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SUSTAINABLE INTERIOR MATERIALS: A REVIEW OF ECO-FRIENDLY INNOVATIONS AND CIRCULAR DESIGN

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Abstract

The rising environmental impacts tied to the construction and building sectors have kind of pushed the need for more sustainable routes in interior design, especially when it comes to choosing and handling interior materials. This review, looks at what's been happening lately with sustainable interior materials, with an emphasis on ecofriendly innovations and circular design strategies that can boost resource efficiency and environmental sustainability. To start, the review outlines the basic ideas behind sustainable interior materials, by separating green materials from sustainable ones and then laying out the core sustainability principles in interior design. After that it sorts the main kinds of materials, like renewable natural materials, recycled and reclaimed materials, plus bio based and biodegradable options. Then the review checks out newer material innovations such as advanced bio composites, phase change materials, and AI assisted material selection, showing how these could raise environmental results while also supporting occupant comfort and well being. In addition, circular design strategies are reviewed too, including design for disassembly, modular interior systems, material re-use, product life extension, and digital tracking of materials. These are treated as workable ways to keep materials in use longer and to lessen waste, across the whole life cycle. Finally, the review points to current obstacles and research gaps, related to things like material performance, standardization, digital integration, and how to actually apply circularity in real projects. Overall, the findings pull together today's knowledge in a way that is fairly complete, and they should give useful guidance for researchers' designers, and people in industry who want to move sustainable and circular interior architecture forward, even when the path is a bit complicated.

Keywords: Sustainable interior materials; Eco-friendly materials; Circular design; Interior architecture; Sustainable building materials.

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المواد المستدامة في التصميم الداخلي: مراجعة للابتكارات الصديقة للبيئة والتصميم الدائري

نافع حمد

الملخص

أدت الآثار البيئية لقطاعي البناء والتشييد إلى تزايد الحاجة إلى تبنّي أساليب مستدامة في التصميم الداخلي، ولا سيما في اختيار المواد وإدارتها. تستعرض هذه الدراسة المواد المستدامة المستخدمة في التصميم الداخلي، مع التركيز على الابتكارات الصديقة للبيئة واستراتيجيات التصميم الدائري التي تدعم كفاءة استخدام الموارد والاستدامة البيئية. وتبدأ بوضع إطار مفاهيمي يميّز بين المواد الخضراء والمواد المستدامة، ويوضح المبادئ الأساسية للاستدامة في التصميم الداخلي. ثم تتناول الفئات الرئيسة لهذه المواد، بما فيها المواد الطبيعية المتجددة، والمواد المعاد تدويرها والمسترجعة، والبدائل ذات الأساس الحيوي والقابلة للتحلل الحيوي. كما تستعرض الابتكارات الناشئة، مثل المركّبات الحيوية المتقدمة، ومواد تغيير الطور، واختيار المواد بمساعدة الذكاء الاصطناعي، من حيث إمكاناتها في تحسين الأداء البيئي ودعم راحة شاغلي المباني ورفاههم. وتناقش الدراسة أيضًا استراتيجيات التصميم الدائري، بما يشمل التصميم القابل للتفكيك، والأنظمة الداخلية المعيارية، وإعادة استخدام المواد، وإطالة العمر التشغيلي للمنتجات، والتتبّع الرقمي للمواد. وتتيح هذه الاستراتيجيات فرصًا للحفاظ على قيمة المواد، وإطالة مدة استخدامها، وتقليل النفايات طوال دورة حياتها. وتتمثل أبرز التحديات والفجوات البحثية في أداء المواد، وتوحيد المعايير، والتكامل الرقمي، والتطبيق العملي للتصميم الدائري في مشروعات التصميم الداخلي. ومن خلال الربط بين هذه المحاور، تقدم الدراسة إطارًا لفهم إسهام الابتكار في المواد والتصميم الدائري في تحقيق عمارة داخلية أكثر استدامة، وتحدد أولويات البحث والتطبيق مستقبلًا.

الكلمات المفتاحية :المواد المستدامة في التصميم الداخلي؛ المواد الصديقة للبيئة؛ التصميم الدائري؛ العمارة الداخلية؛ الابتكار في المواد.

