Research on the Construction of an Indoor "Reversible Decoration" System Based on Material Cycle Mapping

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ABSTRACT Efficient material traceability and lifecycle management are essential for achieving circular utilization in indoor renovation projects. This study proposes a reversible decoration framework based on a Digital Material Cycle Map (DMCM) to support the tracking, recovery, and reuse of construction materials throughout their service lifecycle. The framework integrates Digital Product Passport concepts, RFID- and QR-based identification, distributed ledger technology, and lifecycle data management to establish a unified material information architecture. A modular and detachable construction strategy is further developed using standardized interfaces and non-destructive disassembly mechanisms, enabling efficient component recovery and reuse. In addition, a material traceability workflow is introduced to support condition assessment, lifecycle auditing, and recycling decision-making based on dynamically updated records. The framework promotes information sharing among manufacturers, designers, contractors, and recycling organizations through standardized data interfaces. By combining material identification, information transmission, and lifecycle monitoring, the proposed approach provides an engineering-oriented solution for digital material governance, intelligent sensing, and distributed infrastructure management.

INDEX TERMS digital material cycle map, RFID-based tracking, information propagation, lifecycle monitoring

I. INTRODUCTION

CHINA 's interior decoration industry is currently experiencing rapid development, generating a massive amount of construction waste and discarded decorative annually, resulting in significant resource waste. The integration of circular economy principles in fiber recycling and sustainable material manu-facturing is essential to mitigate the environmental impact of these accumulating interior finishing residues. Traditional decoration methods employ irreversible construction techniques, with materials fixed to the building structure. When renovations are needed, destructive demolition is the only option, leading to a large amount of materials being unrecyclable. This extensive development model not only wastes resources but also increases the environmental burden. Under the "dual carbon" target (carbon reduction and environmental degradation), the interior decoration industry must transform and upgrade, exploring a path to sustainable development. Reversible decoration is a new concept that advocates for the disassembly, recycling, and reuse of decoration materials, including modular components and recyclable fiber structures, aligning with the requirements of a circular economy. This approach emphasizes the application of high-performance sustainable materials that can be easily recovered and repurposed to reduce waste throughout the lifecycle of interior spaces.

II. THE SIGNIFICANCE OF CONSTRUCTING AN INTERIOR "REVERSIBLE DECORATION" SYSTEM

A. RESPONDING TO THE NEEDS OF SUSTAINABLE DEVELOPMENT AND CIRCULAR ECONOMY

Reversible decoration system is an implementation of sustainable development strategy. The country has proposed to promote the comprehensive green transformation of economic and social development and establish a sound green, low-carbon and circular economic system. Interior decoration is an important part of the entire life cycle of buildings, and its resource consumption and environmental impact cannot be ignored [1]. Reversible decoration relies on the Material Cycle Map, which functions as a relational spatial-temporal graph. Unlike a standard Lifecycle Assessment (LCA) database—which typically provides linear, aggregate environmental impact data—the "Map" visualizes the specific trajectories and physical locations of materials within a circular network. It maps the "topology" of material flows, allowing stakeholders to see not just the impact, but the relational connections between production nodes, usesites, and recovery hubs [2].

B. REDUCE WASTE OF DECORATION RESOURCES AND ENVIRONMENTAL BURDEN

Traditional decoration methods cause serious waste of resources and environmental pollution. Most of the waste generated during the decoration process is treated as construction waste. Landfilling or incineration will occupy land resources and may also produce harmful substances that pollute the environment [3]. Reversible decoration system relies on creating a material cycle map to determine the environmental properties, recyclability and recycling value of various decoration materials, thereby prompting the design stage to first use renewable, degradable or high recycling value materials [4].

TABLE 1. Three Core Significances of Constructing an Indoor Reversible Decoration System

Meaning Dimension	Core content	Specific manifestations	Expected results
Sustainable Development Response	Implementing the circular economy strategy	Full lifecycle tracking and management of building materials, ensuring effective recycling and re-entry into the production cycle after the end of their usage period.	Transforming the linear economic cycle of “resource-product-waste” into a closed-loop system of “resource-product-recycled resources” reduces resource consumption at its source.
Resource and environmental protection	Reduce resource waste and environmental burden	Employing renewable, biodegradable, or high-recycling-value materials, and using removable construction techniques to maintain material integrity.	Significantly improve material recycling rates, reduce the amount of construction waste, and alleviate the dual pressures of resource shortages and environmental pollution.

