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Process Structure and Circulate of Sustainable Furniture Product Design through TRIZ Methodology

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Abstract:

Enterprises use creative environmental solutions to develop sustainability in industry. Theory of Inventive Problem Solving (TRIZ)-based furniture design enhances production sustainability. Environmental footprints, critical issues, and TRIZ solutions are examined in this study. To inform design decisions, the study meticulously assesses life cycle inventory, environmental effect, and end-of-life scenarios. Results indicate that TRIZ can enhance furniture production life cycle pricing, DfD, and material selection. Researchers examine environmental variables, apply TRIZ and DfD, and lead design. Practical implications aid furniture designers and producers in being green, while theoretical implications debate circular economy and design's role in sustainability. This study emphasizes inventive problem-solving to satisfy furniture sector sustainability targets, which affect environmental and social well-being. Sustainable furniture design requires TRIZ. Problem-solving using TRIZ emphasizes innovation and contradiction resolution. TRIZ concepts in sustainable furniture design assist manufacturers solve complicated problems and reduce environmental effect. TRIZ inspires material, product, and end-of-life design innovation. This study found that TRIZ promotes greener furniture design through sustainable innovation. Circular economy requires eco-friendly furniture. Resource efficiency, waste minimization, and product lifecycle assist manufacturers minimize environmental impact and increase resource use. This study found environmental issues critical from material procurement to end-of-life management. Furniture companies may create a circular economy by eliminating new raw materials and waste with holistic sustainability.

Keywords: *TRIZ methodology, Design for Disassembly (DfD), Circular Economy (CE), Life Cycle Assessment (LCA), Environmental impact assessment*

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1. Background of the study

In many industries, including the furniture industry, sustainability is no longer a trend. Sustainable furniture demonstrates ethical consumption and environmental consciousness. These products are made, disposed of, and employ environmentally friendly materials(Uribe Ocampo & Kaminski, 2023). Green materials are used to make sustainable furniture. Manufacturers like bamboo, reused metal, and carefully selected wood. By limiting the use of virgin materials and deforestation, sustainable furniture preserves biodiversity and ecosystems. Sustainable furniture production also emphasizes green manufacturing. waste reduction, GHG reduction, and energy efficiency(Fiorineschi et al., 2021). Businesses minimize their influence on the environment by installing closed-loop garbage recycling systems and optimizing processes through the use of cutting-edge technologies. Eco-friendly furniture is unimaginably sustainable. Robust design and construction provide minimum maintenance requirements and long product life. Durability reduces trash from landfills and furnishings. Concepts of the circular economy encourage upcycling, restoration, and repair in environmentally friendly furniture design. Modular designs and repairable parts make maintenance and customization easier, extending the life of products and using less resources. Programs for product take-backs recycle goods and finish the cycle(Yao et al., 2022).

For the furniture industry, environmentally friendly furniture is a comprehensive solution. 'Take-make-dispose' is rejected in favor of attention and renewal(Azman et al., 2021). People may furnish their homes ethically and sustainably thanks to eco-friendly materials, sustainable manufacturing practices, and circular design. The "Theory of Inventive Problem Solving," or TRIZ for short, can be applied to the design and production of sustainable furniture. A lot of the problems with making sustainable furniture fit the conflict detection and resolution method for ordered systems in TRIZ. TRIZ starts with durability against environmental friendliness (Jai-Ai et al., 2019; Phuah et al., 2022). Subsequently, the method identifies innovative ideas and concepts for solutions that have been successful in comparable circumstances, offering a bank of options for overcoming obstacles. Furniture is preserved by TRIZ. According to TRIZ, design should balance environmental impact and aesthetics. TRIZ meticulously examines competing requirements in order to produce original design solutions. To address issues creatively, apply TRIZ. Segmentation, asymmetry, and biomimicry could minimize wasteful furniture use while maximizing resource utilization. TRIZ is a creative and effective way for designers and manufacturers of sustainable furniture to address complicated problems. Through methodical problem-solving, TRIZ may assist stakeholders in overcoming sustainability constraints, coming up with creative designs, and greening the furniture industry. TRIZ supports sustainable furniture manufacturers' growth and development (Fox, 2022).