Introduction

The construction sector is one of the major contributors to the depletion of natural resources, the emission of greenhouse gases, and solid waste generation, making sustainability a central part of modern architectural and interior design practice. Attention has traditionally been focused significantly on making the structural optimization of surface areas and structures efficient in enhancing environmental performance. In recent times, however, interior spaces have emerged as places of significance because of the materials used, frequency of renovation cycles, and the direct impact they have on the health and well-being of their occupants. Interior materials according to the typical practices usually have high embodied energy, toxic emissions, and low recyclabilitybilaties, causing enormous environmental and human health risks through their complete life cycle. Designers, researchers, and manufacturers are searching for alternatives for materials that can reduce the environmental impacts and still maintain functionality, durability, and appearance (Khoshnava et al., 2020; Varnam & Kodali, 2024).

In addressing such issues, one of the crucial parts of green design elements involves the sustainable interior materials for green indoor habitats. These products include renewable natural resources, recycled and reclaimed products that can be used in innovative bio-based alternatives which - among basic environmental conservation capacity in carbon emissions-reduction-also significantly saves natural resources and secures indoor environmental quality. The rapid evolution of technology witnessed the development of advanced eco-friendly materials, such as agricultural wastes composites, engineered wood products, natural acoustic panels, and materials based on phase change with contributions to sustainability and building performance. All these can demonstrate that sustainability can be accomplished without dwelling design flexibility, revolutionizing the occupants' comfort or practical requirements needed; it promotes transformation toward broad green and resilient built environment (Darwish & Midani, 2023; Ghamari et al., 2024; Abera, 2024).

This is due to how design should be coupled with material innovation but since the concept of circular design is now a widely discussed model of expanding the material life cycle and reducing waste production. Circular design does not follow the traditional linear model in which the material is processed, used, then disposed of; instead, it promotes such conservation strategies as the recycling of materials, modular construction, design for disassembly, and prolonging product life. Therefore, material as much as possible would retain the value of the recycling. These design approaches are already having effect in the arena of sustainable architecture, but most textbooks have tended to examine individually the materials environmentalists argue should be used and the strategies of circular design without considering their integrated assimilation into the field of interior design practice. Besides all this, rapid advancement in digital technology and intelligent managing systems of materials will further open up improved possibilities towards

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material traceability, resource efficiency and life cycle optimization. However, these developments have remained unfocused in recent reviews (Rupasinghe, 2024; Almaz et al., 2024; Sahlol et al., 2021).

This review critically addresses the gaps in the modern sustainable interior materials and recent eco-friendly innovation, formulated in light of circular design. Principally, the review is based on the discussion of the basic concepts in the use of sustainable interior materials and major types of environmentally responsible materials, besides evaluating recent technological innovations and analyzing the circular design strategies pertinent to instil space architecture. It assesses recent technological innovations and circular design strategies relevant to space architecture. The paper also elaborates on the current challenges and future research directions. This review entwines materials science with the principles of sustainable design and the economy of circularity into one discussion, thus providing a broad perspective on the development and an outlook into the future from the point of today for researchers, designers, and practitioners in the industry.

Conceptual Foundations of Sustainable Interior Materials

Sustainability principles in interior design

Sustainability refers to the idea of building ecological, material, and social criteria in every phase of the planning, design, construction, operation, and maintenance of the built environment. One of the major differences between traditional ways of designing and designing in a sustainable environment lies in that whereas the first two accentuate additional beauty, functionality, and space, the last seeks to curtail environmental damage by benefiting human health, comfort, and quality of life. In the broader sense, this viewpoint emphasizes the entire life cycle of materials and products, linking resource extraction and manufacturing to their reincorporation into products or terminated disposal. By these means, long-term environmental responsibility is fostered (Alfuraty, 2020).

One leading principle to establish sustainable interior design is the principle of efficiency in resources: minimizing raw material, energy, and water consumption while not renouncing the productivity of the design itself. It encourages designers to prioritize the use of renewable resources, recycled products, and locally available products so as to reduce the carbon present in embodied-and also transportation-related emissions. Life cycle thinking catapults this effort through the simple method of undertaking before taking a closer look at doing, evaluating the environmental impacts throughout their lifetime of various materials to support smarter, vaster, and wiser material selection (Sahlol et al., 2021).

Another principle is personal comfort within indoor spaces that come from the choice of construction materials which emit fewer pollutants and improve the quality of indoor air. Natural materials including wood and bamboo, when incorporated with an appropriate

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mix of low-emission coatings and finishes, reduce occupant exposure to volatile organic compounds while providing warmth and visual comfort. Therefore, this view that durability goes beyond nature protection toward human well-being and occupant satisfaction is the main aim of contemporary interior design. (Alapieti et al.., 2020).