C. ENHANCING THE FLEXIBILITY AND ECONOMIC EFFICIENCY OF INDOOR SPACES

Reversible decoration systems make interior spaces more adaptable and flexible. With the development of society and changes in lifestyle, the functional needs of interior spaces are constantly changing. Traditional fixed decoration can no longer meet the ever-changing usage requirements, and frequent renovations and alterations bring a great economic burden. Reversible decoration adopts a modular and standardized construction system, and decoration components can be easily disassembled, combined or replaced, so that the space function can be changed quickly and the service life of the decoration can be improved [5]. From an economic point of view, the material recycling spectrum provides the possibility for the preservation and appreciation of decoration materials. While traditional interior assets depreciate rapidly, a reversible system utilizes the Material Cycle Map to implement a “Residual Value Preservation” strategy. High-quality removable materials with verified durability data can still retain a portion of their economic value. However, this assumes that the “Avoided Disposal Cost” and “Reduced Installation Time” in subsequent cycles outweigh the labor costs of professional disassembly. By utilizing modular components, the value is recovered not merely through resale, but through the internal reuse of standardized components across a facility’s portfolio, effectively lowering the Total Cost of Ownership (TCO) over multiple renovation cycles [6].

TABLE 2. Three Core Issues in Implementing Reversible Interior Renovation

Problem Type	Main manifestations	Specific obstacles	Impact and consequences
Lack of a standard system	The material recycling standards and evaluation system are incomplete.	The lack of classification standards and evaluation indicators for material environmental properties and durability; incomplete data recording systems for material manufacturers, making it difficult to trace the flow of materials; and a lack of authoritative standards for the testing of recycled materials.	Designers and construction teams lack clear criteria for material selection, and the value of recycled materials is difficult to determine, affecting the economic feasibility of material recycling.
Insufficient application of technology	Low adoption rate of detachable interior decoration technology	Traditional wet construction methods are difficult to disassemble and easily cause material damage; the research and application of detachable connection technology is lagging behind, resulting in few market products, low standardization, and poor compatibility; design and construction require consideration of modular coordination and other requirements.	The impact on the versatility and substitutability of materials limits the practical application of the reversible renovation concept.

III. LACK OF MATERIAL RECYCLING STANDARDS AND EVALUATION SYSTEMS

A. LACK OF MATERIAL RECYCLING STANDARDS AND EVALUATION SYSTEM

At present, the lack of unified material recycling standards and scientific evaluation system in the field of interior decoration has affected the promotion and application of reversible decoration. On the one hand, there are many types of decoration materials, and the environmental properties, durability, disassembly and recyclability of different materials vary greatly. However, the industry has not yet established standards and evaluation indicators for classifying these characteristics, resulting in designers and construction parties having no clear basis for material selection [7]. On the other hand, the creation of material recycling map relies on complete data, namely, information such as carbon emissions generated during the material production process, performance degradation during the use stage, and recycling treatment methods after demolition [8]. In addition, the material life cycle traceability mechanism has not yet been established, and there is a lack of information recording system for each link from production, circulation to use and recycling. This results in the inability to effectively transmit key information such as material source, quality status, and usage history, further exacerbating the difficulty of material recycling and restricting the in-depth implementation of the reversible decoration concept in actual projects.

B. INSUFFICIENT APPLICATION OF DETACHABLE DECORATION STRUCTURE TECHNOLOGY

Demountable construction technology is an important support for realizing reversible decoration, but its application rate in interior decoration is currently low. Traditional decoration mostly adopts wet construction methods, such as cement mortar to stick tiles, gypsum board to fix ceiling keel, etc. Once these connection methods are hardened, they are difficult to disassemble, and disassembly will inevitably lead to material damage [9]. Although the concept of prefabricated decoration has become popular, the research and application of demountable connection technology is still lagging behind. However, this "lag" is not merely a lack of technology, but a structural tension between rapid material innovation and rigid industry standards. Currently, there are few demountable systems on the market, and the low level of standardization leads to poor compatibility between brands. To resolve this, the industry must move away from static, monolithic standards toward a "Dynamic Interface Standardization" model. This approach focuses on unifying the connection interfaces (the "nodes") rather than the materials themselves, allowing for continuous innovation in sustainable fibers and composites without compromising the modular integrity of the overall system [10]. At the same time, construction workers do not have enough knowledge and mastery of new demountable technologies, traditional construction habits are deeply rooted, and the initial investment cost of demountable decoration systems is relatively high, so owners and construction parties tend to choose mature traditional processes, which makes it difficult for advanced technologies to be promoted in the market. This disconnect arises because existing standards are often too rigid to accommodate the "trial and error" phase of new material development. A balanced reversible system should incorporate "Forward-Compatible Standards"—a framework that provides clear geometric and load-bearing constraints for disassembly, while leaving sufficient "performance space" for the integration of next-generation eco-friendly and recyclable polymers.