Sustainable design and innovation research can benefit from TRIZ study of furniture product design process structure and circulation(Uribe Ocampo & Kaminski, 2023). Sustainable materials and production methods have been studied in the furniture business, but TRIZ has not been applied to improve design and circularity. This research emphasizes TRIZ in sustainable furniture design. Sustainable furniture designers haven't tried TRIZ, but engineers and manufacturers do. Learning how to use TRIZ for sustainable furniture design is vital. Research on how TRIZ might boost furniture product circularity is also important. Reusing products reduces waste and maximizes resource efficiency in circular design. TRIZ principles like contradiction resolution and ideality can assist researchers create goods with greater lifetime, reparability, and recyclability to help the furniture sector transition to a circular economy (Uribe Ocampo & Kaminski, 2023). Visit TRIZ-based sustainable furniture design partnership. Complex sustainability concerns require collaboration between designers, engineers, materials scientists, and others. Interdisciplinary research on TRIZ-based sustainable furniture design can show the pros and downsides of different viewpoints and talents. TRIZ for sustainable furniture product design process structure and circulation is understudied. Addressing this gap can help academics promote circular, sustainable, and furniture industry environmental impact(Chew Xiang, 2023; Hartono et al., 2019; Moran et al., 2021; Uribe Ocampo & Kaminski, 2023).

The study found that TRIZ optimises sustainable furniture product design process structure and circulation. This study has numerous objectives. TRIZ's suitability for sustainable furniture design is assessed first. This involves researching how TRIZ may balance environmental concerns with practical and aesthetic needs in sustainable design. The paper assesses TRIZ's sustainable furniture design challenges and opportunities. The research addresses these problems to demonstrate TRIZ's pros and downsides in this business. It uses TRIZ-based creative design to make sustainable furniture more durable, repairable, and recyclable. The rigorous problem-solving of TRIZ is applied to improve furniture designs' environmental performance. TRIZ contradiction resolution and ideality can create products that use less material, last longer, and recycle better. Researchers study these approaches to make furniture more sustainable. The study will also examine how TRIZ-guided furniture design may enhance sustainability and circularity. This involves studying how TRIZ affects product circularity, material circulation, resource efficiency, and waste reduction. Lifetime and comparative studies demonstrate TRIZ-guided design's environmental benefits. The study closes by exploring how interdisciplinary collaboration improves sustainable furniture design TRIZ. For holistic and successful design solutions, designers, engineers, materials scientists, and other stakeholders must collaborate on complex sustainability issues. To improve knowledge sharing and collaboration, TRIZ-guided design processes' multidisciplinary cooperation dynamics will be examined. Circular furniture and sustainable design innovation benefit from study.

2. Literature Review

Homes, societies, and lives were impacted by furniture design. The ergonomics, aesthetics, sustainability, and material innovation of furniture design have all been investigated by scholars and professionals (Li & Wen, 2021). The trends and contributions in furniture product design research are covered in this literature review. Knowing the history of furniture design highlights aspects related to culture, technology, and economy. Historical studies emphasized design tendencies by examining furniture styles, materials, and manufacturing processes (Cao, 2019; Romadhona & Joedawinata, 2023; Yao et al., 2022). During the handicraft-to-industry transition of the Industrial Revolution, (Uribe Ocampo & Kaminski, 2023) conducted research on the impact of technology on furniture design. Ergonomics was incorporated into furniture design to create comfortable and useful pieces. This study looked at user behavior, furniture ergonomics, and anthropometrics. According to (Moran et al., 2021; Uribe Ocampo & Kaminski, 2023) to (Moran et al., 2021), comfort and health should come first in user-centered design. Enhanced computer modeling and simulation aided designers in optimizing the ergonomics of furniture. Furniture's aesthetic appeal made it both culturally significant and widely used. Form, proportion, and visual harmony of furniture were studied in design theory through the application of art and aesthetics. Form and function were studied by Adolf Loos and Christopher Alexander, while modern experts focus on furniture's sensory experiences and emotional design. Research indicates that cultural and societal elements influenced design patterns (Chew Xiang, 2023; Hartono et al., 2019; Li & Wen, 2021).