Sustainability and adaptability are the two characteristics with growing significance in the interior design process. This involves a "long-life" approach and flexibility, apart from an internal reduction of the specific or construction materials used. The strategies include all the ideas of responsibility that require all these terms (maintenance, repair, replacement, and future reuse) into the building of interiors that will change over time to cater to altered change demands and the like. The designs make it feasible for today and into the future to reuse resources, maintaining the flow closed within the scope. Thus, more comprehensive sustainable development aims are assured, as defined by Varnam and Kodali (2024).

Green materials versus sustainable materials

In the scientific literature, the concept of green materials and sustainable materials tends to be synonymous; however, both terms point to different connotative meanings with different areas of evaluation. Green materials refer to those products that tend to have lower environmental costs in production or use due to lesser hazardous characteristics, as well as recycle, reuse, or products that save energy for manufacturing processes. Generally, green materials can be considered such products as to elicit low environmental impact from/to all specific environmental aspects, such as cutting down emissions, making energy efficiency, or not containing certain substances proven hazardous (Tian, et al., 2018).

In opposite to traditional materials, sustainable materials expand to an environmental, economic, and social point of view, called the life cycle point of view. Besides the minimization of environmental impacts, sustainable materials are actually expected to have responsible sourcing, durability, efficient use of resources, and should facilitate reuse or recycle at the end of its service life. The comprehensive evaluation has been considered that materials cannot just be sustainable in the terms of one sole environmental attribute but on their overall life cycle bottlenecks, making an impact all the way into the future (Khoshnava et al., 2020).

This also applies to interior design, where the materials directly impact indoor environment quality, environmental degradation, and long-term performance. Thus, a material may be termed green just because it contains an element of recycling or some material properties including low volatile organic compounds. Yet, such material could turn out to be short in service life or less recyclable. On the other hand, sustainable sources of raw wood or bamboo for example reify an almost unruly political ecology of renewable resource management, long-term durability, and high ecological potential performance-recycling. As such, it is closely aligned with more general political goals like sustainable

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development being made sustainable by including a focus on long-term functionality and circular performance in material selection (Yadav & Mathur, 2021).

There is a necessity now to consider materials with respect to the integrated dimensions as leant towards evaluation encouraged by sustainable standards instead of counting on their green product labels only. This will facilitate a better evidence-strengthened decision regarding alternative materials. Sustainable materials are to include a regrouping and cogent categorization into three aspects, namely life cycle assessment, certification systems, and circular economy principles-certainly more encompassing ways to compare material alternatives, and enable designing with facts. This is because there are primarily three options thoroughgoing green and sustainable materials from which interior designers can select finally materials that, in addition to reducing environmental effect, also hedge on resource use, achieve high indoor quality, and ensure sustainability over the long term (Abera, 2024).

Table 1. Comparison between Green Materials and Sustainable Materials

Criterion	Green Materials	Sustainable Materials
Primary objective	Reduce specific environmental impacts	Achieve environmental, economic, and social sustainability throughout the life cycle
Evaluation focus	Individual environmental attributes (e.g., low VOCs, recycled content)	Full life-cycle performance and long-term sustainability
Resource management	May not consider resource renewability	Emphasizes renewable and responsibly managed resources
Durability	Not always a primary consideration	Long service life is a key criterion
End-of-life	May have limited consideration for reuse or recycling	Designed to support reuse, recycling, or circular resource flows
Typical examples	Low-VOC paints, recycled-content products	FSC-certified wood, bamboo, bio-based composites, reclaimed materials

Classification of Sustainable Interior Materials

Renewable natural materials

Natural regenerated resources are indeed one of those most imported kinds of sustainable interior materials as they are resources that can be regenerated in relatively short periods. Renewable materials typically require lower energy during production than do conventional synthetic materials, emit fewer greenhouse gases and promote the

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sustainable utilization of resources. Consequently, their applications in the interior design business have increased so that now minimizing environmental impacts is just as much a priority as maintaining functional and aesthetic performance (Widayat & Studyanto, 2021). Bamboo crop has received a lot of attention for renewable materials with very high mechanical strength. These bamboo materials can be installed as simple flooring, wall panels and ceilings into various types of furniture elements and decorative elements. Highly durable, bamboo has an impressively lower environmental footprint than so many traditional building materials. As a fast greenhouse grower, bamboo can be replanted continuously and harvested with little or no long-term use of all natural resources, making it one of the most sustainable alternatives for interior design today (Yadav & Mathur, 2021).