C. INADEQUATE MATERIAL RECYCLING MECHANISM

A sound material recycling mechanism is an important guarantee for the closed-loop operation of the reversible decoration system. However, the mechanism is not yet sound and there are many obstacles. The recycling channels for decoration materials are not smooth, there is a lack of professional recycling companies and recycling networks, and most decoration materials are disposed of together with construction waste after demolition, resulting in the loss of recyclable materials [11]. Secondly, there is a lack of economic incentive mechanism for material recycling. There is a fundamental economic barrier where the costs of non-destructive disassembly, sorting, and refurbishing often exceed the market price of new materials. This "Economic Deficit" is exacerbated by the hygiene requirements and aesthetic aging of textiles and leathers. Companies are currently unenthusiastic because the Current Market Value (CMV) of recycled goods does not account for the environmental externalities of new production. Therefore, the reversible model requires a transition from a "Resale Model" to a "Product-as-a-Service" (PaaS) or "Leasing Model," where the manufacturer retains ownership and manages the refurbishment at scale to achieve economies of scale. Secondly, the material reuse technology system is not sound, and there is little investment in the research and development of core technologies such as cleaning treatment, performance repair and remanufacturing processes for recycled materials [12]. Furthermore, the relevant policies and regulations are not strong enough, there is a lack of mandatory material recycling requirements and clear division of responsibilities, which leads to a lack of constraints and motivation for participation of decoration companies, material suppliers, owners and other parties in the recycling process. The entire recycling chain is in a spontaneous state and it is difficult to form a large-scale and systematic operation mode.

TABLE 3. Construction Strategy of Reversible Decoration System Based on Material Cycle Map

Strategy Direction	Core mission	Implementation path	Key technologies and tools
Material Atlas Establishment	Establish a Material Lifecycle Digital Atlas	Develop a relational database architecture containing multiple categories of decoration materials; implement a Digital Twin tracking mechanism; build a unified industry information platform.	A Decentralized Material Data Architecture; Cloud-based Relational Databases using QR codes and RFID as hardware entry points for edge-data acquisition; recording multidimensional data of materials; Automated Lifecycle Assessment (LCA) algorithms for quantifying and scoring the value of materials; and API-integrated middleware connecting the entire industry chain.
Construction System Building	Constructing a modular and detachable decoration structure system	Conduct standardized and modular design of interior decoration components; formulate modular coordination standards; develop specialized detachable connection systems; research flexible connections and quick-installation tools; and establish a technical standard system.	Dry connection technology; dedicated detachable installation frame system; compilation of technical guidelines and construction manuals; ensuring component compatibility and interchangeability.

IV. CONSTRUCTION STRATEGY OF "REVERSIBLE DECORATION" SYSTEM BASED ON MATERIAL CYCLE MAP

To more clearly present the complete path of material recycling, Figure 1 shows the entire life cycle process from material production to recycling, as well as the key management nodes and the supporting role of the data platform in each stage.