As environmental worries developed, researchers looked into sustainable furniture design and eco-friendly materials. Recycled polymers, bamboo, and recovered wood were investigated for sustainability in furniture. Academics such as (Aliman et al., 2019; Ningjun & Tongan, 2020; Wang et al., 2024) advocated for closed-loop, infinitely recyclable cradle-to-cradle design. The environmental impact of furniture was examined using life cycle assessment (LCA) in order to identify improvements. Furniture manufacture and prototype have been revolutionized by modern digital design and manufacturing(Chen et al., 2020; Fu & Fang, 2018; Romadhona & Joedawinata, 2023). Researchers looked into additive manufacturing, generative algorithms, and parametric design to build complex shapes. Mass-customized furniture was made possible by CNC and 3D printing, combining craft and industrial. Lastly, a variety of themes and disciplines were covered in the research on furniture product design. In order to create goods that are beautiful, functional, and environmentally friendly, academics and practitioners have progressed design innovation from historical viewpoints to sustainability and digital fabrication. The obstacles facing the furniture industry in the twenty-first century call for multidisciplinary cooperation and user-centered design(Cao, 2019; Koleini Mamaghani & Barzin, 2019; Mansor & Ibrahim, 2022).

TRIZ stimulates creativity in a variety of fields, including furniture design. Since TRIZ's invention in the Soviet Union until now, it has been the subject of in-depth research. It has been shown that TRIZ's paradoxes, ideality, and creativity may solve challenging issues and spur innovation. TRIZ enhances management creativity and problem-solving in engineering, product development, company strategy, and management. TRIZ was used beyond theory by academics to make sustainable furniture. Using TRIZ, this multidisciplinary study maximizes furniture design, utility, and environmental impact. TRIZ addresses sustainable material selection, production, and disposal in design and manufacturing. Research demonstrates that TRIZ-guided design can provide fashionable, resource-efficient, sustainable, and circular economy furniture(Chen & Pang, 2023; Labuda, 2015; Liu, 2023).

Designing furniture takes sustainability, durability, and energy efficiency into account. researching the recyclability, resource consumption, and carbon footprint of furniture materials. Product life is increased through remanufacturing, modular construction, and maintenance disassembly. Using TRIZ, researchers want to increase resource efficiency, innovation, and circularity in sustainable furniture design. Both the environment and consumers will gain. Sustainable furniture research includes eco-friendly design, production, and materials. Numerous publications address the topic of environmental challenges and sustainable furniture manufacturing. Furniture made of wood, plastic, metal, and composite materials has had studies done on resource depletion, energy use, and emissions. Research has been done on the effects bamboo, rescued wood, and recycled polymer furniture have on the environment(Ningjun & Tongan, 2020; Phuah et al., 2023; Yang & Shao, 2023).

Industrial processes have been enhanced by research to preserve resources and the environment. To reduce energy, emissions, and waste throughout the production lifecycle, optimization, lean manufacturing, and waste reduction have all been researched. Designers have been able to increase sustainability and streamline production with the aid of additive printing, parametric modeling, and CAD. Studies reveal that design principles impact the longevity, repairability, and recycling of products. The study of modular design, repair disassembly, and remanufacturing aims to decrease waste and extend product life (Lippert & Cloutier, 2019). According to study, closed-loop and cradle-to-cradle technologies enhance environmental impact and resource efficiency. These design methodologies are utilized by researchers to create furniture that is profitable, fashionable, eco-friendly, and useful (Hartini et al., 2021; Zielenbach et al., 2023).

Research on sustainable furniture design is lacking greatly. It is necessary to LCAify the environmental impact of furniture, from the extraction of raw materials to manufacturing, consumption, and disposal. Few sustainability studies have looked at the environmental effects of individual components; most have focused on material choices or industrial processes. Research on consumer behavior, market dynamics, and supply chain management in the furniture industry is crucial for ensuring social and economic sustainability. By bridging these gaps, greater research can improve the sustainability and equality of the furniture industry. The furniture business is becoming more environmentally conscious, as seen by recent developments in the TRIZ technique, sustainable design, and research on furniture manufacture. TRIZ uses innovative and methodical problem-solving techniques to improve furniture design and sustainability. Sustainable material, manufacturing, and disposal objectives are met by designers and manufacturers with the use of TRIZ principles such as contradiction resolution and ideality. TRIZ promotes remanufacturing and circular furniture DfD(Aliman et al., 2019; Ramanathan et al., 2022; Wang et al., 2024).