Wood is one amongst the most widely used renewable materials. It can be sourced from sustainably managed forests although it can be used for structural and aesthetic purposes, wood serves to make the indoors a few notches more comfortable by regulating humidity and creating a visually pleasing space. There is evidence proving that wooden interior surfaces make the occupants comfortable and enjoy a better well-being. Wooden interior surfaces are seen as playing a further role in sustainable interior environments in the fact that they would positively affect the occupant comfort and overall well-being (Alapieti et al., 2020).

Materials like cork, wool, and other types of natural fibers aside from bamboo and wood are currently being incorporated into the finishes of interior structures and furnishings because of their biodegradability, ability to insulate, and low environmental impact. Selecting these certified and responsibly managed materials also strengthens the sustainability performance of these materials as it safeguards the resource conservation and long-term ecological balance. Table 2 shows the primary renewable natural materials: characteristics, sustainability advancements, and interior applications in common, for key use.

Table 2. Renewable Natural Materials Used in Sustainable Interior Design

Material	Main Characteristics	Sustainability Advantages	Typical Interior Applications
Bamboo	Rapid growth, high strength, lightweight	Highly renewable, low embodied carbon	Flooring, wall panels, furniture, ceilings
Wood (certified)	Durable, aesthetic, humidity regulation	Renewable when sustainably managed, recyclable	Flooring, wall cladding, cabinetry, furniture

Cork	Lightweight, elastic, sound-absorbing	Harvested without tree removal, biodegradable	Flooring, wall coverings, insulation panels
Natural fibers (e.g., jute, sisal)	Flexible, biodegradable, renewable	Low energy production, recyclable	Carpets, textiles, decorative panels
Wool	Thermal and acoustic insulation	Renewable, biodegradable, non-toxic	Upholstery, rugs, acoustic insulation

Recycled and reclaimed materials

Recycled and recovered materials make up a great part of sustainable interior design; they decrease the demand for virgin materials and keep that garbage out of the landfill. Unlike newly manufactured materials that undergo an industrial process, recycled materials are formed by collecting waste and reprocessing it into a new product, whereas reclaimed materials are usually recovered and reused with just minor reprocessing. Both mean minimizing waste and, therefore, have an energy-saving effect. At the same time, materials go a long way towards fostering principles of the circular economy in broader usage (Rupasinghe, 2024).

Among the recycled materials mostly used are the recycled wood, glass, and metals besides the plastics. Wood mostly used for floors, furniture, and wall finishes. It retains the aesthetic qualities of wood and prevents deforestation. Recycled glass can be used to make decorative panels, countertops, and tiles and can be useable while producing far less energy than new glass. Recycled metals like aluminum and steel retain structural properties even after multiple cycles of recycling and possess great value for framing furniture, partitions and decorative components (Abera, 2024).

Hardly any energy is consumed in assembling such items as against contributions from reclaimed sources. After all, recycled bricks and lumber would always tend to conserve and release such long saved energy-the whole energy was used during the first manufacture, while little in building and demolition. To such environmental advantages, reclaimed materials often present unique textures, historical character and a visually inspiring quality that could improve the visual look of the indoor space. Their progressively increasing use reaffirms that it is possible to merge sustainable builds with great design quality and cultural capital (Moubarak & Qassem, 2018).

Material selection for recycled and salvaged materials should take into consideration various factors like structural strength, durability, maintenance requirements, and being indoor environmental standard-compatible. A well-done assessment assures that these materials will give good long-term performance, while supporting the objectives in environmental considerations. Table 3 presents the main categories of recycled and

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reclaimed materials together with their sustainability benefits and common interior applications.

Table 3. Recycled and Reclaimed Materials for Interior Design

Material	Source	Sustainability Benefits	Typical Interior Applications
Recycled wood	Processed wood waste	Reduces deforestation and material waste	Flooring, furniture, wall panels
Reclaimed timber	Salvaged buildings and structures	Preserves embodied energy, minimizes waste	Furniture, beams, decorative walls
Recycled glass	Glass bottles and industrial waste	Reduces raw material extraction and energy use	Countertops, tiles, decorative panels
Recycled metals	Aluminum and steel scrap	Highly recyclable with long service life	Furniture frames, partitions, fixtures
Recycled plastics	Plastic waste	Diverts waste from landfills and oceans	Decorative panels, furniture, wall cladding
Reclaimed bricks	Demolished buildings	Extends material life and reduces construction waste	Feature walls, decorative finishes

Bio-based and biodegradable materials

There has emerged a novel promise in utilizing bio-based and biodegradable materials as a substitute for conventional interior materials in the fact that these materials are from sustainable, renewable resources and biodegrade naturally at the end of service life. These reduce the dependence on fossil-based products enabling lowercarbon emission and efficiency utilization of resources, an added advantage over the non-renewable counterparts. This development is consistent with the evident emphasis of the present trend in areas of market replacing energy/material-intensive materials with ethically sustainable solutions more profoundly aligned with sustainable production and a circular economy concept (Abera, 2024).