A. ESTABLISHING A MATERIAL LIFE CYCLE MAP

Establishing a systematic Material Cycle Map—functioning as a Digital Product Passport (DPP)—is the foundational software infrastructure of a reversible decoration system. First, a database system containing all categories of decoration materials should be established, including basic information on various decoration materials such as wood, metal, glass, ceramics, stone, leather, plastics, and composite materials. Detailed records should be made of the main data such as initial physical properties and aging coefficients [13]. For textile and leather materials, special attention should be paid to time-dependent degradation factors. The Material Cycle Map must include a "Performance Decay Model" that tracks UV degradation, cumulative dust permeability, and the residual efficacy of chemical treatments (such as fire retardants and anti-microbial coatings) over a 5–10 year service cycle. Second, a material flow tracking mechanism should be established, built upon a hierarchical data architecture. While QR codes and RFID tags serve as the physical identification layer, the core involves a back-end Distributed Ledger Technology (DLT) that ensures the immutability of material history. This architecture allows for the seamless tracking of the entire life cycle of decoration materials, creating a dynamic and verifiable material history archive. Third, a material recycling assessment model should be developed. This model distinguishes itself from standard LCA by providing "Dynamic Mapping," which illustrates how the material's value and physical state change as it moves through different spatial loops (e.g., from one renovation project to another), rather than merely calculating a static carbon footprint. In addition, the sharing and interconnection of material recycling map information should be promoted, and a unified Material Cycle Map Software Ecosystem should be built. This interface acts as a cross-terminal SaaS platform connecting all links in the industrial chain, such as material manufacturers, design institutions, and recycling companies, allowing for real-time data synchronization via a standardized API [14].

B. CONSTRUCTING A MODULAR AND DETACHABLE DECORATION STRUCTURE SYSTEM

Modular and detachable interior decoration construction systems are the core technology of reversible decoration. When constructing the system, the first step is to establish a dual-track standardization strategy.

This involves: 1) Rigid standardization of structural interfaces to ensure cross-brand interchangeability; and

2) Flexible performance envelopes for decorative surface materials. This ensures that as textile technology evolves (e.g., from synthetic to bio-based fibers), the physical "reversible" framework does not need to be redesigned. Dedicated detachable connection systems are developed for different decoration parts such as walls, floors, ceilings, and partitions, using dry connection processes to replace traditional wet work, such as mechanical connections like clips, bolts, magnetic closures, and mortise and tenon joints, ensuring the integrity of components after disassembly and allowing for reuse. Secondly, research efforts are intensified on detachable construction technology, focusing on the flexible connection between decoration components and building structures, rapid installation and disassembly tools, and protective packaging for components. Dedicated detachable installation frame systems are developed for soft furnishing materials such as textile wall coverings and leather upholstery, enabling non-destructive mechanical disassembly. However, "reuse" is not guaranteed by disassembly alone; it is contingent upon a "Post-Disassembly Vitality Audit." This audit evaluates whether the material has suffered irreversible physical embrittlement or loss of safety-critical properties (e.g., fire resistance) during its previous occupation phase. Another point is to establish a technical standard system for detachable decoration structures, specify the requirements for design depth, construction process, quality acceptance standards, etc., and compile technical guidelines and construction manuals for detachable decoration to provide specific guidance for design and construction [15].