Sustainable furniture design reduces waste, resource consumption, and product lifespan. Because they are environmentally friendly, bamboo, recovered wood, and recycled polymers are being researched for furniture design. Optimization of the manufacturing process is also researched in order to lower energy, emissions, waste, and product circularity throughout time. LCA evaluates the environmental impact of furniture manufacturing, usage, and disposal, as well as the extraction of raw materials. LCAs are used by academics to evaluate and improve the environmental effects of design. LCA information assists producers and designers in creating sustainable products(Cui et al., 2022; Kapuria et al., 2020; Opiyo et al., 2023). Furniture made with a circular economy uses less resources and produces less trash. CE processes include recycling, remanufacturing, and EoL reuse. CE uses DfD to expedite product disassembly, reuse, and recycling. Researchers can create profitable, equitable, and sustainable furniture by using CE principles.

3. Research Methodology

Sustainable Furniture Design Methodology:

A Cyclical Approach, TRIZ theory encourages circular economy and eco-friendly furniture, lessening furniture's environmental impact. The TRIZ theory encourages innovation and cycle improvement, guiding each phase toward sustainable goals. Researching environmental issues, market trends, material availability, and consumer preferences starts the design process. TRIZ-based research, ideation, and conceptualization create sustainable solutions that maximize sustainability without sacrificing utility or aesthetics through creative problem-solving and contradiction resolution. We analyze sustainable design proposals for material availability, manufacturing methods, energy efficiency, durability, recyclability, and disposal. This complete assessment helps designers optimize and make educated decisions by identifying strengths and shortcomings. Testing and prototyping confirm design principles and find pre-production errors and inefficiencies, decreasing revision costs. For sustainability and user happiness, testing customer input informs incremental changes.

Before production and execution, prototypes are developed and validated for production, supply chain, and distribution logistics. All industrial processes use renewable energy, waste reduction, and ethical sourcing to reduce environmental effect. Post-implementation monitoring and optimization allow designers to assess product performance in real-world settings, identify areas for improvement, and incorporate feedback into sustainable development. This cycle approach keeps product design dynamic and innovative to fulfill high sustainability standards and encourage furniture circular economy. Methodical, cyclical TRIZ theory can help designers create sustainable, green furniture.

Complete Life Cycle Inventory starts sustainable furniture design. From raw material extraction to disposal or reuse/recycling, furniture's life cycle must be planned. Every life cycle stage is assessed for resource inputs, energy, emissions, waste, and transportation. Assess raw material procurement sustainability and transportation or processing auxiliary resource environmental impact. After the Life Cycle Inventory, an Impact Assessment evaluates each furniture life cycle step's environmental impact. Energy, water, air, water pollution, greenhouse gas emissions, and resource depletion are measured by LCA. Here, furniture design's environmental influence is examined. Impact Assessments identify furniture product life cycle environmental "hotspots". Hotspots suggest need for design changes to lessen environmental effect. Impact Assessments help furniture designers plan sustainably. Raw material procurement, manufacture, distribution and transportation, utilization, and end-of-life scenarios are crucial to the LCI and ITA. Designers assess environmental impact throughout furniture product life cycles to innovate. Design and lifespan management incorporate sustainability. Sustainable furniture design begins with LCA-based EFA. Furniture designers can support sustainability throughout its life cycle by considering environmental consequences. The extensive study equips designers to develop circular, sustainable furniture.

Circular Economy (CE) principles tackle LCA environmental hotspots in sustainable furniture design's second stage. Prioritize resource efficiency, waste reduction, and product lifetime. Furniture designers target LCA environmental hotspots to reduce resource, energy, and waste use throughout its life cycle. This exploration follows Circular Economy principles of closing material loops and boosting resource value. Reuse and remanufacturing are CE furniture options. Furniture must be easy to disassemble and reassemble for reuse. This technique enables users reuse or relocate products as needed. Remanufacturing involves making furniture parts that can be disassembled and reused. Furniture parts can be reused or modified due to modular design and standardized connections, minimizing waste and virgin material.

EOL approach and circularity depend on material choice. To conserve resources and the environment, designers employ renewable or repurposed materials. Reuse and remanufacturing materials should be non-toxic and easy to disassemble and reassemble, decreasing consumer and worker health risks. Material selection should also include durability and endurance to extend product life and reduce waste. Circular Economy principles can help designers create eco-friendly, profitable, and socially beneficial furniture. Innovative design and material choices make sustainable furniture ideas more circular by boosting resource efficiency, lowering waste, and prolonging product lifespan. Sustainable furniture design benefits individuals and the planet via environmental stewardship and sustainable development.