It has been observed in recent times that agricultural residues and natural fibers have the ability to yield high-quality interior materials. Such composite materials have been made of rice husk, wheat husk, wood fibers, and textile waste and have been beneficially employed in providing effective thermal insulation by not only reducing the losses of agricultural and industrial waste but also because resource utility has been found to happen. Such materials suit a variety of interior applications as they improve resource utilization much more, while providing competitive mechanical and thermal properties (Muthuraj et al., 2019).

Much more important is that by-products of agricultural waste could be used in the manufacture of functional indoor components. They are already used in date-palm midribs for the production of ecological acoustic panels that show good sound insulation

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performance at the same time that their effect on the environment is reduced. This particular step, as shown by Darwish and Midani (2023), can be further explained with locally available renewable biomass resources that can be eventually used in new functional interior products so that their consideration as the best practices in most regions, where agricultural waste is plentiful, could prevail.

The increasing interest in bio-based materials induces motives for welfare to evolve innovative interventions such as mycelium composites, various algae-based products, and other bio-degradable materials complementing the alternative of traditional plastics and artificial composites in interior space. However, many materials are still under development, but they have a major testament to sustain design flexibility and product performance while improving sustainability. Table 4 will be a summarized overview of all main bio-based and biodegradable materials with its characteristics and interior applications typically.

Table 4. Bio-based and Biodegradable Materials Used in Interior Design

Material	Biological Source	Key Sustainability Benefits	Typical Interior Applications
Rice husk composites	Agricultural residue	Waste utilization, thermal insulation, biodegradable	Insulation panels, wall systems
Wheat husk composites	Agricultural residue	Renewable resource, low environmental impact	Interior insulation, composite boards
Wood fiber composites	Wood processing residues	Renewable, recyclable, lightweight	Decorative panels, insulation
Date palm fiber panels	Date palm midribs	Agricultural waste valorization, acoustic performance	Acoustic panels, wall coverings
Mycelium composites	Fungal mycelium	Biodegradable, low embodied carbon	Decorative panels, furniture, insulation
Algae-based materials	Algae biomass	Renewable, biodegradable, carbon sequestration potential	Surface finishes, decorative products

Recent Innovations in Eco-Friendly Interior Materials

Today, technology has increased greatly that it has widened and enhanced platforms for the use of those processes using all these types of things. It enables designers to imbue to environmental responsibility with the new function as well as with the aesthetic additionally. What has changed within the area of materials over the most recent advancements is the culmination of these as everything that impacts the environment.

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Recent inventions do not only serve to lessen the impact caused by the material but also pertain to an enhancement in energy efficiency, indoor environmental quality (IEQ), and durability. This shifts also indicate the shift taking place from antediluvian material substitutions toward the development of new focus on high-performance materials, which actively enhance the sustainability of the building (Varnam & Kodali, 2024).

We seldom think what has allowed major progress in the recent renewable energy sector, but surely phase-change materials (PCMs) are among them. They showcase the augmented thermal performance needed to absorb, store and discharge energy as per internal temperature shifts. Implementing them in any construction of wall panels, ceilings, or any other interior element induces a comfortable indoor environment that saves much energy by greater heating and cooling energy demands. This represents one of the passive measures that can be adopted to enhance a structure's energy efficiency without the involvement of other forms of mechanical systems (Ghamari et al., 2020).

Another significant field of development is bio-composites that provide advanced bio-composites manufactured from renewable raw materials and agricultural waste. Biological composites have been prepared with natural fibers, rice husk, textile waste, and wood residues, all of which have been observed to have higher insulation properties, have low embodied carbon, and improve the environmental performance compared to many conventional synthetic material. The development of engineered wood and composite materials has seen major progress since the introduction of the process of modification (Sandberg et al., 2021).

Material innovations are now highly influenced by digital technologies, considering the fact that these technologies can make the task of choosing the material far more effective and assess its sustainability. Rather, Artificial Intelligence can quantify each of those materials in terms of parameters related to performance, functionality, and design requirements which can indeed serve as evidence for the decision making based on early interior design stages. This development in technologies is expected to enhance the material market and demand for eco-friendlier resources across the entire building sector (Almaz et al., 2024). In table 5 are summarized not less than three recent innovations in eco-friendly interior materials slated to drive sustainable interior design.

