Crafting Interactive Paper Composites through Ancient Papermaking Techniques

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Figure 1: A collection of interactive paper samples showcasing various crafted textures and properties.

Abstract

Papermaking is an ancient yet evolving craft, with changes in techniques and materials giving paper contemporary qualities that keep it relevant for everyday use. This adaptability makes papermaking an ideal process for crafting computational composites for tangible interactions. We began by studying ancient Chinese papermaking, replicating it by hand and simplifying the practice into five key steps and tools accessible to novices. We then adapted these steps to imbue the paper with interactive and computational properties, such as integrating conductive materials during pulp preparation, modifying fiber properties through soaking, and customizing sheet texture through watermarking, multi-layering, and coating. We detail our exploration in this paper, as well as demonstrate our findings through four interactive systems focusing on expressive applications made with the computational paper from our adapted process. We also document our exploration in a detailed workbook that captures recipes, failures, and key moments of discovery.

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CCS Concepts

• **Human-centered computing → Interaction design**.

Keywords

Paper, Craft, Computational Composites, Making

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1 Introduction

Papermaking is a living practice that has continuously evolved over centuries, shaping human civilization by playing a pivotal role in communication, art, and commerce. This adaptability, rooted in the material's ability to blend fibers, properties, and the openness of its craft processes, positions paper as an ideal foundation for crafting computational composites [90]. In this research, we investigated and adapted ancient papermaking for crafting computational composites by shifting the perspective from treating paper as a substrate to exploring it as a structural material for tangible interaction. We use the term "ancient" rather than "traditional" as traditional craft typically refers to techniques that adhere closely to long-established methods. The term "ancient" underscores the deep historical roots of a craft while highlighting its potential for continued evolution, notably, incorporating new materials and methods into the craft to adapt to changes in the state of materials and tools [37, 88].

Paper is a versatile and welcome material in HCI, offering potential for "weaving technology into everyday life" [100]. While it has been used mostly as a substrate in interactive systems [13, 72, 74, 106], we saw untapped opportunity: investigate paper at a structural level for computational composites, particularly through the lens of its ancient crafting processes. Historically, papermaking process and materials have been modified to serve a wide range of functions, from art and writing to packaging and architecture [5]. Paper's composition, formed with natural materials that shape its fiber properties and network structures, allows it to achieve diverse properties like texture, strength, and flexibility. Material science further supports this understanding, showing how these structural properties can be tailored for new properties (Section 2.1). Therefore, this composite makes paper an ideal material for investigating computational composites in HCI.

In this research, we adopted a Research through Design (RtD) approach to explore ancient papermaking processes and adapted it to imbue paper with computational and interactive capabilities. We began by studying historical resources to understand how ancient paper was made. We then applied hands-on explorations to sensitize ourselves to this ancient craft, simplifying the tools, materials, and conditions involved in the process to facilitate experimentation as contemporary HCI and design practitioners. Next, we systematically modified papermaking across five key steps—pulp preparation, soaking, sheet formation, pressing, and finishing—to imbue paper with new properties such as conductivity, color-changing abilities, and control over transparency. We made use of these modifications and demonstrate four expressive interactive artifacts that showcase the potential for real-world use.

Through this research, we contribute an approach to craft interactive paper-based composites by simplifying and adapting ancient papermaking techniques. We document our explorations and provide the materials, recipes, and processes used for others to learn from. With these details, we open up papermaking for other HCI researchers working in the areas of tangible computing and interactive materials.

2 Background and Related Work

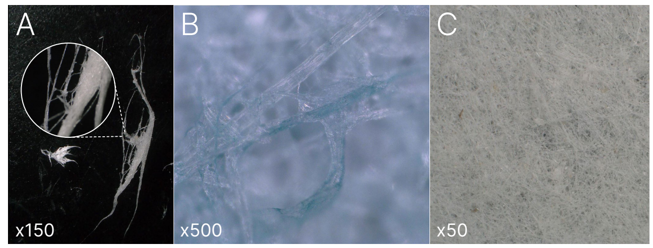

Figure 2: Microscopic views of cellulose fibers in handmade paper composites. (A) Receipt paper fibers (left) and bark tree fibers (right) at 150× magnification, showing the fiber network structure. (B) Cellulose fibers at 500× magnification, blue coloration indicate anthocyanin from red cabbage. (C) A cohesive fiber network formed by mixed fibers after pressing.

2.1 Introducing Ancient Papermaking

2.1.1 Paper is a Composition Formed from Ancient Practices. *Composites* are materials that combine different materials to enhance or introduce specific properties, such as improving material strength through a matrix of different fibers [90]. While the individual properties of the constituent materials can give hints as to the properties of the composite; the structure itself, and the ways that different materials come together, contribute a large part to the emerging qualities of the composite [90]. We can view interactive systems today as a form of computational composites [90]. This extends the concept of composites to include immaterial properties such as electrical logic or chemical behavior—properties that are supported by physical substance and that are woven together into coherent systems that support the translation of input to output.

For designers, framing interactive systems as computational composites emphasizes their materiality and making [75, 102]. On one hand, this involves investigating computation as a material that can be incorporated with physical materials into compositions with a coherent physical-digital texture [102]. On the other hand, it also inspires a broad research agenda into expanding the potential of computational and interaction to new physical materials and the making cultures associated with them [6, 30, 101].

HCI researchers have investigated various traditional material cultures and how they might contribute to designing interactive systems for different contexts [30]. This treats materials as both a technical solution for achieving desired properties [33, 90] as well as a medium for creative exploration, where "composing" material involves making aesthetic judgments about balance, symmetry, and the relationships between details and the whole [52, 102]. Notably, researchers have investigated textiles as a platform for computation [21], as well as a craft process that HCI can learn from [32]—a significant body of work collectively known as *e-textiles*. This includes a specialized microcontroller developed to work with textiles and

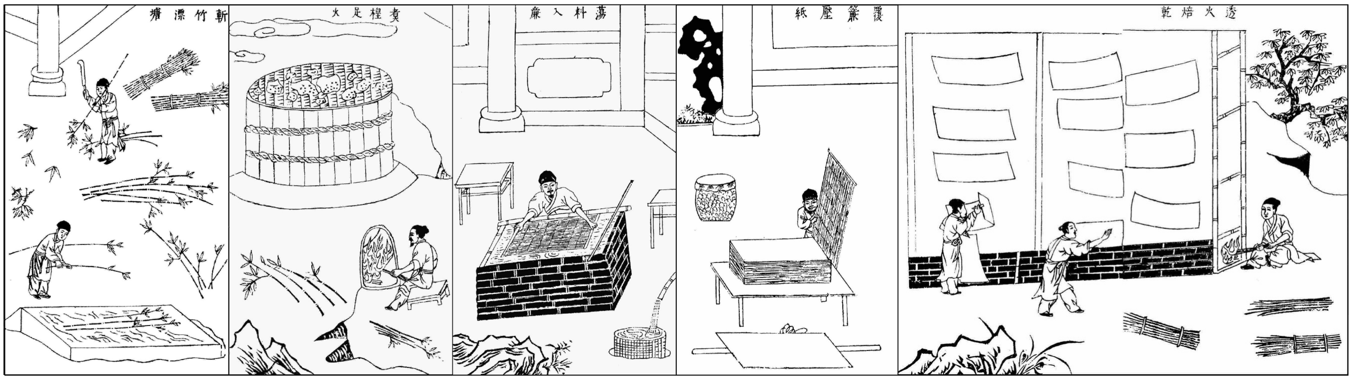

Figure 3: Illustrations from the ancient publication Tiangong Kaiwu, depicting the five main steps in traditional bamboo papermaking [116].

textiles crafts [12], sensors and actuators that balance functional interactive properties with the native materiality of textures [62, 66], and computer-aided design software that enables craftspeople and researchers to plan and fabricate circuits into woven textiles [27].

In this research, we delve into paper, an everyday composite material that we have been using for a long time. Paper is fundamentally made from a network of cellulose fibers[1] [86]. This underlying structure has remained largely unchanged for hundreds of years—from handmade paper in ancient China, to contemporary mass-produced printing paper [36, 89].

Traditionally, the fibers used in papermaking were sourced from a variety of plant-based raw materials, including hemp, mulberry bark, bamboo, rattan, and other bast fibers [1, 89]. Paper's cohesive structure is derived from the interwoven combination of different fibers (Figure 2), where long fibers form stable, interlocked networks that provide tensile strength and structural integrity [44, 79], while short fibers fill gaps and compact the structure by reducing voids (Figure 2C) [44, 79]. This mix-fiber strategy [1, 3, 25, 36] not offers mechanical benefits but is also efficient in terms of material use [25, 91]. Notably, *xuan* paper (宣纸) [1, 38, 89] is a celebrated material for Chinese watercolor painting. It makes use of the combination of long and short fibers to give a material that is highly absorbent—creating the signature blending effect with ink and water. Applying pressure further enhances fiber bonding through hydrogen bonds and alignment, transforming loose fiber web into robust composite structures [86].

Recent material science studies rationalizes the significance of paper's structure of fibers in terms of achieving a composite that is thin and strong for daily use. These studies also demonstrate how paper's structure is amenable to other materials and chemicals that modifies the properties of paper. For example, herbs and flowers have been traditionally integrated into paper not only as decorative elements, but also as a pesticide to imbue paper with insect-resistant properties (狼毒纸 [11, 14]).

This versatility of paper presents a promising opportunity for creating interactive computational composite. Although a few works, such as *Pulp-Based Computing* [18] and *Felted Paper Circuits* [42], provide initial explorations into paper's potential as a composite in HCI, we see an opportunity to dive deeper into paper's structure and how this composite material can be adapted for interactivity. Specifically, paper's structure is rooted in the way that it is made. In this research, we explore ancient papermaking craft, and used it as a practical framework for exploring paper composite materials that can be made with simple tools. We elaborate on the history of traditional papermaking in the following section.

[1] we simply refer to this specific material as "paper" for the rest of this article.

2.1.2 Ancient Papermaking and Evolution. Papermaking originated during the Han Dynasty (206 BCE–220 CE) in China and gradually spread across Asia, including Japan and Korea, before reaching Europe through the Islamic world [36]. The process of papermaking, essential for the formation of a paper composition, are detailed in the encyclopedia "Tiangong Kaiwu" (天工开物) [84, 117], published in 1637. This encyclopedia details many craft techniques for making daily necessities, including paper, porcelain, dyes, and gunpowder. The comprehensive publication highlights the ingenuity of ancient craft [50] and its role in understanding the natural world to unlock new technology [97]. The knowledge in "Tiangong Kaiwu" has been globally studied [80] and validated through archaeological findings, and researchers have used these findings to restore the historical practices documented [54], including using contemporary media such as virtual reality [108].

As shown in the original illustrations (Figure 3), the main five steps of Chinese papermaking include: (1) Pulp preparation: chop bamboo and float it in a basin; (2) Soaking: cook thoroughly over a strong fire; (3) Sheet formation: rinse and spread the material onto a bamboo screen; (4) Pressing: cover the sheet and press to squeeze out excess water; (5) Finishing: heat and bake the sheet dry on a hot wall.

The ancient craft has evolved to integrate advancements in material research and automation for modern paper industries. New materials like wood fibers, rags, recycled waste, and chemical additives have been added to enhance properties for applications such as printing and packaging [3, 24]. Automation technologies, such as fourdrinier machines, enable continuous sheet production to increase scale and efficiency [36, 38]. Nevertheless, these papermaking today still follows the general process laid out in "Tiangong Kaiwu". In addition, manual papermaking provides opportunities for crafters to intervene in the process, introducing adaptions that lead to different outcomes. For instance, interventions during *sheet formation* can reshape the arrangement of fibers to create unique visual and structural effects. This is demonstrated through *watermarking* techniques in Europe and Japan that selectively remove fibers through high-pressure water sprays, creating patterns and textures within paper's structure [36, 99].

Papermaking is adaptable, and the traditional process offers a systematic yet flexible framework for developing new paper composites. With this in mind, we first simplified the ancient process in this research through DIY tools that we can build today (Section 4). Then, we explored how these simplified steps can be extended and adapted to create composites that expand the paper's interactive potential (Section 5).

2.2 Learning from Craft for Designing Interactive Systems

Craft embodies "the desire to do a job well for its own sake" [83]. It involves thinking through the act of manipulating a material by hand [26, 41, 60] and uncovering the maker's formation of thoughts during creative processes [53]. Many HCI researchers have drawn inspiration from craft for designing interactive systems [63, 114]. In these works, the key approach is not only to extract value from craft practice for computational technology, but to align technology development to the values of craft; broadening the contexts and communities included in defining and building interactive systems.

HCI work in this area include combining sand-blasting with handcrafting to create interactive ceramic objects [110], or learning from traditional stained glass techniques to create interactive displays [28]. As mentioned earlier, there is also a significant body of work in e-textiles that demonstrate the value of learning from and adapting traditional textile practices. Researchers in e-textiles have developed wearable sensors and actuators embedded within woven textiles [21, 62, 68, 69, 112], knits [49, 103, 104], and embroidered fabrics [31, 67, 98], even incorporating traditional dyeing methods like batik [34].

Papermaking as a craft practice provides us, as designer-makers, with intimate opportunities for hands-on engagement to explore paper-based interactive systems. We first sensitized ourselves to the steps within the ancient practice, before probing these traditional steps for opportunities to incorporate interactive capabilities.