Design for Disassembly (DfD) promotes repair, reuse, and remanufacturing in third-stage sustainable furniture design. Review the furniture design for disassembly to ease assembly. A full disassembly analysis evaluates and adjusts the design. Designers evaluate component connection, fastening, material, and structure. Designers can simplify disassembly by understanding assembly and disassembly barriers. DfD improves disassembly. Bolts and screws are easier to remove than glue or welding. Removable fasteners let furniture parts be disassembled without damage for repair, reuse, or remanufacturing. DfD supports modularity, making furniture parts interchangeable and convenient. This allows you fix damaged pieces without replacing the whole piece. Modularity simplifies customization, disassembly, and user adaption. Labeling and arranging aids disassembly. Designers mark and direct furniture disassembly for accuracy and speed.

DfD lets designers make durable, practical, and easy-to-maintain, repair, and reuse furniture. Improved resource efficiency and product lifespan make furniture more circular and sustainable. Disassembly designs improve user experience and let users manage their furniture's lifecycle, promoting sustainability and responsible consumption.

Scenario Analysis and Life Cycle Costing (LCC) evaluate End-of-Life (EoL) scenarios' environmental and economic consequences in the fourth step of sustainable furniture design. Reuse or remanufacturing vs. disposal of EoL. EoL scenarios consider furniture reuse or remanufacturing. Standard disposal methods are compared to disassembly ease, material recovery, market demand for reused or remanufactured products, and environmental impact. Designers can evaluate EoL solutions' feasibility and benefits using these scenarios. Lifestyle Costing evaluates EoL's economic and environmental implications. For each scenario, LCC calculates material, production, consumption, and end-of-life processing costs. Reduce virgin material, EoL processing energy, and component reuse/remanufacturing costs. Comparing EoL scenarios' environmental and economic benefits helped designers identify the most eco-friendly and cost-effective furniture design method. The data-driven research helps designers optimize EoL for environmental and economic purposes.

It emphasizes design cycle. Material and DfD implementation benefit from scenario analysis and LCC. These stages allow designers to use new data and insights to improve performance and reduce environmental impact, enhancing furniture sustainability. This method saves resources, reduces environmental impact, and creates a circular furniture company using data-driven furniture design. Scenario Analysis, Life Cycle Costing, and iterative refinement can strengthen the furniture industry by producing sustainable products. All these stages are comprehensively explained in figure 2.