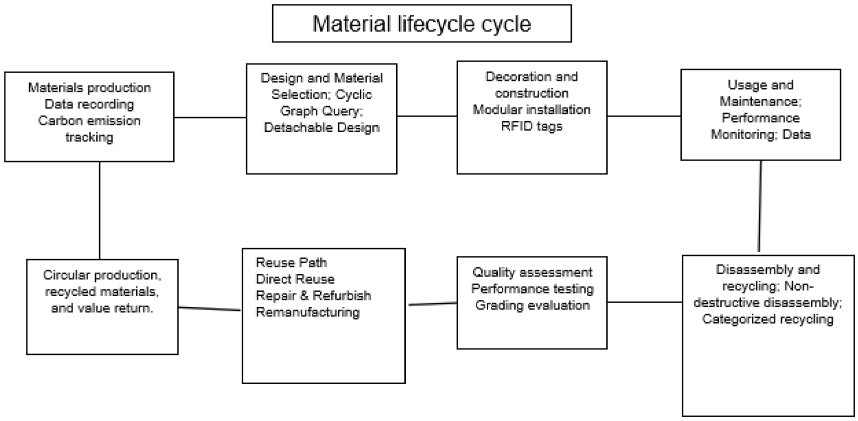

FIGURE 1. Material lifecycle flow chart

C. IMPROVE THE MANAGEMENT MECHANISM FOR MATERIAL RECYCLING AND REUSE

A sound management system for material recycling and reuse is the institutional guarantee for the effective operation of a reversible decoration system. From a mechanism construction perspective, firstly, an extended producer responsibility system should be established, making decoration material manufacturers responsible for the recycling and disposal of their products after disposal. Companies should be encouraged to establish their own recycling channels or entrust professional recycling agencies, forming a "whoever produces, recycles" responsibility system. Secondly, a professional decoration material recycling industry should be cultivated, supporting the establishment of regional decoration material recycling centers equipped with professional sorting, cleaning, testing, and storage facilities. Recycled materials should undergo a rigorous "Depreciation vs. Recovery" audit. A graded utilization system must be established based on empirical performance data stored in the Material Cycle Map. This system determines treatment paths—such as direct reuse, remanufacturing, or downcycling into industrial insulation—specifically when the cost of aesthetic refurbishment for interior use is no longer economically viable. Specialized cleaning technologies for textiles must be automated to reduce the high labor costs associated with traditional manual restoration. If a material fails to meet indoor air quality or fire safety standards after cleaning due to inherent fiber degradation, it must be diverted from "Direct Reuse" to "Industrial Downcycling" (e.g., as acoustic insulation or structural filler), ensuring that material circulation does not compromise user safety. Thirdly, economic incentive policies should be improved, providing tax breaks or subsidies for decoration projects using recycled materials, offering policy preferences to companies participating in material recycling, and establishing a decoration material deposit system to guide material recycling through economic levers. Modular and detachable construction systems are multi-layered and multi-dimensional technical systems. Figure 2 shows the overall architecture of the system, which includes three core pillars: standardized design, detachable connection technology, and technical standards and specifications, as well as specific application systems and implementation guarantee mechanisms for walls, floors, and ceilings.

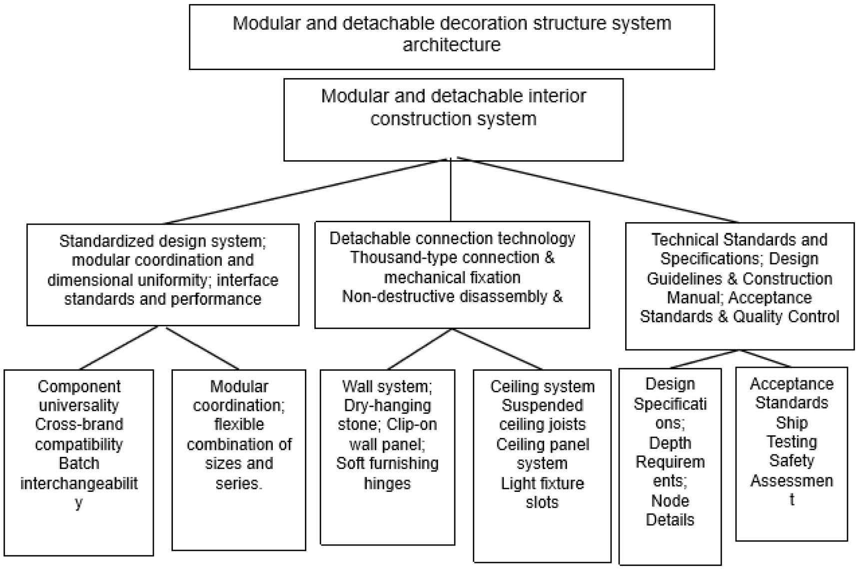

FIGURE 2. Modular and detachable decoration structure system architecture

V. CONCLUSION

The construction of a reversible interior decoration system based on a material cycle map, incorporating recyclable fibers and modular fabric structures, represents an innovative practice for the green transformation of the decoration and industries. This integrated approach ensures the systematic recovery of decorative materials, facilitating a closed-loop circulation that advances sustainable industrial development. Establishing a material lifecycle cycle map, creating a modular and detachable decoration structure system, and improving the material recycling and reuse management mechanism can effectively solve the problems of resource waste and environmental pollution caused by traditional decoration models, achieving the goal of efficient recycling of decoration materials. The promotion of this system relies on the efforts of governments, enterprises, design institutions, and research institutes, strengthening technological innovation, standard setting, policy guidance, and market cultivation to gradually form an industrial ecosystem for reversible decoration. In the future, we should strengthen theoretical research and practical exploration to perfect the reversible decoration technology system through the integration of recyclable fibers and sustainable fabric structures, contributing to a resource-saving society. This cross-industry synergy will promote the high-quality development of the interior decoration by advancing the appli-cation of ecofriendly materials within circular economy frameworks.

AUTHOR CONTRIBUTIONS

Rui Wang designed, collected and analyzed the data, and drafted the manuscript. Rui Wang conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Rui Wang participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

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