2.3 Paper for Interactive Computing

Paper as a versatile substrate that is still widely used today, offers potential for "weaving technology into everyday life" [100]. HCI researchers and designers have used this ubiquity of paper by combining it with computational components for paper-based interactive systems.

One area of work is hybrid interfaces that integrate paper with off-the-shelf electronics and devices. Researchers have demonstrated blending paper and touchscreen devices for tangible interfaces that leverages the materiality of paper to enhance interactions with mobile devices (e.g., [16, 106]). Paper has also been paired with computer vision for tangible interfaces that can be easily deployed with a camera (e.g., [109]), and even large scale interactive environments mediated by paper and projected visuals (e.g., [85]).

Paper is also a versatile substrate for circuits and electronics. Circuits can be embedded using methods like inkjet printing of conductive ink [56], applying copper tape traces [73], and conductive coatings [107]. These circuits can be further integrated with other electronic components for physical computing. Researchers have also embedded shape-memory alloys [72] and polymers [96], as well as ferromagnetic elements [55] into paper to create interfaces with delicate shape-changing interfaces or actuation. [105].

Researchers have also used the composite nature of paper's structure for building interactive systems. For example, HCI researchers have used commercially available paper composites, such as swell paper with built-in heating elements for tactile interfaces [16], or carbon infused paper for sensors that can detect deformation [111]. In our research, we approach the development of interactive paper by making our own composites that infuse different functional properties into paper through modifying the traditional papermaking process.

3 Design Methods

We adopted a Research through Design (RtD) approach [113], leveraging the reflective process of designing artifacts [81] to generate knowledge. RtD surfaces knowledge through the creative exploration, critical reflection, and pattern synthesis [19] that occurs during design. In this research, we used RtD to probe the potential of paper and papermaking for developing computational composites that support tangible interaction.

More specifically, we employed a combination of *material tinkering*, *systematic documentation*, and *prototyping applications* as part of our RtD approach:

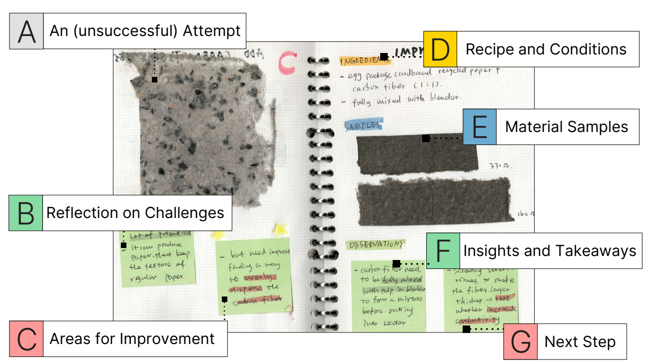

Figure 4: A page from the papermaking workbook, featuring physical samples (A,E) and color-coded annotations. The annotations document the process, challenges (B), and areas for improvement (C), reflection on material exploration (B,F) and design decisions (G).

3.1 Material Tinkering

Designers explore materials through hands-on interaction and experimentation. This method—*material tinkering* [60] emphasizes an experiential approach to exploring and understanding the properties and qualities of materials, and directing this reflective practice with materials towards creative and innovative outcomes. It is particularly relevant for Do-It-Yourself (DIY) materials [76]. In our research, we used the steps laid out in ancient papermaking (Figure 3) as an initial framework to guide our material exploration.

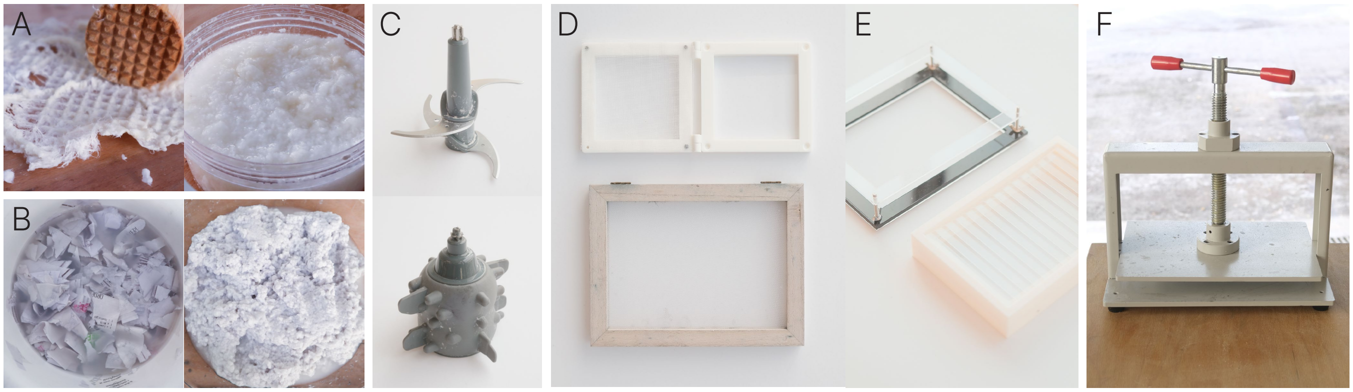

Figure 5: (A) Preparation of bark tree fibers through hammering. (B) Blending recycled paper to create pulp. (C) (Top) Cutting blade and (Bottom) rubber blade used for mixing. (D) (Top) 3D-printed screening frame and (Bottom) wooden frame with 2mm nylon mesh. (E) Laser-cut frame for customizable sizes. (F) A pressing machine.

This revealed both planned and serendipitous insights in two aspects: (1) New materials that might be incorporated into traditional making to develop paper's interactive potential [6]. (2) Adaptations to the traditional paper making process to incorporate new structures for interactive paper composites.

3.2 Systematic Documentation

Material tinkering is a nonlinear process and knowledge generated from it is often messy and tacit, challenging conventional academic documentation to capture transient material insights and nuanced properties emerging during the making process [64]. We captured and organized the emerging insights from our material exploration through systematic documentation of our findings. Various formats have been used for documenting processes in material exploration research in HCI, such as swatch books [39], annotated figures [110], and bookkeeping with notes for design processes [48]. In this research, we adopted a mixed strategy to document and organize findings, focusing on surfacing tacit insights and learning from failures [48, 57]. We combined physical samples (Figure 4A,E) and reflective logs of design challenges and decisions in a workbook [77] (Figure 4B,C,E,G). We also used digital scans and photographs of the materials we made to capture both macro- and micro-level details of our exploration outcomes[2]. Alongside these qualitative documents, we also empirically tested certain properties of the materials we made in the laboratory when appropriate, including mechanical strength and electrical conductivity. This documentation strategy ensures transparency, and aims to improve the replicability of our research from both a process and outcome standpoint.

3.3 Prototyping Applications

In design practice, prototypes externalize design concepts [22] into tangible manifestation, bridging design inquiry with real-world context. We developed our prototypes with two things in mind in this research: (1) Prototypes focused our exploration by and *filtering* [45, 113] what we built based on specific processes we developed on top of ancient papermaking that led to unique interactive paper composites. (2) Prototypes *manifested* [45] our exploration findings into a specific real world contexts that focused on expressive applications, connecting our abstract material insights with other practical considerations (Section 6).

[2]further details in supplementary material

4 Simplification of Ancient Papermaking

In considering how we might adapt papermaking techniques for HCI, we started by sensitizing ourselves as novices to the practices documented in "Tiangong Kaiwu" [117]. This section outlines our hands-on exploration of replicating the ancient papermaking process through simplified materials and tools that were available to us as contemporary makers. To inform this exploration, we also conducted secondary research, as well as laboratory measurements to understand the structure and fiber composition of paper as a composite material (Section 4.1).

4.1 Understanding Paper Structure through Fiber Composition

Paper is a composite material formed from randomly deposited cellulose fibers, typically 1–2 mm in length [86]. Structural integrity is determined by the arrangement of this intricate fiber network [36]. Traditionally, handmade paper employ mix-fiber strategy (long and short fibers) to achieve desired texture and mechanical outcomes [1, 89, 117]. The choice of fibers are influenced by local availability, cost-effectiveness, and specific performance requirements. Recent material science studies further validates (Section 2.1) the structural integrity of a sheet achieved by the composition of fibers formed from traditional papermaking [36, 89].

With this in mind, we adopted a combination of long and short fibers in our attempts to replicate ancient papermaking. We used long fibers (exceeding 2 mm) from bark tree fibers sourced locally from a supplier. This class of fibers are valued in both traditional papermaking and contemporary paper industry for their strength, durability, and compatibility with diverse materials [3, 36, 89]. We used short fibers (under 2 mm) sourced from recycled receipt paper. The receipt paper we used was in fact waste from another design project that we repurposed for papermaking.

4.2 Simplification of Ancient Papermaking Processes

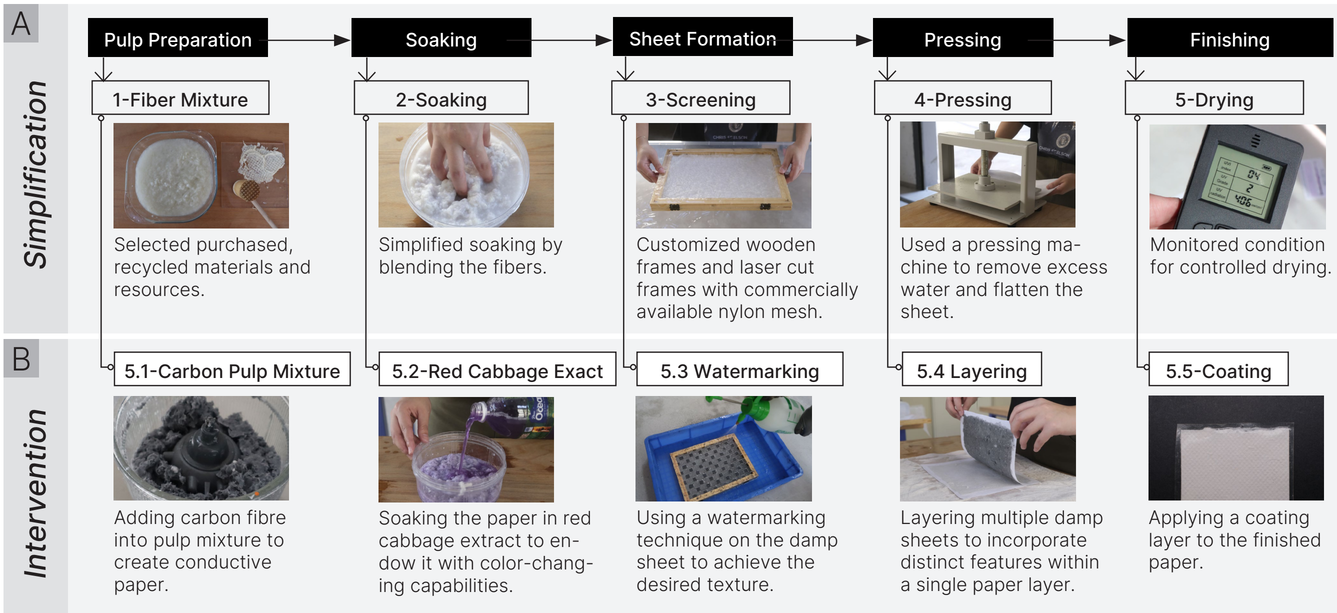

Figure 6: An overview of the transition from the original five ancient papermaking steps to our simplified processes (Section 4.1) and interventions (Section 5).

Building on our selection of paper fibers, we adapted and simplified the five ancient papermaking steps (Figure 6A).

4.2.1 Step 1: Pulp Preparation. To process bark tree fibers (long fibers), we used a wooden hammer to break down the fibers. The fibers are then soaked in water (Figure 5A). Recycled receipt paper (short fiber, Figure 5B) is processed separately using a blade-equipped blender (Figure 5C top), which slices and shreds the fibers to create a homogeneous mixture suitable for integration with long fibers. Once the two fiber types were prepared, they are combined following a ratio by weight Section 4.3.1 by blending in water with a rubber blade (Figure 5C bottom). This ensures a uniform mixture while preserving the integrity of the long fibers.

4.2.2 Step 2: Soaking. In ancient papermaking, fibers were soaked for weeks or months to facilitate the natural enzymatic or microbial breakdown of lignin, softening the fibers for subsequent manual processing [4, 9, 36, 95]. This process occurred in the absence of mechanical or chemical intervention [92, 95]. Modern papermaking, however, employs mechanical refining to disrupt fiber structures, increase surface area, and expedite lignin breakdown—thereby accelerating fiber preparation [43, 47, 93].

Drawing on these principles, we simplified the soaking process through mechanical fiber preparation. By pre-processing the fibers with a blender (as outlined in Step 1), we reduced soaking time from months to a one day. This approach also allows for greater control over fiber hydration and integration with other materials in subsequent steps. Beyond process acceleration, this step enhances the fibers' capacity to absorb desired chemicals, thereby modifying their internal characteristics and improving their interaction with other materials.

4.2.3 Step 3: Sheet Formation. Sheet formation is the signature step of ancient papermaking where everything comes together. This is carried out by drawing a finely meshed screen through paper fibers dispersed in a water bath. Screening relies on the dynamic interplay between fiber distribution driven by the force of water, and the movement of the screen to achieve a unified, cohesive sheet. The damp sheet formed after screening is bonded yet still loose, offering a critical window for adjustments to be made before the fibers fully dry and interlock. This flexibility enables structural modifications and the incorporation of additional features prior to the sheet reaching its final bonded state. Ancient papermaking employs bamboo or wooden screening frames (Figure 5D, bottom) to shape the paper. To simplify this step, we utilized commercially available 2mm spaced nylon mesh screens and customized frames fabricated through laser cutting (Figure 5E) and 3D printing (Figure 5D, top). This approach allowed us to experiment with frame sizes, providing greater flexibility to create sheets tailored to different design requirements.