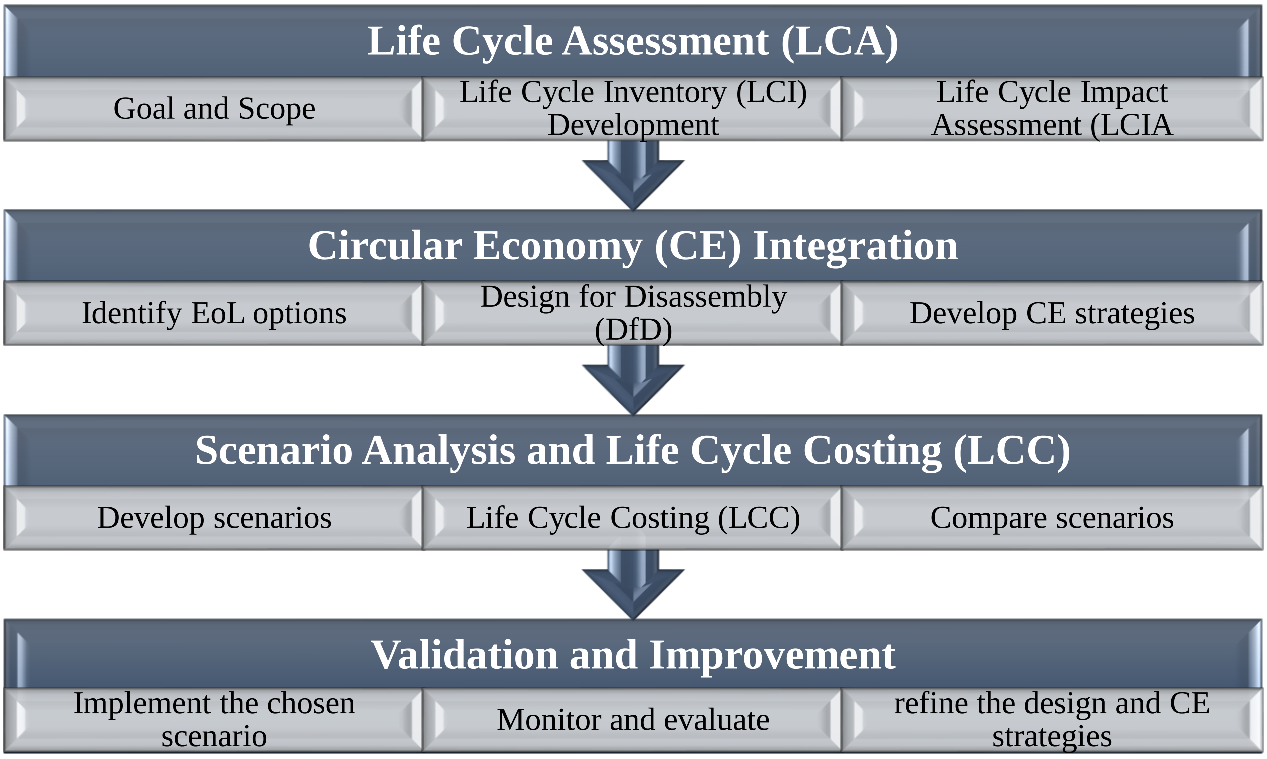

Figure 1. *Model for Designing Furniture for Circularity*

4. TRIZ Methodology Analysis And Findings

Environmental Footprint Analysis with LCA Tables

The Life Cycle Inventory (LCI) of a typical furniture product includes phases, methods, material kinds and quantities, energy use, transportation distances, and waste (Table 1). Buying 1 cubic meter of oak lumber and adhesives during Raw Material Acquisition is wood harvesting. This produces wood waste and sawdust. Mining waste from steel and aluminum processing. Energy is needed to turn lumber into shavings. Metal shaping and refining waste energy. It takes energy and packaging to assemble. Delivery of finished furniture to shops uses gasoline and produces carbon. Distance matters. Minor product maintenance energy consumption is optional in the Use Phase, depending on user behavior and maintenance practices. Finally, scenario-specific disposal incorporates End-of-Life (EoL) landfilling, which takes up space and collects rubbish. Reuse requires travel, but EoL processing always requires transportation, releasing carbon. The Life Cycle Inventory shows the furniture product's processes, inputs, and outputs at each stage to indicate its environmental impact and optimization potential.

Table 1: Life Cycle Inventory (LCI)

Life Cycle Stage	Process	Material Type & Quantity	Energy Consumption (e.g., kWh)	Transportation Distance (e.g., km)	Waste Generated (e.g., kg)
Raw Material Acquisition	Wood harvesting	Lumber (1 m^3 Oak), Adhesives (5 kg)	N/A	500 km	Wood scraps (50 kg), Sawdust (20 kg)
Raw Material Acquisition	Metal extraction & processing	Steel (10 kg), Aluminum (5 kg)	20,000 kWh	1000 km	Mining waste (1 ton)
Manufacturing	Wood processing	N/A	1,000 kWh	N/A	Wood shavings (10 kg)
Manufacturing	Metal processing	N/A	5,000 kWh	N/A	Metal scraps (2 kg)
Manufacturing	Assembly	N/A	500 kWh	N/A	Packaging materials (10 kg)
Distribution	Transportation to retailer	Furniture weight (150 kg)	20 L fuel	200 km	N/A
Use Phase	Furniture use	N/A	(optional) 100 kWh/year for minor maintenance	N/A	N/A
End-of-Life (EoL)	(Scenario Specific)	- Disposal: Landfill space used (1 m^3) - Reuse: Transportation for reuse (100 km)	N/A	Transportation for EoL processing (50 km)	Landfill waste (150 kg)

Table 2 evaluates environmental indicators, probable repercussions, units of measurement, and outcomes at each furniture product life cycle stage. Deforestation and greenhouse gas emissions from resource extraction are indicated by the 2,000 kg CO2 equivalent Raw Material Acquisition Carbon Footprint. Water loss from extraction processes has a minimal impact of 100 m^3. Small manufacturing air pollution from wood and metal processing is 50 kg. Energy Consumption found 26,500 kWh of non-renewable manufacturing energy. Product transportation greenhouse gas emissions affect distribution by 100 kg CO2 equivalent. Based on optional maintenance, 100 kWh/year is minimal. Last, End-of-Life examines scenario implications. Disposal's space utilization raises its Landfill Impact Score. Saving wood and resources through reuse. Remanufacturing saves energy and helps the environment. To help designers make sustainable decisions, the Environmental Impact Assessment highlights the environmental impacts of each furniture product life cycle stage.