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Table 5. Recent Innovations in Eco-Friendly Interior Materials

Innovation	Main Characteristics	Sustainability Contribution	Interior Applications
Phase Change Materials (PCMs)	Thermal energy storage and release	Reduces heating and cooling energy demand	Wall panels, ceilings, partitions
Advanced bio-composites	Manufactured from agricultural waste and natural fibers	Lower embodied carbon and waste utilization	Furniture, decorative panels, insulation
Modified wood technologies	Enhanced durability and moisture resistance	Extends service life of renewable materials	Flooring, wall cladding, cabinetry
Natural acoustic panels	Produced from renewable agricultural by-products	Improves indoor acoustics with low environmental impact	Offices, schools, residential interiors
AI-assisted material selection	Data-driven evaluation of material performance	Supports optimized sustainable material decisions	Interior design planning and material specification

Circular Design Strategies in Interior Architecture

Design for disassembly

Design for disassembly (DfD) actually does the circular interior design strategy designed to facilitate separating, repairing, replacing, and recovering of different kinds of building components and interior elements at the end of their service lives. Nowadays, typical construction types require permanent, glue-based or irreversible connections for building. DfD instead promotes modular assembly and mechanical fastening systems that favor effective material recovery and lessened demotion waste (Rupasinghe 2024). This results in an extension of the life of materials and supports the management of several reuse cycles. Throughout, there is a significant minimization of virgin resource demand and a decrease in environmental impact associated with interior renovations.

In interior design, partitions are proposed for disassembly, particularly in relation to suspended ceilings, flooring panels, cabinetry, and furniture. The components are removed and replaced with minimal damage to adjacent materials, allowing individual components to be fixed or replaced and avoiding the disposal of such entire systems. Such flexibility finds greater relevance in commercial buildings, usually in office use or educational facilities, where needs continually change over time. This makes adapting inside spaces an equally economic and environmentally sustainable component: through

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reduction on material consumption throughout the operational life of the building (Varnam & Kodali, 2024).

DfD process is successful when care is used in material selection and detailed planning at the design stage. Design should consider the union of parts, the compatibility of materials, service accessibility of maintenance, and post-removal possible uses on equipment in the interior. It develops towards a general involvement of these considerations subsisting within the design process, thereby supporting further upstream resource loops and longer sustainability of interiors in building facilities. Since principles of a circular economy captivate the construction sector, the embedding of design-to-disassemble principles is seen within the normative practices in attaining more adjustable, resource-efficient, and ecofriendly interior environments (Sahlol et al., 2021).

Modular interior systems

Modular interior systems are an operative and eco-friendly circular design strategy by which interior spaces become accommodating of changing functional requirements without vast demolition or material replacement. The modular systems are based on standardized and exchangeable components, so the interior elements such as partitions, furniture, storage unit, and ceiling systems are easy to assemble, disassemble, or reconfigure with minimal material wasted (Varnam & Kodali, 2024). In this manner, such materials become a more long-lasting part of the interior system while fewer environmental impacts emerge following periodic renovations.

Indeed, the eminence of a modular system leans heavily on the smart utilization of resources and efficiency in waste elimination which can be achieved through modular systems. It would permit the individual elements to be exchanged or upgraded at any given time while the removal of the complete inner unit was eliminated only for one part that has fulfilled its useful life. For example, a modular system supports offsite manufacturing, and with this advantage, better production efficiency is guaranteed, which saves the construction waste as well as enhances the quality control when weighed beside the conventional onsite periods. It means that, in the end, the overall amount of raw material consumed is lower, i.e., the building lifecycle has been maintained more sustainably (Sahlol et al., 2021).

Indeed, as opposed to its environmental superiority, modular interior systems are more economically and operationally effective by minimizing costs of maintenance and enhancing design flexibility. With the help of these systems, interior spaces quickly serve the latest technology set-ups, organizationally different demands, or evolving user requirements while keeping well away from major alteration. Concerning adaptability to sustainable designs increasing, sustainable design in interior design should in reality possess long-range resource efficient components-the more those sustainable design aspects are featured in the new modular systems associated with any building: Residential, commercial, and institutional for example (Divol, 2019).