4.2.4 Step 4: Pressing. Pressing serves to remove excess water and improve the mechanical properties of paper by compacting the fiber network. By applying mechanical force, pressing increases fiber contact points, facilitating hydrogen bonding, which strengthens the cellulose network and enhances the paper's tensile strength [15, 65, 71]. We used a pressing machine (Figure 5F) to ensure consistent force application. With this machine, we could also adjust the pressure applied; reducing the applied pressure allows the paper to retain a looser, sponge-like fiber texture which we used in a subsequent application (Section 6.4).

4.2.5 Step 5: Finishing. Environmental conditions during paper drying are a fundamental factor in achieving specific paper qualities tailored to particular applications. For instance, the production of handmade paper from Guizhou (丹寨构皮纸) [2] relies on the natural regulation of humidity, temperature, and water pH found in caves, which create optimal conditions for the papermaking process. Drawing on this, we employed contemporary equipment including air conditioners, humidifiers, and UV meters, to precisely regulate drying conditions. Such control is essential for controlling and replicating outcomes, as well as fabricating paper with specialized features such as color-changing properties (Section 5.2) that require stable environmental conditions to maintain the stability of the embedded chemicals.

4.3 Testing Fiber Ratios and Strength

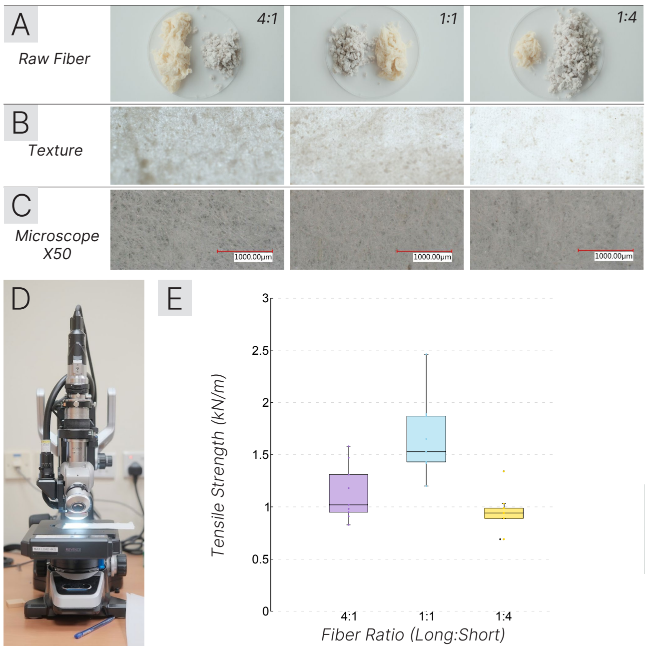

Figure 7: (A) Paper composite samples with three fiber ratios. (B) Photographs capturing the surface texture of paper outcomes for each ratio. (C) Microscopic images revealing the fiber network structure. (D) Examining fibers under a microscope. (E) Tensile strength test results.

4.3.1 Fiber Ratio Characterization. To quantify the ingredients used in our papermaking recipe, we conducted experiments to determine the optimal ratio of bark tree fibers (long fibers) to recycled receipts paper (short fibers). Three different ratios were prepared and analyzed (Figure 7A): (1) a 4:1 long-fiber to short-fiber ratio, (2) an equal ratio, and (3) a 1:4 long-short to short-fiber ratio.

Microscopic observation (Figure 7C, D) revealed distinct structural characteristics for each configuration. A higher proportion of high fibers (4:1) facilitated enhanced fiber interweaving but introduced larger voids and gaps between fibers. A higher proportion of short fibers (1:4) produced a denser structure with reduced inter-fiber bonding. These results align with prior studies on fiber properties and structural cohesion (Section 2.1). Variations in texture were also observed across the different fiber ratios (Figure 7B). The high long-fiber ratio produced a visibly fibrous texture, characterised by a smoother surface, while the high short-fiber ratio yielded a comparatively rougher texture. Tensile strength testing (Figure 7E) showed that the 1:1 ratio exhibited the highest tensile strength, providing the most balanced combination of strength and flexibility.

These findings inform two key considerations: (1) A balanced mixed-fiber ratio (1:1) or a higher long-fiber ratio is recommended for applications requiring strength and durability, such as folding or cutting. (2) A higher short-fiber ratio may be advantageous for contexts prioritising smoother pulp blending or adaptability to additional treatments. This configuration also facilitates the production of customized dampened sheets (e.g., watermarking in Section 5.3), where reduced inter-fiber bonding is desirable.

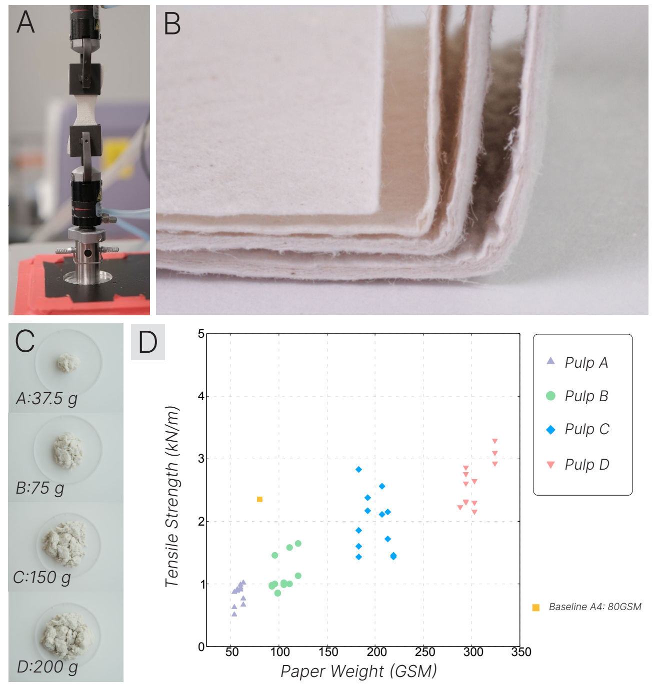

Figure 8: (A) Setup for tensile strength testing. (B) Side view showing the thickness variations in paper outcomes for each pulp type. (C) Raw material fibers for four pulp types (37.5g, 75g, 150g, 200g) mixed with 3L of water at a 1:1 fiber ratio. (D) Range of achievable GSM (grams per square meter) for the four types, alongside tensile strength test results.

4.3.2 GSM Characterization. We quantified the influence of pulp-to-water ratio on paper's weight, measured in terms of GSM (grams per square meter). We control for the paper's weight through the density of fibers in water. We tested four different quantities of a 1:1 long-short fiber pulp mixture in a fixed volume of 3 liters of water: 37.5, 75,150, and 200 grams. As shown in Figure 8B, a higher GSM produces thicker paper. Tensile strength increased with higher GSM (Figure 8D). For reference, we included tensile strength measurements for standard 80 GSM A4 printing paper[3].

5 Adapting Ancient Papermaking

Papermaking is an inherently open process, shaped by numerous parameters that can significantly influence the final outcome. Through our exploration of simplifying the ancient Chinese papermaking process, we identified opportunities for in-situ modifications to guide the production of computational paper composites. These

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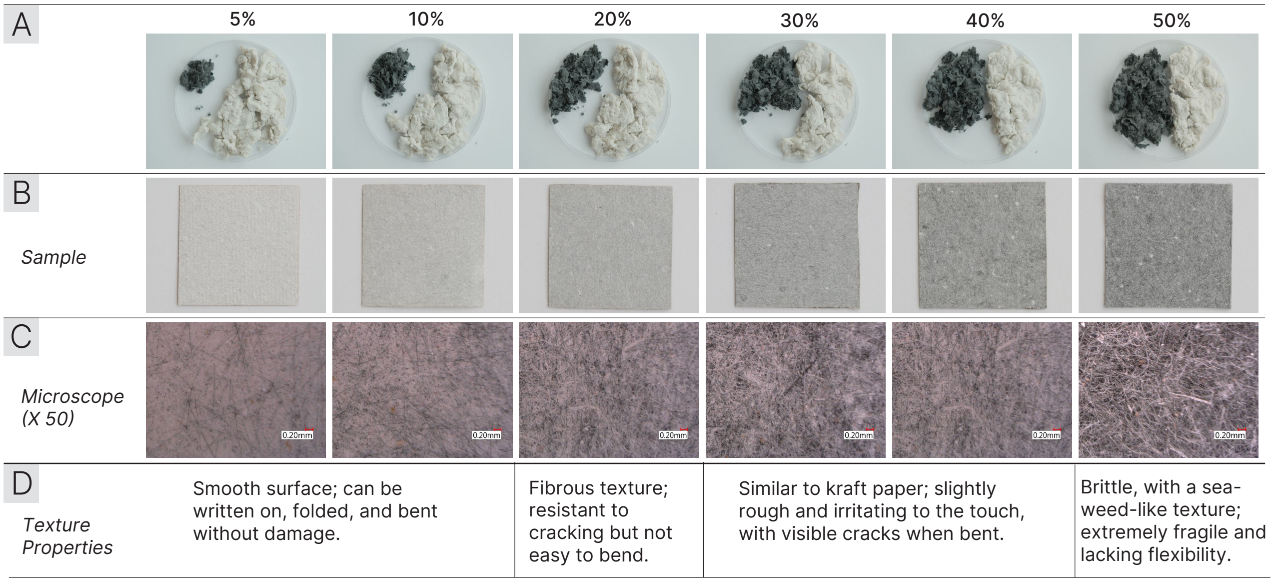

Figure 9: Carbon fiber pulp mixture and its impact on paper properties at varying ratio. (A) Raw carbon fiber samples mixed with pulp in different ratios (B) Surface texture of paper samples at each ratio. (C) Microscopic views (50x magnification) showing fiber bonding and distribution within the paper network at each ratio. (D) Descriptive documentation of the texture properties.

interventions occur across five key steps (Figure 6B): pulp preparation, soaking, sheet formation, pressing, and finishing. While each step operates independently, they can also be combined with interventions from other stages to achieve more complex outcomes, as demonstrated as demonstrated in Section 6.

5.1 Pulp Preparation: Formulating a Carbon Fiber Pulp Mixture

Building on our earlier trials, where we established the a foundational pulp fiber composition and ratio (Section 4.1), we explored modifying the fibers used to make paper electrically conductive.

To introduce conductivity into the paper composite, we incorporated 2mm chopped carbon fiber[4] into the pulp mixture. Carbon fiber, is an organic polymer [17, 61] distinct from the cellulose fibers traditionally used in papermaking. At 2mm length, carbon fiber can function as a long fiber, replacing some bark tree fibers in the pulp mixture. However, compared to cellulose fiber (e.g. bark tree), it is less flexible, leading to a more brittle and crease-prone paper. Its coarse texture, particularly at higher concentrations, may also cause skin irritation [87, 115].

5.1.1 Conductivity Characterization. To optimize conductivity while preserving the texture of handmade paper, we adjusted the 1:1 mixed-pulp ratio to 1:3 ratio of long to short fibers, and incorporated varying proportions of carbon fiber — 5%, 10%, 20%, 30%, 40%, 50% (Figure 9A). At a 20% carbon fiber ratio, the paper exhibited for sufficient structural integrity, with carbon fibers effectively bonding within the network.

Microscopic observations (Figure 9C) revealed that lower carbon fiber ratios (5% and 10%) resulted in weak bonding and limited fiber entanglement. At the highest carbon fiber ratio (50%), the

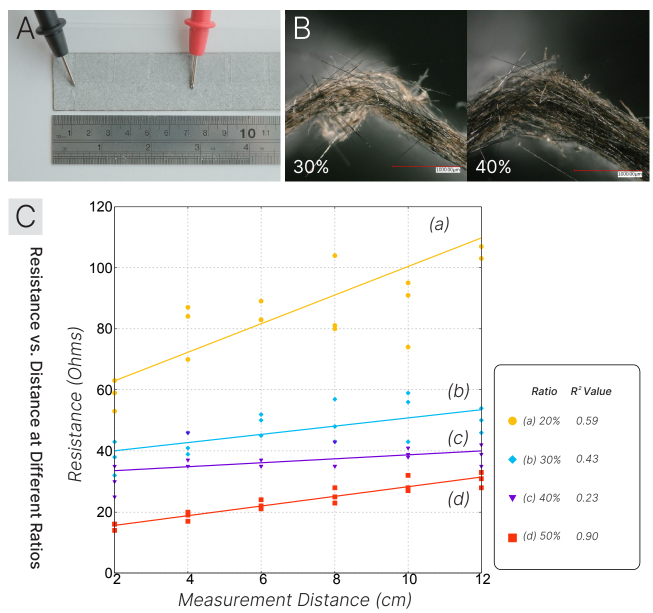

Figure 10: (A) Resistance measurement setup. (B) Microscopic views (100× magnification) of folding creases in 30% and 40% carbon fiber ratios. (C) Resistance changes with distance across different fiber ratios (20%, 30%, 40%, and 50%).

paper texture became rougher, more prone to creases and tearing, resembling Kraft paper.