Table 2: Environmental Impact Assessment

Life Cycle Stage	Environmental Impact Metric	Potential Impact	Units	Results
Raw Material Acquisition	Carbon Footprint	Deforestation, greenhouse gas emissions	kg CO2 equivalent	2,000 kg CO2 equivalent (high impact)
Raw Material Acquisition	Water Usage	Water depletion for resource extraction	m^3	100 m^3 (moderate impact)
Manufacturing	Air Pollution	Emissions from processing wood & metal	kg pollutants	50 kg pollutants (moderate impact)

Manufacturing	Energy Consumption	Non-renewable energy use	kWh	26,500 kWh (high impact)
Distribution	Transportation Emissions	Greenhouse gas emissions from transport	kg CO2 equivalent	100 kg CO2 equivalent (low impact)
Use Phase	Energy Consumption	Energy used for maintenance (if applicable)	kWh	100 kWh/year (low impact)
End-of-Life (EoL)	(Scenario Specific)	- Disposal: Landfill impact - Reuse: Reduced resource consumption - Remanufacturing: Reduced energy use compared to virgin materials	- Landfill impact score (high) - kg resource saved (significant) - kWh energy saved (moderate)	- Landfill impact score is high due to space usage - Reuse saves wood resources - Remanufacturing saves energy compared to new materials

Table 3 shows how TRIZ Inventive Principles are utilized to build structurally sound, easy-to-disassemble furniture for reuse, recycling, or remanufacturing. Furniture without disassembly is incomplete. Example: composite materials, intrinsic disassembly materials, pneumatic or hydraulic rapid release systems. Strength and Disassembly Managing structural integrity and disassembly is hard. To compensate, parameter variation can change feature scale or layout. Detachable furniture modules are phases with specific time or space needs. Universality and Specialization acknowledges furniture joint variations. Nesting makes component storage and disassembly easier. Standardizing joints and disassembly tools ensures module and component compatibility. Resource Utilization prevents screw and nail removal. Material separation and reuse are encouraged by homogeneity. Refusal of Substances and Materials recommends glue-free joinery for disassembly. To support furniture circular economy concepts, TRIZ Inventive concepts can help designers overcome DfD furniture design inconsistencies and improve structural integrity and disassembly simplicity.

Table 3. TRIZ Inventive Principles for DfD Furniture Design

TRIZ Contradiction	Description	Inventive Principles (Examples for DfD)
System Incompleteness	The furniture design lacks features that would facilitate easy disassembly.	* Composite Materials (Composite): Combine different materials with inherent disassembly properties (e.g., wood for strength + self-gripping fasteners for easy detachment). * Pneumatic or Hydraulic Drives (PD): Utilize pressurized air or fluids for quick release mechanisms (e.g., air pistons to pop open locking joints).
Strength and Disassembly Difficulty	Strong joints are necessary for structural integrity, but they can also hinder disassembly.	* Parameter Variation (PS): Change the scale or arrangement of existing features. (e.g., use breakaway tabs on glued joints for easier separation). * Phasing (Ph): Separate functions or properties in time or space. (e.g., design furniture with detachable modules that can be disassembled and reassembled in different configurations).
Universality and Specialization	A single joint type might not be ideal for all furniture components.	* Nesting (Ne): Arrange components such that some can be housed within others for efficient disassembly and storage. (e.g., design stackable chairs with nesting mechanisms). * Compatibility (Cp): Ensure different components or modules are compatible with various disassembly

		methods. (e.g., standardize joint types and disassembly tools).
Resource Utilization	Traditional fasteners (screws, nails) become waste during disassembly.	* Homogeneity (HS): Make components from the same material to simplify separation and potential material reuse. (e.g., use self-locking joints made from the same wood as the furniture frame). * Refusal of Substances and Materials (RM): Minimize the use of materials or components that hinder disassembly. (e.g., explore glue-less joinery techniques where possible).