Material reuse and upcycling

Material reuse and upcycling are fundamental methods in circular interior design, increasing the life of the materials available and thereby decreasing new material requirements. Material reuse goes on when applied or constituent products are placed back to new indoor projects with minimal modifications, and upcycling is done in the addition of value or functionality to discarded products through re-creation. Both methods regard lessening construction waste, preserving embodied energy, and encouraging resource-friendly implementation in buildings (Rupasinghe, 2024).

Through its gradually increasing application in furniture, decorative elements, wall finishes, flooring, and lighting fixtures, interior architecture applies reused and upcycled materials today. Generally, reclaimed wood, recycled glass, metal parts, and upcycled textiles appear as common materials in integration in contemporary interior spaces, bringing cumulative aesthetic value and minimalistic and environmental benefits. This gives raw and wonderful textures through historical character, which are difficult to achieve in newly manufactured products. Consequently, reuse and upcycling strategies have value in filling gaps in environmental responsibility and creative design expression (Moubarak &Qassem, 2018).

The successful implementation of material reuse and upcycling requires thorough assessment on material quality, durability, and safety to guarantee long-term performance. Assessment on structural integrity, maintenance requirement, and compatibility with new interior applications prior to incorporating reclaimed materials should also be made by designers. Therefore, through good planning and quality control, such strategies shall considerably reduce waste, and conserve resources as well as make the broader transition to the circular economy facilitated in interior designs (Abera, 2024).

Product life extension

By the preservation approach or one of progressive circularity's principles where the built space embodies product characteristics, we have product life extension, which keeps things in use for as long as possible with maintenance, repair, refurbishment, and upgrade of materials, furniture, and interior elements. This approach supplants the idea of replacing items when they break or become functionally obsolete, and takes steps to preserve the maintenance and aesthetic value of the product. Extending the life span reduces the use of materials, decreases generation of waste, and decreases environmental impacts that come from manufacturing and transportation of new products (Varnam & Kodali, 2024).

As far as interior architecture is concerned, product life extension can be accomplished by building compartments of durable material so as to be highly resistant to long-term use while also being easy to repair or replace. High-quality wood articles, modular furniture, and removable surface layers can replace partially damaged components without throwing away the whole product. Routine care and refurbishing further increase

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the durability of interior elements, making their longevity that much longer and evolutionarily decreasing new material production. The practices stated above are meant to be more efficient in the utilization of resources through all the cycles of building's life. (Sandberg et al., 2021).

The efficiency of product lifespan improvement could be enhanced, depending on how removal and maintaining issues are incorporated from the very early design phase. Thus, the designers while specifying interior products need to consider nothing but the quality of materials, ease of repair, availability of the replacement components as well as future adaptability. They should highly prioritize those projects mincing interior products that are faster in life and repair, plus they can achieve long-term productivity and sustainability as well as support broad-based objectives for the recycling of resources (Sahlol et al., 2021).

Material passports and digital tracking

One of us mentioned emerging tools to enable the integration of circular economy principles within the design of indoor spaces with full transparency and traceability features: material passports and digital tracking technology. Particularly, a material passport is marked as a digital record with in-depth details about materials itself, as well as the origin, technicalities, maintenance demands, and reusability or recycling potential of a particular product. Thus, all of this information allows designers, contractors, and even building owners an informed choice throughout the life cycle of these materials that permit optimum resource savings and, consequently, material wastage savings as well (Singh & Borah, 2020).

Digital systems for tracking are additional; Building Information Modeling (BIM), radio-frequency identification (RFID), and Quick Response (QR) codes are further tools in material management. Access to product information is available all the time, greatly enhancing material management. This direct documentation of interiors may well assist in planning component replacement as it can indicate where items are located and the condition they are in afterward. This in turn means the value of materials will be more easily reused into new projects instead of being discarded, thus maintaining higher levels of resource efficiency and circularity as outlined in Almaz et al. (2024).

Embedding the data needed for material passports also strengthens sustainability calculability and lasting building overseeing through digital technologies. Thus, for reliable material data, stakeholders can expressly look at the overall environmental aspect, predict the future remaining life, and notice time-related refurbishment or even reuse opportunities before ceiling replacement becomes necessary. This breakthrough in the technological infrastructure is still faced by major hurdles in both technologically and administratively informed societies that are part of the intelligent resource-efficient and circular interior environments beneficial in line with the future sustainable design practices (Sahlol et al, 2021).