We further evaluated the relationship between electrical resistance and the length of conductive paper (Figure 10A). As shown in Figure 10C, resistance increased with distance across all samples. We plotted a a line of best fit through the data from each condition and calculated the R value. The R values indicated that conductivity

[4] 2mm chopped carbon fiber

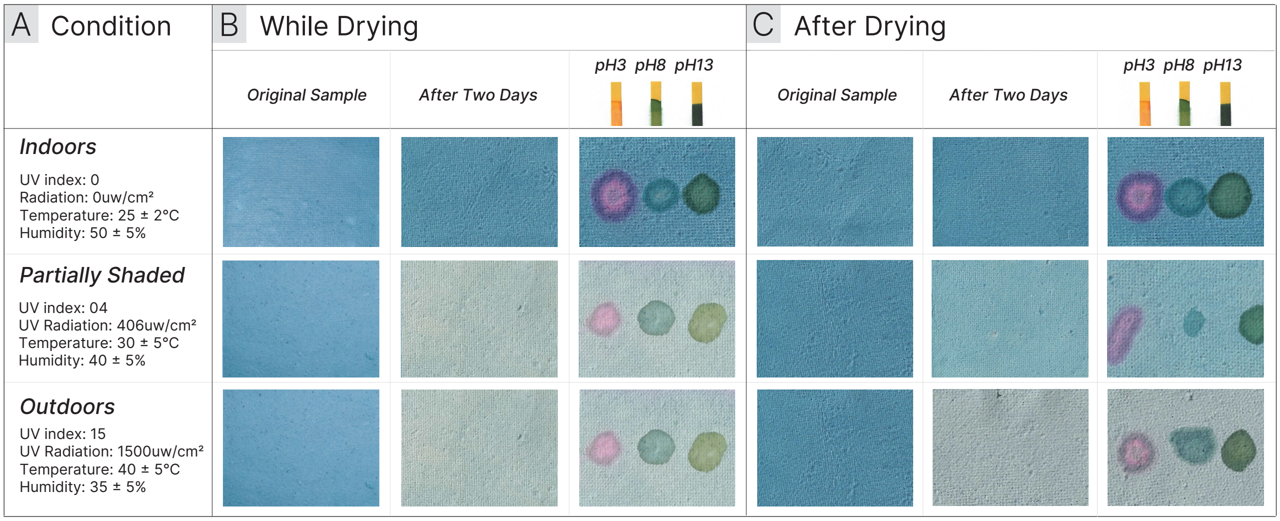

Figure 11: (A) Three drying conditions with varying UV index, radiation levels, temperature, and humidity. (B) Comparison of the original sample with samples dried under each condition for two days. (C) Comparison of the original sample with samples stored for five days under the same conditions.

for the materials was most consistent with 50% of carbon-fiber. Microscope observation (Figure 10B) of the 30% and 40% samples revealed never fiber arrangement, which likely contributed to less consistent electrical conductivity.

Based on these findings, we empirically conclude that carbon fiber ratios exceeding 30% are more suitable for conductive structures that do not require direct human contact. A 20% ratio is recommended for applications involving direct touch provide, provide the interaction remains static, without folding or bending of the paper surface.

5.2 Soaking: Red Cabbage Extract

Rather than relying solely on specific fibers (Section 5.1), the hydrophilic nature of cellulose-based fibers allows them to absorb chemicals, enabling the integration of additional functional properties [10, 40]. Building on this principle, we adapted the soaking step to introduce pH-responsive, color-changing capabilities using red cabbage extract, which is notably rich in stable anthocyanins, a chemical that changes color at different pH levels [29]. However, anthocyanin stability is sensitive to high temperatures, prolonged heating, and elevated pH levels [20, 23], presenting challenges for juice extraction, soaking, and environmental control.

To address these challenges, the paper pulp was thoroughly blended and washed to ensure a neutral pH. Red cabbage juice was extracted at room temperature and maintained below 35° C, as recommended for anthocyanin stability [20, 23]. The paper pulp was soaked in the red cabbage extract (Figure 12A) for more than 24 hours at an indoors temperature of 24° C (Figure 11A). A total of 1.5 liters of freshly prepared extract and 1.5 liters of distilled water were used to screen the soaked pulp (Figure 12B). pH testing was conducted using substances with varying pH levels to evaluate the paper's color change response, in comparison to a commercial pH indicator [5]. The resulting paper exhibited a distinct color gradient corresponding to pH levels, shifting from pink, purple-red, and blue to green and lime green, as illustrated in the test sample (Figure 12D).

Figure 12: (A) Soaking pulp in red cabbage extract under indoor conditions. (B) Screening the soaked pulp using a 3-liter mixture of extract and distilled water. (C) Extracted juice in a bottle alongside a dried paper sheet after one day of soaking. (D) Gradient of colors on the paper corresponding to varying pH levels.

5.2.1 Condition Characterization . The efficacy of the paper's color-changing property depends on the stability of anthocyanin, which degrade under high temperatures and UV exposure. To evaluate the effect of this degradation, we conducted experiments under different drying and storage conditions in real-world scenarios.

[5] pH indicator

These conditions were categorized as **Indoors**, **Partially shaded**, and **Outdoors**, with UV radiation[6], temperature, and humidity[7] monitored (Figure 11A).

As shown in Figure 11B, higher UV exposure, temperature, and low humidity led to greater chemical degradation, resulting in less vibrant reactive colors after drying. For storage testing (Figure 11C), fully dried samples (prepared and dried indoors) were stored in the same three conditions for five days. The results mirrored the drying process, with UV exposure, temperature, and humidity significantly affecting color vibrancy and chemical stability. These findings suggest that to preserve the color-changing efficacy, the papermaking process and storage conditions should minimize UV exposure and maintain room temperature.

5.3 Sheet formation: Watermarking

Screening is the step that controls fiber distribution using the force of water and relies heavily on the maker's skill to create a cohesive, unified sheet. Once the sheet is formed, the fibers are bonded but remain loose, allowing opportunities for customization. By applying a design stencil mask to the sheet and employing a watermarking technique, patterns can be embedded as the sheet dries. Adjusting the spray pressure and frequency during this process determines the amount of fiber washed away, influencing the sheet's thickness—less fiber retention results in a thinner sheet.

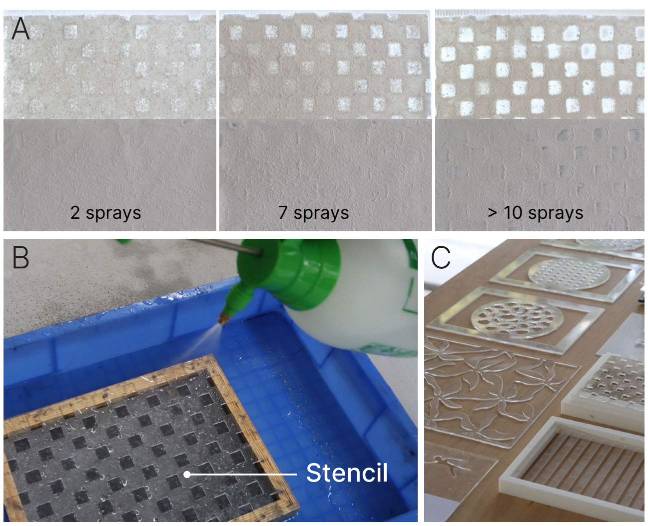

Figure 13: (A) Opacity change based on varying spray times; (B) High-pressure water bottle spraying on a damp sheet with a stencil mask; (C) Laser-cut stencil masks for customized designs.

5.3.1 *Opacity Characterization.*

For the watermark technique, we used a high-pressure spray bottle (Figure 13B), directed perpendicular towards the stencil mask placed a few centimeters above the damp sheet. The spray bottle was held 30 cm away from the stencil mask (Figure 13C). We conducted tests with different times of sprays to observe how fiber residue affects light transmission. The Figure 13A illustrates that spraying two times retains enough fiber to keep the sheet intact while allowing slight light penetration. Seven sprays achieve a semi-transparent effect, though some fibers begin to separate. Spraying more than ten times effectively washes away the fibers, creating distinct sections within the sheet.

5.4 Pressing: Layering

Layering is a technique for combining different features into a single sheet. This process involves fusing multiple damp (pre-dried) sheets (Figure 14A) by stacking and applying pressure on them (Figure 5F). For instance, a conductive layer can be fused with a non-conductive layer while still wet, resulting in a single sheet with one side that is conductive and one side that is non-conductive. Additionally, layering can be combined with watermarking, where specific areas of a sheet are selectively exposed and then layered with another sheet to achieve patterned or functional effects, allowing for selective interaction (as demonstrated in Section 6.2)

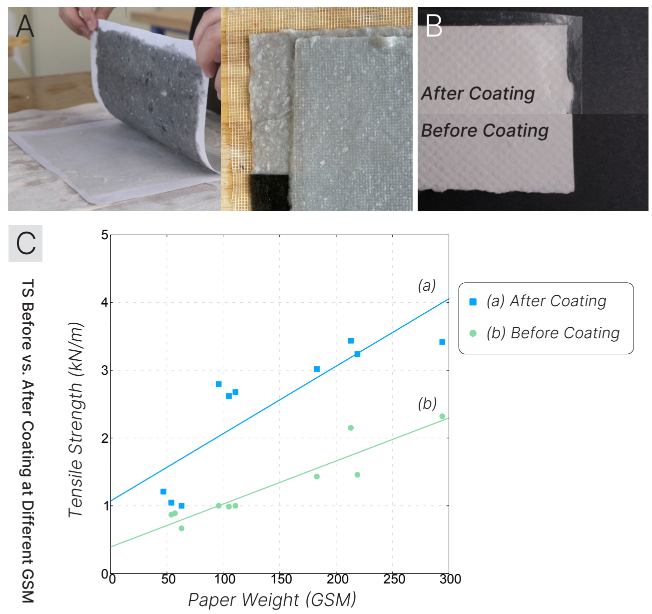

Figure 14: (A) Layering multiple damp sheets to fuse them into a single sheet. (B) Comparison of paper surfaces before and after applying an agar-based coating. (C) Graph showing tensile strength improvements after coating across four GSM samples.

5.5 Finishing: Coating

In the finishing stage, the paper can also be coated to enhance surface protection, increase GSM, or improve texture. We applied an agar-based coating using formulations from *Alganyl* [7] to damp (pre-dried) paper, which not only increased its GSM but also enhanced its tensile strength, as shown in (Figure 14C). Additionally, the coating imparts a leather-like texture (Figure 14B Top), provides water resistance and aids in bonding multiple layers together after drying, thereby improving the structural integrity of the final product (as demonstrated in Section 6.4).

[6]Qinlorgo B085TKPN2R UV tester
[7]Xiaomi Temperature and Humidity Monitor Clock

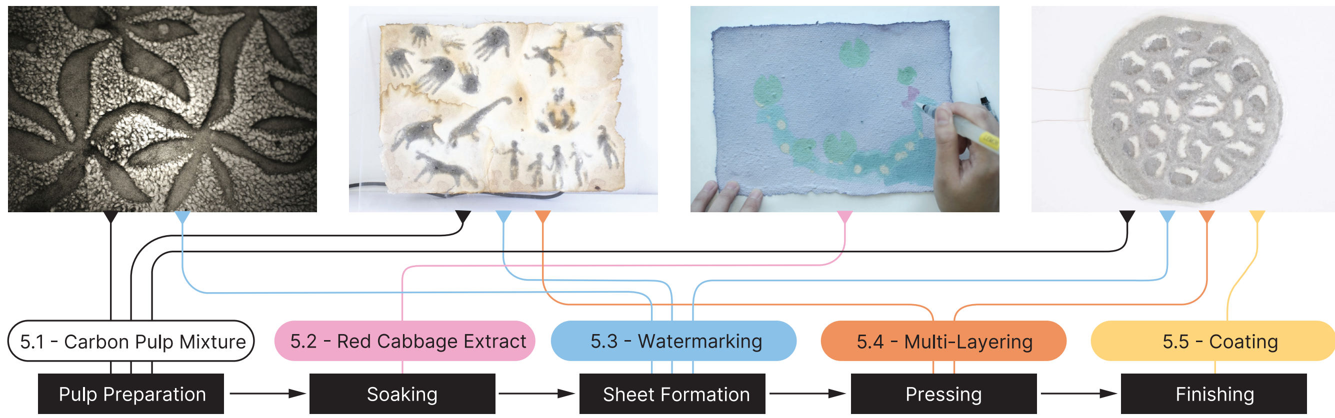

Figure 15: Overview of the four applications created through our adapted papermaking processes.

