. These materials provide optical compatibility, mechanical support, and reversibility and thus, are a modern, low-impact conservation option(Fornari et al., 2022).

While these technologies have been broadly applied, a few researchers have expressed their concerns about the possible long-term risks that contemporary materials might have on the authenticity and re-treatability of the objects. To illustrate, it was Bookkeeper® process has been found to leave magnesium-based particulate deposits on paper surfaces that may cause uneven distribution, changes in transparency, and tactile qualities' variation(Malešič et al., 2022). Gels used for cleaning, if not thoroughly removed, could deposit gellan gum in the paper fibres which may become a source of instability or difficult to be consistent with future treatments(Henniges et al., 2024). In the red rot leather conservation, the commonly employed consolidant Klucel G (hydroxypropyl cellulose) when combined with wax emulsions has shown inconsistent ageing behaviour, such as becoming brittle and dulling of the surface, thus causing questions being raised about the long-term performance and reversibility of certain polymer systems(Johnson, 2013). These instances point to ethical concerns as well as technical problems that have arisen due to the use of modern materials in the conservation of cultural heritage.

In turn, a substantial amount of research is backing the implementation of scientific methods and systematized controls of the process to gradually lower these dangers. To begin with, closed-loop workflows allow for the up-to-the-minute recording of material condition and possible side effects via pre-tests, process monitoring, and post-treatment analysis. Nowadays, Quantitative methods such as HPLC and ATR-FTIR are getting more common to measure leftover cleaning agents or stabilizers(Henniges et al., 2024). Secondly, standards like ISO 9706:2025 and ISO 11108:2025 serve as objective yardsticks to vital paper properties—pH, mechanical strength, and alkaline reserve—thus, making material choosing more grounded in the facts. Thirdly, the regionalization plan sorts out the materials depending on the functional zones. For example, Paraloid B-72 has been successfully utilized as a reversible barrier layer in polymer-based adhesives, thereby disassemblability and treatment flexibility have been improved(Podany et al., 2001). Simultaneously, polymer-based substances are removed from figured areas in order to keep the visual and material authenticity intact. In short, first of all, modern and traditional substances should not be regarded as two separate groups. Their combined and supplementary use, which is under the moral norms of minimal intervention, reversibility, and re-treatability, is not only allowed but necessary. Conservators, being guided by the scientific match of material, pathology, and process, and supported by closed-loop workflows and regionalized treatment strategies, can keep the cultural heritage authentic while they are also able to strengthen its structural durability and extend the treatment options which in turn contribute to the sustainability and accountability of contemporary conservation practices.

3.4 Future trend and challenges

Looking ahead, the core aim of paper conservation research is to develop highly compatible, low-residue, monitorable, and reprocessable material systems. Current advances mainly follow three directions: homogeneous nano-reinforcement (such as nanocellulose), mild deacidification (using nano-$Ca(OH)_2$ or $Mg(OH)_2$ systems), and programmable cleaning (through microgels and solvent gels). Nevertheless, long-term ageing behaviour, multi-scale residue analysis, and re-treatability evaluation remain pressing challenges(Fornari et al., 2022; Khaksar-Baghan et al., 2024).

Nanocellulose can significantly enhance mechanical strength even at low concentrations by forming hydrogen bonds with cellulose fibres, ensuring homogeneity and avoiding incompatibility issues found in heterogeneous composites (Jiang et al., 2025). Hybrid bacterial-cellulose/nano-MgO composites have demonstrated dual functionality—simultaneous reinforcement and mild deacidification—showing stability under accelerated ageing conditions(Jiang et al., 2025; Mou et al., 2024). Calcium hydroxide nanoparticles, when applied in alcoholic dispersions, can carbonate in situ to form $CaCO_3$, providing a persistent alkaline reserve that supports long-term cellulose stabilization(Chelazzi et al., 2013). Meanwhile, microgel and solvent gel systems allow precise control over solvent diffusion at the microscale, improving the safety and efficiency of cleaning operations(David et al., 2020).

However, the ageing mechanisms and cross-scale residue behaviours of these new materials are still not fully understood. Khaksar-Baghan et al. (2024) highlighted that microgels may generate residue entrapment within fibres, while excessive functionalization could complicate future reprocessing. To address these concerns, future material systems should adopt ISO 9706/11108 standards as performance boundaries and incorporate "reprocessability" explicitly into treatment design. Material selection should prioritize compositionally homogeneous or easily removable materials, supported by accelerated ageing tests, multi-scale analytical methods, and long-term documentation, forming a closed evidence loop. Such a system can ensure a verifiable and iterative balance between ethical integrity and technical effectiveness (ISO, 2025a, 2025b).

4. Conclusion

By conducting a systematic conclusion of all these case studies of traditional and modern restoration materials, this article shows that culture heritage restoration should find a balance between "structure durability" and "priority of reversibility". Traditional materials have an irreplaceable value on insuring the culture authenticity and continuation of restoration methods. They are more suitable for restoration scenarios that prioritize cultural representation and visual coherence. As for the modern materials, they are better suited for addressing the structural reinforcement and functional continuation needs of severely degraded or high-use documents. The paper proposes a tiered conservation strategy of a "reversible base + localized reinforcement," which balances visual restoration with structural stability. It also recommends conducting material tests and environmental assessments prior to treatment. In ethical aspect, restoration should always keep four core principles of authencity, minimum intervention, retreatable and comprehensive documentation. The direction of further search can pay more attention on finding new materials that have better ageing mechanisms, controlling residue substances and retreatability. Through multi-scale testing and standardized protocols, a scientific and verifiable framework for material selection shall be established. In conclusion, this paper provides a material choosing support that contain both therical and realistic guiding significance for culture heritage restoration.

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