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Challenges and Research Gaps

Still, despite advances in the development of sustainable interior materials, there are significant impediments to their adoption by the construction or interior design industry. One of the major difficulties that have to be declared by the opponents of green building materials and advanced manufacturing technologies is that some eco-friendly materials are reportedly more expensive at their initial stages. Despite providing long-term cost and environmental advantages due to enhanced durability and decreases in maintenance requirements, the higher capital required for investing in such materials initially may sway clients and developers from going towards this sustainable alternative, particularly for a cost-sensitive project (Abera, 2024).

Moreover, there are various technical challenges posed by the use of emerging sustainable materials, and these are regarding the technical performance and long-term reliability. Although bio-based and recycled materials indeed have shown promising environmental characteristics, additional research is required in relation to this aspect to evaluate their durability against moisture, fire performance, and aging behavior in different environmental conditions. Moreover, the absence of standardized evaluation techniques makes it problematic to compare the material alternatives and make someone expect their longevity within the indoor environment (Khoshnava et al. 2020).

Although digital technologies such as Building Information Modeling (BIM), artificial intelligence, and material passports have the ability to revolutionize life-cycle management, the integration of such technologies into the practice of interior design in everyday situations remains generally marginal. One thus calls for enhanced interdisciplinary collaboration and the digital integration of material recovery and circular resource management (Almaz et al., 2024). Within a circular design paradigm, the practical realization is hamstrung by restricted material traceability and deficient recirculation infrastructure, along with unequal collaboration between designers, manufacturers, contractors, and facility managers.

The importance of the current research still leaves many research gaps that have to be pursued further. Most of the previous works were focused on environmental performance research based largely on individual materials, while none has tested the linked environmental, economic, and social sustainable performance at the interior spaces. Also, few studies have taken this problem empirically to be acceptance of users to innovate with new bio-based materials, long-term performance of the circular interior system, and practical applications of digital technologies in material tracking and optimization throughout the lifecycle. This gap needs to be addressed for the development of theoretically more robust comprehensive sustainability frameworks and expeditions in transitioning into a circular architecture within space. **Table 6** summarizes the principal challenges identified in the literature together with the corresponding research gaps and recommended directions for future research.

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Table 6. Challenges, Research Gaps, and Future Research Directions in Sustainable Interior Materials

Current Challenge	Identified Research Gap	Future Research Direction
High initial cost of sustainable materials	Limited life-cycle cost comparisons with conventional materials	Conduct long-term economic and life-cycle cost analyses
Uncertainty regarding long-term material performance	Insufficient evidence on durability, fire resistance, and aging of emerging bio-based materials	Perform long-term experimental and field-based performance studies
Lack of standardized evaluation methods	Limited comparative assessment frameworks for interior materials	Develop standardized sustainability assessment criteria and benchmarking tools
Limited implementation of circular design practices	Few empirical studies on large-scale application of circular interior systems	Evaluate real-world implementation through case studies and post-occupancy assessments
Limited adoption of digital technologies	Insufficient integration of AI, BIM, and material passports into material lifecycle management	Investigate digital platforms that support circular material tracking and decision-making
Limited understanding of user perspectives	Few studies on occupant acceptance and behavioral responses to sustainable materials	Explore user satisfaction, health outcomes, and adoption factors across different building types

Conclusion

Because the current space includes those responsible for international architectural interiors, one main issue is the integration of sustainability components that will revolutionize the way houses are developed now -- into an environmentally responsible and environmentally efficient way in the direction of built environments. Renewable natural materials, recycled and repurposed products, and bio-based alternatives have been identified today as strategies resulting in significant reductions in environmental impact with aesthetic and functional requirements for interior space. Furthermore, newer works have proven to show advancements as considerably improved bio-composites have been introduced and may now also include phase change materials along with material nano-engineering, while digital technologies design wall finishes.

This continues to show that circular design strategies, such as those employing direction towards their lifecycle, can contribute to disassembly, modular intra- and inter-system

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materials, material reuse, product life extension, and material digitization, all of which contribute towards extending material life cycles, reducing the generated waste, and creating a more optimized resource utilization within the interior environment. However, together, this requires the pertinent involvement of designers, manufacturers, policymakers, and the building owners overcoming various technical, economic, and organizational barriers.

Despite the great strides made, there are a few complications like assessing long-term performance of emerging materials for sustainability, no standardized methods, and less use of digital technologies in the development of circular material management. These issues can be covered under research and in-practice demonstration so as to establish sustainability in interior architectural embedding. As the heavy-polluting laws or policies are getting stricter and that circular economy practices are increasing their influence in the construction industry, sustainable interior materials are predicted to play a major role in creating healthier, more resilient, and green interior spaces.

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