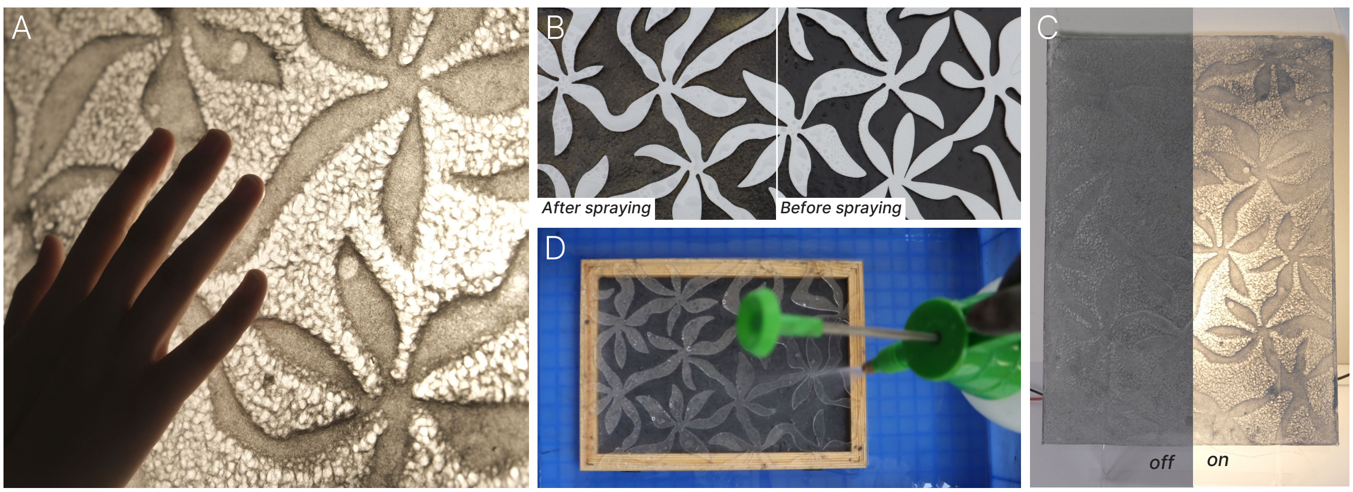

Figure 16: A: Interactive paper-wall light; B: Comparison of fiber density before and after two sprays; C: Paper surface touch interaction to light up; D: Watermarking process used to create delicate patterns and texture.

6 Applications

We crafted four interactive applications that demonstrate how our papermaking interventions might be woven together for paper composites relevant to a variety of design contexts (Figure 15). In directing our applications toward expressive interfaces, we sought to emphasize paper's historical and cultural significance not just as a functional material but as a medium of human expression. Paper has long played an important role in various cultures, such as Chinese landscape painting, calligraphy, and its use in religious or festive decorations. While modern mass production has replaced many of the traditional uses of handmade paper, it has also made it unnecessary for handmade paper to compete in terms of utilitarian performance. Instead, handmade paper offers the potential to achieve effects that are less commonly seen in industrial processes.

Therefore, in our applications, we aimed to: (1) Demonstrate the unique effects made possible by our papermaking interventions (Table 1), which are difficult to achieve through conventional industrial papermaking. (2) Present paper itself as an artifact outcome of the application, rather than its more conventional role in design as a material for further construction. (3) Highlight paper's role as an expressive [45] medium in daily life.

6.1 Paper-Wall Light

We designed a Paper-Wall light that activates with a gentle touch on its surface. The paper that covers the light measures 420mm by 594mm (A2 size) and we made a custom screen to fabricate it as a single sheet. Touching the paper surface turns the light on, revealing a translucent floral pattern, as shown in Figure 16A.

We built this artifact using carbon fiber pulp (Section 5.1) and watermarking techniques (Section 5.3). By connecting these two interventions, we discovered that we could create delicate patterns that combine light diffusion with interactive touch. Touch sensing is achieved through capacitive sensing with the entire sheet as a single conductive electrode. The carbon fiber pulp recipe used in this application followed the material ratios and recipes outlined in (Section 5.1). This formulation facilitates the smooth blending of carbon fibers with other paper fibers, resulting in a less textured final surface while also improving the effectiveness of the watermark technique used during screening, as shown in Figure 16B,D. To maintain pattern integrity and ensure effective conductivity, the fiber sheet was sprayed twice, preserving the pattern's connectivity and ensuring visibility when backlit, as illustrated in Figure 16C. These modifications enable the paper to function as both a sensitive input device and an aesthetically appealing lampshade.

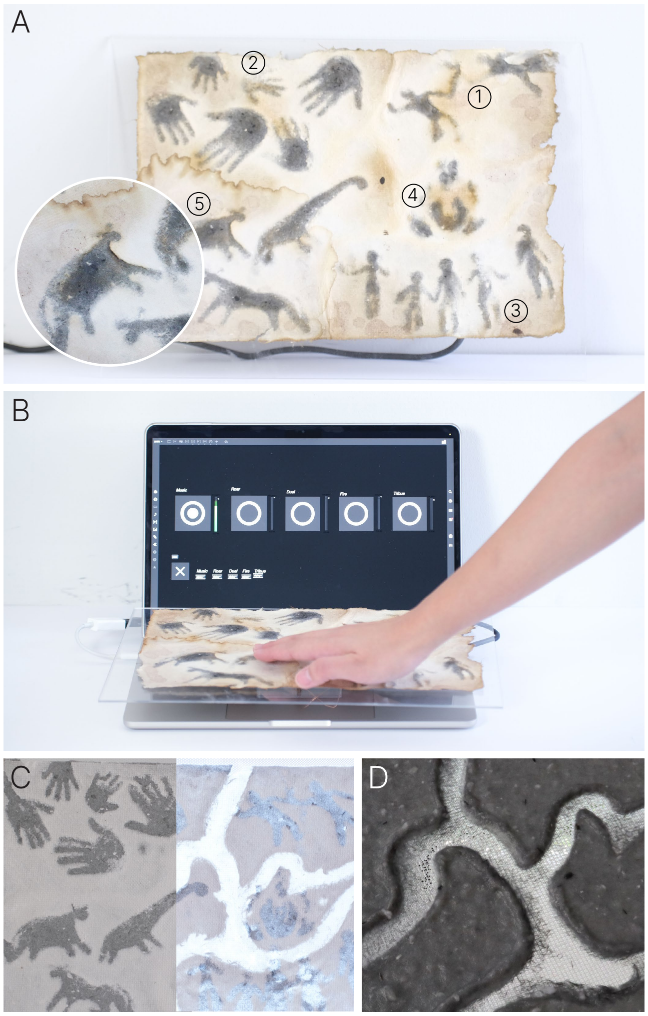

Figure 17: A: The cave art interface featuring five individual touch inputs that trigger corresponding sounds: 1-duel, 2-tribe, 3-dancing, 4-fire, 5-roar. B: Sound generated using Max/MSP software. C: A backlit view through two layers of the paper composite. D: Bottom conductive layer, created by fully washing away fibers in specific zones using the watermarking technique, to separate the inputs.

6.2 Cave Art

Cave Art is a tactile and visual display that triggers specific sounds when different graphical elements are touched (Figure 17B). The application combines our interventions of watermarking (Section 5.3), layering conductive and non-conductive layers (Section 5.4). Touch sensing is facilitated by placing a non-conductive paper with designed patterns over a conductive paper layer, which is divided into five separate touch zones. Both conductive and non-conductive layers went through an extended watermarking process to fully remove fibers (Figure 17D) that were exposed by the stencil. After watermarking, we manually sprayed the conductive layer at targeted regions to remove conductive connections and separate the areas to create independent input zones (Figure 17A). After watermarking, the damp conductive and non-conductive sheets are pressed together immediately, resulting in a single sheet that is selectively conductive on one side and non-conductive on the other (Figure 17C). For visual effect, we used coffee grounds to dye the paper to create a rock wall-like texture.

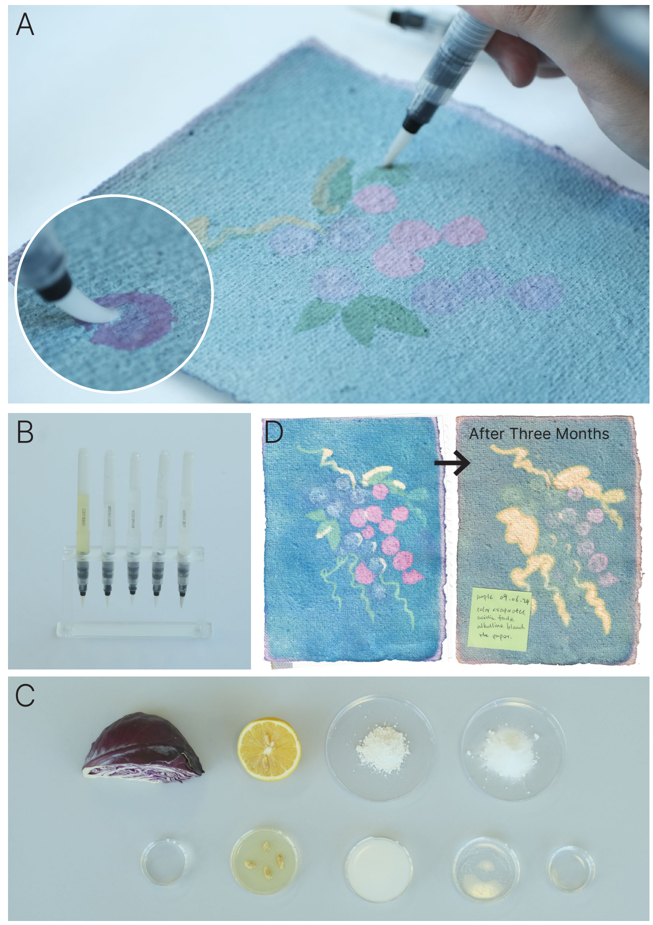

Figure 18: (A) Sample drawing of a grape using the pH-responsive drawing kit. (B) Designed a set of five liquid pen brushes, each filled with different pH liquids, displayed on a pen holder. (C) Food-safe ingredients used for the color-changing liquids: red cabbage extract, fresh lemon juice extract, baking soda, calcium hydroxide, white vinegar, and distilled water. (D) The drawing was preserved after three months of storage in indoor conditions (Section 5.2)

6.3 Drawing Kit

This drawing kit (Figure 18A) demonstrates how modifying the soaking step can create paper with color-changing properties that responds to different pH levels. We soaked paper pulp in red cabbage extract as described in Section 5.2. This transforms the kit into a bio-safe, food-grade painting tool. The kit includes brush pens (Figure 18B) filled with common, kitchen-safe ingredients (Figure 18C) that remain colorless within the pen but reveal a range of

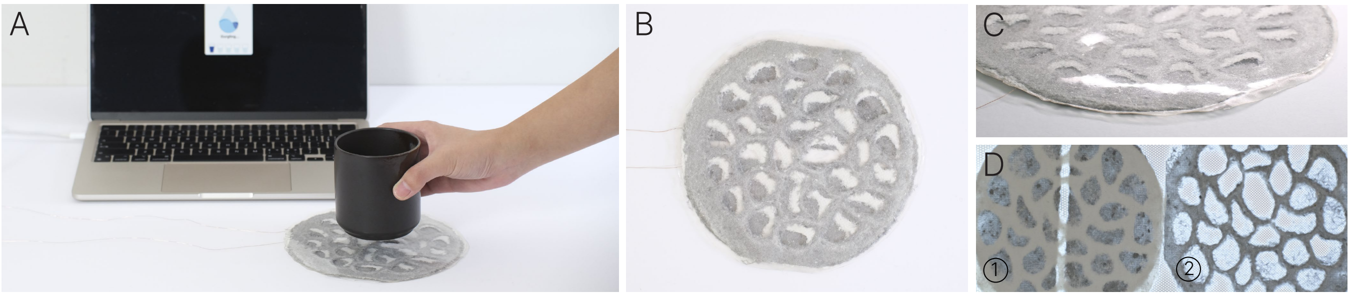

Figure 19: A: A pressure-sensitive trivet detects the weight of a cup to monitor a person's hydration. B: A close-up of the trivet's structure. C: The coating used to seal the sandwich structure. D: A view of the three layers of the trivet under backlighting.

colors across the hue spectrum when applied to the color-changing paper. We prepared a variety of substances with distinct pH levels: lemon juice (pH $\approx$ 3), white vinegar (pH $\approx$ 4), baking soda solution (pH $\approx$ 8), alkaline water (pH $\approx$ 10), and calcium hydroxide (pH $\approx$ 12). When applied to the paper, these substances trigger color changes ranging from pink, purple-red, blue, green, to yellow, as demonstrated in the sample drawing (Figure 18D).

6.4 Trivet

This application demonstrates pressure-sensitive trivets designed to detect the weight of a cup to monitor a person's hydration (Figure 19A). Through our exploration of the layering technique (Section 5.4) and agar coating (Section 5.5), we discovered that sealing multiple layers together with agar coating creates an air gap in between the layers (Figure 19C). This could be used to as an approximate sensor for pressure, as the electrical resistance of the conductive paper will decrease as more gaps are closed with increasing weight or pressure [51]; which is analagous to the crafted pressure sensors demonstrated in [62].

We designed a trivet (Figure 19B), with a sandwich structure featuring a non-conductive, porous middle layer between two conductive layers. Our process involved several material and structural adjustments to enhance the functionality and responsiveness of the trivet. The bottom layer was segmented into two independent sections to create a gap in a conductive trace, which is bridged by the conductive top layer when pressed. To improve the responsiveness of this sensor, we adjusted the ratio of bark fiber to recycled paper in the middle layer from 1:1 to 2:1. This created a thicker, more sponge-like texture that was better suited to responding to pressure changes. The middle layer was watermarked and thoroughly sprayed to remove excess fibers, ensuring effective contact points when pressure is applied. After screening, the bottom and middle layers were combined while still damp (Figure 19D1), and the top layer was coated with an agar solution (Figure 19D2) to seal the structure.

7 Discussion

7.1 Limitations and Opportunities in Craft-based Research

Our research adopted a Research through Design (RtD) approach, widely embraced in HCI craft research, as outlined in Section 3. Specifically, we employed material tinkering, systematic documentation, and prototyping to explore ancient papermaking as a framework for developing interactive composites. While this methodology enabled hands-on engagement with craft to generate new knowledge [113], it presented inherent challenges and limitations. For instance, the craft ethos of "doing things well for its own sake" can sometimes lead to prioritizing the artifact over broader research goals [26]. With this in mind, we balanced open-ended exploration with focused research experimentation. Material tinkering, structured by our simplified papermaking processes, served as both a framework and a boundary, encouraging unexpected outcomes while keeping our efforts aligned with the research objectives. Similarly, the "filtering" and "expressive" approaches in application prototyping helped us remain grounded in our goals while retaining flexibility for creative exploration. Another challenge lies in the specialized skills required for craft-based research, which may hinder accessibility for others in the HCI community. Simplification and systematic documentation were therefore integral to this research. By breaking down ancient techniques into reproducible steps and tools, we aimed to make this approach approachable and traceable.

Our craft-driven approach to making computational composites stands in contrast to approaches in scientific fields (such as material sciences). Rather than defining goals based on achieving specific material properties and performance, we were led by the opportunities that emerged from immersing ourselves in the actions, tools, and materials along the ancient papermaking process. However, this craft-driven exploration, and our manual approach to papermaking, inherently introduced variability in the process and outcomes that we developed. We discuss the limitations of our findings in this section, as well as our strategies we adopted to address these limitations.

7.1.1 Variability in the Manual Approach.

Inconsistent Conductivity While the carbon fiber papers we built demonstrated conductive properties, the conductivity varied across different samples of the same type (Section 5.1), indicating inconsistencies in fiber bonding and alignment.

Other research have demonstrated the feasibility of fabricating conductive paper with a greater consistency through mass-production processes [35]. Our approach, while lacking the same level of consistency, enabled us to manipulate other features of paper alongside its conductive properties. For example, in the paper-wall lamp (Section 6.1), we demonstrate how conductive paper can be combined with watermarking to define the shape of conductive regions within a paper sheet, therefore creating localized areas for capacitive sensing. We also demonstrate how conductive and non-conductive sheets can be fused together in one single sheet through pressing them together during the drying process, enabling us to define a sheet with both conductive and non-conductive regions (Section 6.2). In these applications, we also chose to use capacitive touch sensing to detect interactions as it is not significantly affected by the conductive consistency of the material.

Moreover, our exploration of integrating carbon fibers into paper's structure highlights further possibilities for introducing other fiber types. For example, we see potential in incorporating transparent cellulose fibers [59] for visual interactivity or ferrous fibers [46] that can be magnetized for actuated paper applications. These directions are of interest for future work.

Inconsistent Dyeing Similarly, the red cabbage extract we used for color-changing paper presented challenges in achieving consistent dyeing outcomes. Environmental factors such as UV exposure and storage conditions vary the paper's color degradation over time (Section 5.2). While other researchers have addressed this by affixing the dye with chemicals like aluminum sulfate [112], we deliberately avoided this in our research as we wanted to make paper from natural ingredients as much as possible. To this end, we focused on expressive applications that made used of the variable color of this specific material (Section 6.3), rather than use the color-changing paper we made as an accurate pH indicator. For example, as shown in Figure 20C, a lighter colored substrate (made from shorter soaking time) better highlights blue and green tones, while the darker colored substrate (longer soaking time) better highlights pink and yellow tones.

7.1.1 Variability in the Manual Approach. Our manual approach made it difficult to produce large sheets of paper (larger than A2 size, Section 6.1) or achieve high volumes of production. This limitation reflects not only the constraints of our setup, but also our skills as novices who are learning this craft. As such, we took a different approach where we instead focused on making specialized paper that caters to the design and construction of high-quality outputs [45]. This approach is inspired by Japanese washi paper [78], which endures because of the labor and ingenuity embedded in its small-batch production. The contemporary washi paper industry demonstrates how small-batch, high-quality outputs can complement large-scale industrial practices, especially when tailored for specific design needs.

7.1.3 Durability of Handmade Paper.

While studies have shown that traditional handmade paper is durable and can last for hundreds of years [1, 11, 14], the longevity of handmade paper depends on factors such as specific material composition and environmental conditions. We are not able to make claims for the durability of the paper we made throughout the course of this research given the limited timeframe of the project so far (less than one year). We will continue to monitor the quality of our handmade paper, including testing its conductivity and tensile strength periodically over a long duration.

Figure 20: (A) A failed screening attempt that can be rehydrated and re-screened. (B) Leftover pulp in the water can be collected with a sieve and recycled for further use. (C) Two color variations of red cabbage paper, influenced by soaking duration and drying conditions.

7.2 Composing Paper

Humans have a long history of transforming raw materials into functional and expressive artifacts through diverse craft practices, both in ancient times and in contemporary practices. The craft community in HCI designs computational systems by rethinking how materials are formed and how we interact with them. In this research, our journey to papermaking was a process of composing, requiring observation of material responses, iterative adjustments, and recombination of elements to shape its structure and properties. We treated the papermaking process as a systemically reflective conversation. Much like a jazz musician improvising and adapting to feedback within a "schema" [82], we composed paper by working within the "bounds" of its traditional process which gives it is fundamental structure. This process provided both a framework for exploration, as well as opportunities for intervention. Within this schema, we made continuous adjustments, such as tinkering with fiber compositions, designing DIY tools, hacking traditional techniques like screening, and integrating computational materials. It is an open-ended process, making it ideal for intervention and exploration. We were also inspired by Benabdallah & Peek's reflection of technical mentality [8] that encourages researchers and designers to intervene in fabrication processes, treating such conventionally opaque processes as an open system that can be explored and modified. Our approach to papermaking aligns with the call to dive into these fabrication black boxes.

Papermaking was initially an unfamiliar process to us, and as designers, we saw paper as a starting material to be constructed into other things. We demonstrated how papermaking can be "hacked" to change into interactive composite that can be conductive, color-reactive, and varying in opacity. By composing our own paper, we also became more sensitive to how this materials comes to be, and were more aware of the concerns around development more sustainable relationships between human makers and the materials that we are *designing-with* [58, 94]. For example, strategies like rehydrating leftover pulp (Figure 20A,B) for subsequent trials allowed us to minimize waste and maximize resource use. Through this journey, we begin to open pathways towards how we might be able to craft paper for interactive systems with greater respect for the preciousness [70] of material at play and the ways that they come together.

By treating paper as a composite with adaptable fibers and understanding the processes of paper formation, we influence both its physical and computational properties, eventually shaping its texture [102]. In this work, we developed recipes and interventions that shaped the physical and computational texture of interactive paper composites. As researchers who are broadly interested in the materiality of tangible interactions, this project served as a lens that revealed new potentials [6] of materials that we were already familiar with.

8 Conclusion

In this research, we revisited and adapted ancient papermaking techniques to explore new possibilities for interactive and computational applications in HCI. By modifying five key steps—pulp preparation, soaking, sheet formation, pressing, and finishing—we demonstrated how paper, a material with deep historical significance, can be transformed into an interactive medium. The expressive applications developed through this process showcase unique features like diverse texture, conductivity, and color-changing abilities, which are only achievable through our adapted methods. Our contributions include demonstrating how ancient papermaking can be adapted to create computational composites, and providing a detailed material database for future exploration. We hope this research opens new possibilities for both craft practitioners and HCI researchers, encouraging further integration of ancient techniques into interactive materials.

Acknowledgments

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References

[1] 2023. 中国手工纸工艺与纤维分析图释. 上海科学技术出版社. https://books.google.com.sg/books?id=X6bTzwEACAAJ

[2] 2023. 寻纸. 浙江人民美术出版社. https://books.google.at/books?id=r7YI0AEACAAJ

[3] Essam S Abd El-Sayed, Mohamed El-Sakhawy, and Mohamed Abdel-Monem El-Sakhawy. 2020. Non-wood fibers as raw material for pulp and paper industry. *Nordic Pulp & Paper Research Journal* 35, 2 (2020), 215–230.

[4] Raimo Alén. 2018. Manufacturing cellulosic fibres for making paper: A historical perspective. *Technological Transformation in the Global Pulp and Paper Industry 1800–2018: Comparative Perspectives* (2018), 13–34.

[5] Shigeru Ban. 1995. Paper House. https://shigerubanarchitects.com/works/paper-tubes/paper-house/

[6] Bahareh Barati and Elvin Karana. 2019. Affordances as materials potential: What design can do for materials development. *International Journal of Design* 13, 3 (2019), 105–123.

[7] Fiona Bell, Latifa Al Naimi, Ella McQuaid, and Mirela Alistar. 2022. Designing with Alganyl. In *Proceedings of the Sixteenth International Conference on Tangible, Embedded, and Embodied Interaction* (Daejeon, Republic of Korea) *(TEI '22)*. Association for Computing Machinery, New York, NY, USA, Article 2, 14 pages. doi:10.1145/3490149.3501308

[8] Gabrielle Benabdallah and Nadya Peek. 2024. Technical Mentality: Principles for HCI Research and Practice. In *Proceedings of the CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 283, 14 pages. doi:10.1145/3613904.3642720

[9] Henry Kreitzer Benson. 1930. The story of paper. *Journal of Chemical Education* 7, 8 (1930), 1738.

[10] AK Bledzki and Jochen Gassan. 1999. Composites reinforced with cellulose based fibres. *Progress in polymer science* 24, 2 (1999), 221–274.

[11] Alessandro Boesi. 2016. Paper plants in the Tibetan world: A Preliminary study. *Tibetan Printing: Comparison, Continuities, and Change; Diemberger, H., Ehrhard, K., Kornicki, PF, Eds* (2016), 501–530.

[12] Leah Buechley, Mike Eisenberg, Jaime Catchen, and Ali Crockett. 2008. The LilyPad Arduino: using computational textiles to investigate engagement, aesthetics, and diversity in computer science education. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Florence, Italy) *(CHI '08)*. Association for Computing Machinery, New York, NY, USA, 423432. doi:10.1145/1357054.1357123

[13] Cuauhtli Campos, Matjaž Kljun, Jakub Sandak, and Klen Čopič Pucihar. 2023. Interactive Paper Displays: Enabling Digital Functionalities on Physical Paper. In *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI EA '23)*. Association for Computing Machinery, New York, NY, USA, Article 461, 5 pages. doi:10.1145/3544549.3583932

[14] CGTN. [n. d.]. Papermaking in China: History of Craftsmanship. https://news.cgtn.com/news/3d3d414e3367544d32457a6333566d54/index.html. Accessed: 2024-12-08.

[15] Yangmei Chen, Yu Jiang, Jinquan Wan, Qitang Wu, Zebin Wei, and Yongwen Ma. 2018. Effects of wet-pressing induced fiber hornification on hydrogen bonds of cellulose and on properties of eucalyptus paper sheets. *Holzforschung* 72, 10 (2018), 829–837.

[16] Tingyu Cheng, Zhihan Zhang, Bingrui Zong, Yuhui Zhao, Zekun Chang, Yejun Kim, Clement Zheng, Gregory D. Abowd, and HyunJoo Oh. 2023. SwellSense: Creating 2.5D interactions with micro-capsule paper. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 424, 13 pages. doi:10.1145/3544548.3581125

[17] D.D.L. Chung. 1994. *Carbon Fiber Composites*. Elsevier Science. https://books.google.com.sg/books?id=FHoBkd6PGXUC

[18] Marcelo Coelho, Lyndl Hall, Joanna Berzowska, and Pattie Maes. 2009. Pulp-based computing: a framework for building computers out of paper. In *CHI '09 Extended Abstracts on Human Factors in Computing Systems* (Boston, MA, USA) *(CHI EA '09)*. Association for Computing Machinery, New York, NY, USA, 35273528. doi:10.1145/1520340.1520525

[19] Nigel Cross. 1982. Designerly ways of knowing. *Design studies* 3, 4 (1982), 221–227.

[20] Aslıhan Demirdöven, Kenan Özdoğan, and Kader Erdoğan-Tokatlı. 2015. Extraction of anthocyanins from red cabbage by ultrasonic and conventional methods: optimization and evaluation. *Journal of Food Biochemistry* 39, 5 (2015), 491–500.

[21] Laura Devendorf, Joanne Lo, Noura Howell, Jung Lin Lee, Nan-Wei Gong, M. Emre Karagozler, Shiho Fukuhara, Ivan Poupyrev, Eric Paulos, and Kimiko Ryokai. 2016. "I don't Want to Wear a Screen": Probing Perceptions of and Possibilities for Dynamic Displays on Clothing. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 60286039. doi:10.1145/2858036.2858192

[22] Charles M Eastman and Anastassios Siabiris. 1995. A generic building product model incorporating building type information. *Automation in construction* 3, 4 (1995), 283–304.

[23] Lutfiye Ekici, Zeynep Simsek, Ismet Ozturk, Osman Sagdic, and Hasan Yetim. 2014. Effects of temperature, time, and pH on the stability of anthocyanin extracts: Prediction of total anthocyanin content using nonlinear models. *Food Analytical Methods* 7 (2014), 1328–1336.

[24] Yehia Fahmy, Fardous Mobarak, Mohamed El-Sakhawy, MH Fadl, et al. 2017. Agricultural residues (wastes) for manufacture of paper, board, and miscellaneous products: Background overview and future prospects. *International journal of chemtech research* 10, 2 (2017), 424–448.

[25] Celso Foelkel. 2009. Papermaking properties of Eucalyptus trees, woods, and pulp fibers. *Eucalyptus online book & newsletter* (2009), 110.

[26] Raune Frankjær and Peter Dalsgaard. 2018. Understanding Craft-Based Inquiry in HCI. In *Proceedings of the 2018 Designing Interactive Systems Conference* (Hong Kong, China) *(DIS '18)*. Association for Computing Machinery, New York, NY, USA, 473484. doi:10.1145/3196709.3196750

[27] Mikhaila Friske, Shanel Wu, and Laura Devendorf. 2019. AdaCAD: Crafting Software For Smart Textiles Design. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 113. doi:10.1145/3290605.3300575

[28] Daniel Gagnon-King, Lee Jones, and Sara Nabil. 2023. Interactive Stained-Glass: Exploring a new design space of traditional hybrid crafts for novel fabrication methods. In *Proceedings of the Seventeenth International Conference on Tangible, Embedded, and Embodied Interaction* (Warsaw, Poland) *(TEI '23)*. Association for Computing Machinery, New York, NY, USA, Article 25, 15 pages. doi:10.1145/3569009.3572796

[29] Nazila Ghareaghajlou, Somayeh Hallaj-Nezhadi, and Zahra Ghasempour. 2021. Red cabbage anthocyanins: Stability, extraction, biological activities and applications in food systems. *Food Chemistry* 365 (2021), 130482.

[30] Elisa Giaccardi and Elvin Karana. 2015. Foundations of Materials Experience: An Approach for HCI. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI '15)*. Association for Computing Machinery, New York, NY, USA, 24472456. doi:10.1145/2702123.2702337

[31] Sofia Guridi, Tamara Vicencio, and Rodrigo Gajardo. 2021. Arpilleras Parlantes: Designing Educational Material for the Creation of Interactive Textile Art Based on a Traditional Chilean Craft.. In *Proceedings of the Fifteenth International*

Conference on Tangible, Embedded, and Embodied Interaction (Salzburg, Austria) *(TEI '21)*. Association for Computing Machinery, New York, NY, USA, Article 38, 11 pages. doi:10.1145/3430524.3440657
[32] Nur Al-huda Hamdan, Simon Voelker, and Jan Borchers. 2018. Sketch&stitch: Interactive embroidery for e-textiles. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–13.
[33] Bryan Harris et al. 1999. Engineering composite materials. (1999).
[34] Cedric Honnet, Hannah Perner-Wilson, Marc Teyssier, Bruno Fruchard, Jürgen Steimle, Ana C. Baptista, and Paul Strohmeier. 2020. PolySense: Augmenting Textiles with Electrical Functionality using In-Situ Polymerization. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 113. doi:10.1145/3313831.3376841
[35] Liangbing Hu and Yi Cui. 2012. Energy and environmental nanotechnology in conductive paper and textiles. *Energy & Environmental Science* 5, 4 (2012), 6423–6435.
[36] Martin A Hubbe and Cindy Bowden. 2009. Handmade paper: a review of its history, craft, and science. *BioResources* 4, 4 (2009).
[37] Tim Ingold. 2009. The textility of making. *Cambridge Journal of Economics* 34, 1 (07 2009), 91–102. doi:10.1093/cje/bep042 arXiv:https://academic.oup.com/cje/article-pdf/34/1/91/4746308/bep042.pdf
[38] Irving H Isenberg. 1956. Papermaking fibers. *Economic Botany* 10, 2 (1956), 176–193.
[39] Lee Jones, Sara Nabil, and Audrey Girouard. 2020. Swatch-bits: Prototyping E-textiles with Modular Swatches. In *Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction* (Sydney NSW, Australia) *(TEI '20)*. Association for Computing Machinery, New York, NY, USA, 893897. doi:10.1145/3374920.3374971
[40] MM Kabir, Hao Wang, KT Lau, and Francisco Cardona. 2012. Chemical treatments on plant-based natural fibre reinforced polymer composites: An overview. *Composites Part B: Engineering* 43, 7 (2012), 2883–2892.
[41] Elvin Karana, Bahareh Barati, Valentina Rognoli, Anouk Zeeuw Van Der Laan, et al. 2015. Material driven design (MDD): A method to design for material experiences. *International journal of design* 9, 2 (2015), 35–54.
[42] Nicholas A. Knouf. 2017. Felted Paper Circuits Using Joomchi. In *Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction* (Yokohama, Japan) *(TEI '17)*. Association for Computing Machinery, New York, NY, USA, 443450. doi:10.1145/3024969.3025071
[43] Arvind Kumar, SP Singh, and AK Singh. 2016. Comparative study of cellulose nanofiber blending effect on properties of paper made from bleached bagasse, hardwood and softwood pulps. *Cellulose* 23 (2016), 2663–2675.
[44] Per Tomas Larsson, Tom Lindström, Leif A Carlsson, and Christer Fellers. 2018. Fiber length and bonding effects on tensile strength and toughness of kraft paper. *Journal of materials science* 53 (2018), 3006–3015.
[45] Youn-Kyung Lim, Erik Stolterman, and Josh Tenenberg. 2008. The anatomy of prototypes: Prototypes as filters, prototypes as manifestations of design ideas. *ACM Trans. Comput.-Hum. Interact.* 15, 2, Article 7 (July 2008), 27 pages. doi:10.1145/1375761.1375762
[46] Shilin Liu, Lina Zhang, Jinping Zhou, and Ruixin Wu. 2008. Structure and properties of cellulose/Fe2O3 nanocomposite fibers spun via an effective pathway. *The Journal of Physical Chemistry C* 112, 12 (2008), 4538–4544.
[47] Tom Lundin. 2008. *Tailoring pulp fibre properties in low consistency refining*. Åbo Akademi.
[48] Elizabeth Meiklejohn, Laura Devendorf, and Irene Posch. 2024. Design Bookkeeping: Making Practice Intelligible through a Managerial Lens. In *Proceedings of the 2024 ACM Designing Interactive Systems Conference* (Copenhagen, Denmark) *(DIS '24)*. Association for Computing Machinery, New York, NY, USA, 3549. doi:10.1145/3643834.3660754
[49] Annika Muehlbradt, Gregory Whiting, Shaun Kane, and Laura Devendorf. 2022. Knitting Access: Exploring Stateful Textiles with People with Disabilities. In *Proceedings of the 2022 ACM Designing Interactive Systems Conference* (Virtual Event, Australia) *(DIS '22)*. Association for Computing Machinery, New York, NY, USA, 10581070. doi:10.1145/3532106.3533551
[50] WANG Nan. 2018. Ancient Chinese Attitudes toward Technics: Chinese Philosophy of Technology Prior to the 1800s. *Philosophy of Engineering, East and West* (2018), 61–73.
[51] Joanna M Nassar, Marlon D Cordero, Arwa T Kutbee, Muhammad A Karimi, Galo A Torres Sevilla, Aftab M Hussain, Atif Shamim, and Muhammad M Hussain. 2016. Paper skin multisensory platform for simultaneous environmental monitoring. *Advanced Materials Technologies* 1, 1 (2016), 1600004.
[52] Harold G Nelson and Erik Stolterman. 2014. *The design way: Intentional change in an unpredictable world*. MIT press.
[53] Nithikul Nimkulrat. 2012. Hands-on intellect: Integrating craft practice into design research. *International Journal of Design* 6, 3 (2012), 1–14.
[54] Jiangxi Provincial Institute of Cultural Relics, Archaeology, and Gao' an Municipal Museum. 2011. The Hualin Papermaking Mill Remains in Gao' an City, Jiangxi. *Chinese Archaeology* 11, 1 (2011), 40–49.
[55] Masa Ogata and Masaaki Fukumoto. 2015. FluxPaper: Reinventing Paper with Dynamic Actuation Powered by Magnetic Flux. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI '15)*. Association for Computing Machinery, New York, NY, USA, 2938. doi:10.1145/2702123.2702516
[56] Hyunjoo Oh, Tung D. Ta, Ryo Suzuki, Mark D. Gross, Yoshihiro Kawahara, and Lining Yao. 2018. PEP (3D Printed Electronic Papercrafts): An Integrated Approach for 3D Sculpting Paper-Based Electronic Devices. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 112. doi:10.1145/3173574.3174015
[57] Doenja Oogjes and Audrey Desjardins. 2024. A temporal vocabulary of Design Events for Research through Design. In *Proceedings of the CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 224, 12 pages. doi:10.1145/3613904.3642560
[58] Doenja Oogjes and Ron Wakkary. 2022. Weaving Stories: Toward Repertoires for Designing Things. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 98, 21 pages. doi:10.1145/3491102.3501901
[59] Hannes Orelma, Ari Hokkanen, Ilona Leppänen, Kari Kammiovirta, Markku Kapulainen, and Ali Harlin. 2020. Optical cellulose fiber made from regenerated cellulose and cellulose acetate for water sensor applications. *Cellulose* 27 (2020), 1543–1553.
[60] Stefano Parisi, Valentina Rognoli, and Marieke Sonneveld. 2017. Material Tinkering. An inspirational approach for experiential learning and envisioning in product design education. *The Design Journal* 20, sup1 (2017), S1167–S1184.
[61] Ton Peijs, Robert Kirschbaum, and Pieter Jan Lemstra. 2022. A critical review of carbon fiber and related products from an industrial perspective. *Advanced Industrial and Engineering Polymer Research* 5, 2 (2022), 90–106.
[62] Hannah Perner-Wilson, Leah Buechley, and Mika Satomi. 2010. Handcrafting textile interfaces from a kit-of-no-parts. In *Proceedings of the Fifth International Conference on Tangible, Embedded, and Embodied Interaction* (Funchal, Portugal) *(TEI '11)*. Association for Computing Machinery, New York, NY, USA, 6168. doi:10.1145/1935701.1935715
[63] Hannah Perner-Wilson, Leah Buechley, and Mika Satomi. 2010. Handcrafting textile interfaces from a kit-of-no-parts. In *Proceedings of the Fifth International Conference on Tangible, Embedded, and Embodied Interaction* (Funchal, Portugal) *(TEI '11)*. Association for Computing Machinery, New York, NY, USA, 6168. doi:10.1145/1935701.1935715
[64] Hannah Perner-Wilson and Irene Posch. 2022. How Tangible is TEI? Exploring Swatches as a New Academic Publication Format. In *Proceedings of the Sixteenth International Conference on Tangible, Embedded, and Embodied Interaction* (Daejeon, Republic of Korea) *(TEI '22)*. Association for Computing Machinery, New York, NY, USA, Article 55, 4 pages. doi:10.1145/3490149.3503668
[65] Gunilla Pettersson, Sven Norgren, Per Engstrand, Mats Rundlöf, and Hans Höglund. 2021. Aspects on bond strength in sheet structures from TMP and CTMP–a review. *Nordic Pulp & Paper Research Journal* 36, 2 (2021), 177–213.
[66] Irene Posch. 2018. The Embroidered Computer. http://ireneposch.net/the-embroidered-computer/ Accessed: 2024-12-09.
[67] Irene Posch and Ebru Kurbak. 2016. CRAFTED LOGIC Towards Hand-Crafting a Computer. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI EA '16)*. Association for Computing Machinery, New York, NY, USA, 38813884. doi:10.1145/2851581.2891101
[68] Ivan Poupyrev, Nan-Wei Gong, Shiho Fukuhara, Mustafa Emre Karagozler, Carsten Schwesig, and Karen E. Robinson. 2016. Project Jacquard: Interactive Digital Textiles at Scale. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 42164227. doi:10.1145/2858036.2858176
[69] Emmi Pouta and Jussi Ville Mikkonen. 2022. Woven eTextiles in HCI — a Literature Review. In *Proceedings of the 2022 ACM Designing Interactive Systems Conference* (Virtual Event, Australia) *(DIS '22)*. Association for Computing Machinery, New York, NY, USA, 10991118. doi:10.1145/3532106.3533566
[70] Precious Plastic. 2024. Precious Plastic - A Global Community for Plastic Recycling. https://www.preciousplastic.com/. Accessed: 2024-12-09.
[71] Piotr Przybysz, Marcin Dubowik, Marta Anna Kucner, Kazimierz Przybysz, and Kamila Przybysz Buzała. 2016. Contribution of hydrogen bonds to paper strength properties. *PloS one* 11, 5 (2016), e0155809.
[72] Jie Qi and Leah Buechley. 2010. Electronic popables: exploring paper-based computing through an interactive pop-up book. In *Proceedings of the Fourth International Conference on Tangible, Embedded, and Embodied Interaction* (Cambridge, Massachusetts, USA) *(TEI '10)*. Association for Computing Machinery, New York, NY, USA, 121128. doi:10.1145/1709886.1709909
[73] Jie Qi and Leah Buechley. 2014. Sketching in circuits: designing and building electronics on paper. In *Proceedings of the SIGCHI Conference on Human Factors*

in Computing Systems (Toronto, Ontario, Canada) *(CHI '14)*. Association for Computing Machinery, New York, NY, USA, 17131722. doi:10.1145/2556288.2557391

[74] Raf Ramakers, Kashyap Todi, and Kris Luyten. 2015. PaperPulse: An Integrated Approach for Embedding Electronics in Paper Designs. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI '15)*. Association for Computing Machinery, New York, NY, USA, 24572466. doi:10.1145/2702123.2702487

[75] Erica Robles and Mikael Wiberg. 2010. Texturing the "material turn" in interaction design. In *Proceedings of the Fourth International Conference on Tangible, Embedded, and Embodied Interaction* (Cambridge, Massachusetts, USA) *(TEI '10)*. Association for Computing Machinery, New York, NY, USA, 137144. doi:10.1145/1709886.1709911

[76] Valentina Rognoli, Massimo Bianchini, Stefano Maffei, and Elvin Karana. 2015. DIY materials. *Materials & Design* 86 (2015), 692–702.

[77] Niek Rutten, Jef Rouschop, Louise Mathiasen, Oscar Tomico, Bruna Goveia Da Rocha, and Kristina Andersen. 2022. Flipping Pages: Exploring Physical Workbooks as Reflective Method for Documentation. In *Nordic Human-Computer Interaction Conference* (Aarhus, Denmark) *(NordiCHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 90, 14 pages. doi:10.1145/3546155.3547296

[78] Shouji Sakamoto and Yoshihiro Okada. 2013. Paper analysis and paper history from ancient Chinese paper to Japanese washi. In *2013 International Conference on Culture and Computing*. IEEE, 51–56.

[79] WW Sampson. 2001. The structural characterisation of fibre networks in papermaking processes—a review. In *Proceedings of the Transactions of 12th Fundamental Resource Symposium, Oxford*. 1205–1288.

[80] Dagmar Schäfer. 2019. *The crafting of the 10,000 things: knowledge and technology in seventeenth-century China*. University of Chicago Press.

[81] Donald A Schön. 1992. Designing as reflective conversation with the materials of a design situation. *Knowledge-based systems* 5, 1 (1992), 3–14.

[82] Donald A Schön. 2017. *The reflective practitioner: How professionals think in action*. Routledge.

[83] R. Sennett. 2008. *The Craftsman*. Yale University Press. https://books.google.com.sg/books?id=LmtQAQAACAAJ

[84] Yingxing Song. 1637. *Tian Gong Kai Wu*. Library of Congress. https://www.loc.gov/item/2021666134/ Retrieved from the Library of Congress: https://www.loc.gov/item/2021666134/.

[85] Dynamicland Team. n.d.. Dynamicland: A New Way to Use Computers. https://dynamicland.org/ Accessed: 2024-12-08.

[86] Alvaro Tejado and Theo GM van de Ven. 2010. Why does paper get stronger as it dries? *Materials today* 13, 9 (2010), 42–49.

[87] Sandra A Thomson. 1989. Toxicology of carbon fibers. *Proceedings Occupational Health Aspects of Advanced Composite Technology in the Aerospace Industry, Health Effects and Exposure Considerations* (1989), 164–176.

[88] Mert Toka, Samuelle Bourgault, Camila Friedman-Gerlicz, and Jennifer Jacobs. 2023. An Adaptable Workflow for Manual-Computational Ceramic Surface Ornamentation. In *Proceedings of the 36th Annual ACM Symposium on User Interface Software and Technology* (San Francisco, CA, USA) *(UIST '23)*. Association for Computing Machinery, New York, NY, USA, Article 24, 15 pages. doi:10.1145/3586183.3606726

[89] Tsuen-Hsuin Tsien. 1973. Raw materials for old papermaking in China. *Journal of the American Oriental Society* (1973), 510–519.

[90] Anna Vallgårda and Johan Redström. 2007. Computational composites. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '07)*. Association for Computing Machinery, New York, NY, USA, 513522. doi:10.1145/1240624.1240706

[91] C Ververis, K Georghiou, N Christodoulakis, P Santas, and R Santas. 2004. Fiber dimensions, lignin and cellulose content of various plant materials and their suitability for paper production. *Industrial crops and products* 19, 3 (2004), 245–254.

[92] Kathrine D Vickerman. 1995. Papermaking: Then and Now. A History of Hand Papermaking from Its Beginning, Plus a Process for Using Natural Fibers To Make Paper. (1995).

[93] Alexey Vishtal and Elias Retulainen. 2014. Boosting the Extensibility Potential of Fibre Networks: A Review. *BioResources* 9, 4 (2014).

[94] Ron Wakkary. 2021. Things We Could Design. *Things We Could Design: For More Than Human-Centered Worlds* (2021).

[95] John CF Walker and John CF Walker. 2006. Pulp and paper manufacture. *Primary wood processing: principles and practice* (2006), 477–534.

[96] Guanyun Wang, Tingyu Cheng, Youngwook Do, Humphrey Yang, Ye Tao, Jianzhe Gu, Byoungkwon An, and Lining Yao. 2018. Printed Paper Actuator: A Low-cost Reversible Actuation and Sensing Method for Shape Changing Interfaces. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 112. doi:10.1145/3173574.3174143

[97] Nan Wang. 2014. A Chinese Perspective on Technological Literacy. In *New Frontiers in Technological Literacy: Breaking with the Past*. Springer, 105–119.

[98] Qi Wang, Yuan Zeng, Runhua Zhang, Nianding Ye, Linghao Zhu, Xiaohua Sun, and Teng Han. 2023. EmTex: Prototyping Textile-Based Interfaces through An Embroidered Construction Kit. In *Proceedings of the 36th Annual ACM Symposium on User Interface Software and Technology* (San Francisco, CA, USA) *(UIST '23)*. Association for Computing Machinery, New York, NY, USA, Article 20, 17 pages. doi:10.1145/3586183.3606815

[99] Ozu Washi. [n. d.]. Washi Papermaking Workshop. https://www.ozuwashi.net/en/workshop.html. Accessed: 2024-12-08.

[100] Mark Weiser. 1991. The Computer for the 21 st Century. *Scientific American* 265, 3 (1991), 94–105. http://www.jstor.org/stable/24938718

[101] Mikael Wiberg. 2014. Methodology for materiality: interaction design research through a material lens. *Personal and ubiquitous computing* 18 (2014), 625–636.

[102] Mikael Wiberg and Erica Robles. 2010. Computational compositions: Aesthetics, materials, and interaction design. *International Journal of Design* 4, 2 (2010), 65–76.

[103] Irmandy Wicaksono, Don Derek Haddad, and Joseph Paradiso. 2022. Tapis Magique: Machine-knitted Electronic Textile Carpet for Interactive Choreomusical Performance and Immersive Environments. In *Proceedings of the 14th Conference on Creativity and Cognition* (Venice, Italy) *(C&C '22)*. Association for Computing Machinery, New York, NY, USA, 262274. doi:10.1145/3527927.3531451

[104] Irmandy Wicaksono, Peter G. Hwang, Samir Droubi, Franny Xi Wu, Allison N. Serio, Wei Yan, and Joseph A. Paradiso. 2022. 3DKnITS: Three-dimensional Digital Knitting of Intelligent Textile Sensor for Activity Recognition and Biomechanical Monitoring. In *2022 44th Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC)*. 2403–2409. doi:10.1109/EMBC48229.2022.9871651

[105] Di Wu, Emily Guan, Yunjia Zhang, Hsuanju Lai, Qiuyu Lu, and Lining Yao. 2024. Waxpaper Actuator: Sequentially and Conditionally Programmable Wax Paper for Morphing Interfaces. In *Proceedings of the CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 865, 16 pages. doi:10.1145/3613904.3642373

[106] Qian Ye, Zhen Zhou Yong, Bo Han, Ching Chiuan Yen, and Clement Zheng. 2024. PaperTouch: Tangible Interfaces through Paper Craft and Touchscreen Devices. In *Proceedings of the CHI Conference on Human Factors in Computing Systems*. 1–15.

[107] Yang Zhang and Chris Harrison. 2018. Pulp Nonfiction: Low-Cost Touch Tracking for Paper. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 111. doi:10.1145/3173574.3173691

[108] Zhiqiang Zhang, Jianyong Wu, and Yuzhou Wu. 2023. Research on Application of Virtual Reality Technology in Digital Restoration of Tiangong Kaiwu. In *2023 9th International Conference on Virtual Reality (ICVR)*. IEEE, 536–541.

[109] Clement Zheng, Peter Gyory, and Ellen Yi-Luen Do. 2020. Tangible Interfaces with Printed Paper Markers. In *Proceedings of the 2020 ACM Designing Interactive Systems Conference* (Eindhoven, Netherlands) *(DIS '20)*. Association for Computing Machinery, New York, NY, USA, 909923. doi:10.1145/3357236.3395578

[110] Clement Zheng, Bo Han, Xin Liu, Laura Devendorf, Hans Tan, and Ching Chiuan Yen. 2023. Crafting Interactive Circuits on Glazed Ceramic Ware. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 474, 18 pages. doi:10.1145/3544548.3580836

[111] Clement Zheng, HyunJoo Oh, Laura Devendorf, and Ellen Yi-Luen Do. 2019. Sensing Kirigami. In *Proceedings of the 2019 on Designing Interactive Systems Conference* (San Diego, CA, USA) *(DIS '19)*. Association for Computing Machinery, New York, NY, USA, 921934. doi:10.1145/3322276.3323689

[112] Jingwen Zhu, Nadine El Nesr, Christina Simon, Nola Rettenmaier, Kaitlyn Beiler, and Cindy Hsin-Liu Kao. 2023. BioWeave: Weaving Thread-Based Sweat-Sensing On-Skin Interfaces. In *Proceedings of the 36th Annual ACM Symposium on User Interface Software and Technology* (San Francisco, CA, USA) *(UIST '23)*. Association for Computing Machinery, New York, NY, USA, Article 35, 11 pages. doi:10.1145/3586183.3606769

[113] John Zimmerman, Jodi Forlizzi, and Shelley Evenson. 2007. Research through design as a method for interaction design research in HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '07)*. Association for Computing Machinery, New York, NY, USA, 493502. doi:10.1145/1240624.1240704

[114] Amit Zoran. 2015. Hybrid craft: showcase of physical and digital integration of design and craft skills. In *ACM SIGGRAPH art gallery*. 384–398.

[115] Michael A Zustra. 1987. Evaluation of the Potential Health Hazards Associated with the Machining of Carbon Fiber Composites. (1987).

[116] 宋应星. 1637. Woodcuts depicting the five seminal steps in ancient Chinese papermaking. https://commons.wikimedia.org/wiki/File:Making_Paper_5.PNG. Accessed: 2024-12-10. Public domain image from *Tiangong Kaiwu* (1637)..

[117] 宋应星. 1637. 天工开物. http://read.nlc.cn/allSearch/searchDetail?searchType=25&showType=1&indexName=892&fid=411999010751

A Experimental Setup and Details

A.1 Fiber Ratio Preparation and Testing

To explore the impact of different fiber ratios on paper properties, we prepared batches with a total weight of 60 grams of fibers (long and short fibers combined). Each batch was mixed with 3 liters of water for screening. Three paper samples of 215mm by 155mm were made for each fiber ratio (4:1, 1:1, 1:4) and then cut into smaller pieces for subsequent analysis. The tensile strength of each fiber ratio was tested by cutting the samples into 70mm by 10mm strips, with a total of 9 samples tested per ratio using an Instron 34SC-05 machine.

A.2 GSM and Tensile Strength Testing

The GSM (grams per square meter) and tensile strength of the paper samples were evaluated based on the fiber density and pulp-to-water ratio. Four different densities were tested: 37.5g, 75g, 150g, and 200g of fiber pulp mixed with a fixed 3 liters of water. Three 215mm by 155mm samples were made for each density. The samples were then cut into 70mm by 10mm strips, with a total 12 samples per density for tensile strength testing.

A.3 Conductivity Testing

The fiber ratio was set at 1:3 (long to short fibers), with varying proportions of carbon fiber (5%, 10%, 20%, 30%, 40%, and 50%). A total of 75 grams of the pulp mixture was combined with 3 liters of water and screened to maintain a consistent GSM. Conductive paper samples of 140mm by 30mm were prepared for each carbon fiber ratio.

A.4 Environmental Testing

The color-changing paper samples were soaked in red cabbage extract for three days and then subjected to different environmental conditions during the drying process. These conditions were categorized as: Indoors: Fully shielded from sunlight, with room temperature ($25 \pm 2^\circ$ C) and moderate humidity ($50 \pm 5\%$). Partially shaded: A balcony environment with medium UV levels, higher temperatures ($30 \pm 5^\circ$ C), and lower humidity ($40 \pm 5\%$). Outdoors: Fully exposed to sunlight, with high UV levels, elevated temperatures ($40 \pm 5^\circ$ C), and low humidity ($35 \pm 5\%$). After soaking, the samples were subjected to these conditions, with all samples drying within two days. UV exposure, temperature, and humidity were monitored to assess the effect on the color-changing properties and chemical stability of the paper.

A.5 Recipes of Applications

Table 1: Table of formulations and specifications

6.1-Paper-Wall Light					
Carbon fiber(20%)	Bark Tree fiber(long)	Receipt paper(short)	Water	Watermarking Spray	Frame Size
64g	64g	192g	24L	2×	A2
6.2-Cave Art					
Carbon fiber(20%)	Bark Tree fiber(long)	Receipt paper(short)	Water	Watermarking Spray	Frame Size
	19.2g	76.8g	6L	10×	A4 Top
19.2g	28.8g	48g	6L	10×	A4 Bottom
6.3-Drawing Kit					
	Bark Tree Fiber(long)	Receipt paper(short)	Distilled Water		Frame Size
	37.5g	37.5g	1.5L Red Cabbage Extract 1.5L		A5
6.4-Trivet					
Carbon Fiber(30%)	Bark tree fiber(long)	Receipt paper(short)	Water	Watermarking Spray	Frame Size
22.5g	15g	37.5g	3L	5×	A5 Top
	32	16g	3L	10×	A5 Middle
22.5g	15g	37.5g	3L	5×	A5 Bottom