Figure 2. *Design for Disassembly by TRIZ (Theory of Inventive Problem Solving)*

The research may show mechanical and design aspects in Figure 2 to demonstrate how TRIZ can aid disassemble furniture. These methods simplify furniture disassembly for recycling, reuse, and remanufacturing. A TRIZ principle portrayed in the collage is Composite Materials (CM), which mix disintegration-prone materials. Wood offers strength while snap-fit connectors divide parts. Separating functions or qualities in time or space is phasing. Disassembling and moving furniture with removable legs or arms is easy. PS, another TRIZ approach, improves disassembly by changing feature scale or layout. Breakaway tabs on bonded connections could separate furniture without damage. The collage may also represent the Nesting principle (Ne), which allows components to be nested for easier disassembly and storage. Interlocking stackable chairs are easy to stack and disassemble. To encourage sustainability and circularity in furniture manufacture, creative furniture design may emphasize material quality, component arrangement, and ease of separation.

Furniture disposal, reuse, and remanufacturing are compared in Table 3. Every situation requires sustainable furniture lifespan management. The Disposal scenario entails 50-mile furniture delivery to a dump. Waste disposal costs $50 per ton landfill tipping. Old furniture is generally discarded this way. Reuse involves many important tasks to prolong furniture life and prevent landfilling. Use removable fasteners to disassemble the furniture. Disassembled parts travel 100 miles for reuse. Cleaning and small repairs are optional for furniture reuse, considering condition. Remanufacturing reuses furniture. Save hardware and frames after disassembling furniture for reuse or restoration. Disassembled parts are rebuilt 200 miles elsewhere. Sorting, cleaning, woodworking, and upholstery are examples. Reassembling furniture may include comfort and style cushions. The chart lists furniture disposal, reuse, and remanufacturing for sustainability. Each scenario uses circular economy and sustainability principles to improve resource efficiency, waste reduction, and furniture lifespan.

Table 3: End-of-Life (EoL) Scenario Comparison

EoL Scenario	Key Activities
Disposal	- Transportation to landfill (50 km) - Landfill tipping fees ($50/ton)
Reuse	- Disassembly (focusing on easily detachable fasteners) - Transportation for reuse (100 km) - Cleaning and minor repairs (optional, depending on condition)
Remanufacturing	- Disassembly (focusing on salvageable components like hardware and frames) - Transportation for remanufacturing (200 km) - Cleaning and sorting components - Remanufacturing processes (e.g., refurbishing wooden surfaces, re-upholstery) - Reassembly of furniture (potentially with new components like cushions)

Figure 3 shows numerous EoL responsibilities in product management. Reuse, remanufacturing, recycling, and disposal are end-of-life material management options. Reusing products without major changes improves their lifespan and saves resources. Remanufacturing makes new goods by disassembling, reconditioning, and reassembling. Reduced waste and resource conservation are emphasized. Recycling creates raw resources for new goods. The circular economy benefits from reduced virgin material consumption and environmental effect. A product's life ends with landfill or combustion. This procedure is sometimes needed but less environmentally friendly and prioritized than other EoL processes. Transportation expenditures for EoL management may be included. Local processing and EoL condensing may help transit. These solutions cut transportation fuel use and emissions, lowering EoL management's environmental impact. Figure 3 depicts EoL actions that promote product reuse, remanufacturing, recycling, disposal, and transportation efficiency.

Figure 3. *Activities of End-of-Life (EoL)*

Table 4 compares furniture disposal, reuse, and remanufacturing EoL. Material, energy, transportation, disposal, and cost savings are considered in each scenario. The disposal scenario includes material expenses and $100/ton trash disposal. Just 100 kWh is used for landfill transportation by EoL. Remote landfills impose moderate transportation costs ($1/km). It's not saving money. Furniture is reused without modification, therefore material expenses are nothing. Simple cleaning (50 kWh) and transit (200 kWh) use little energy. Reduced reuse distance reduces transportation costs ($0.5/km). $10 per piece of furniture material savings saves money. In remanufacturing, recycled materials ($20/kg) cost less than raw materials ($30/kg). Remanufacturing (1,000 kWh) and EoL disassembly (500 kWh) use moderate energy. Transportation costs are moderate ($1/km) due to remanufacturing distance. Cost savings of $30 per unit material and $20 per unit reuse revenue might be significant. Reuse $130, disposal $250, and remanufacturing $220 or less. This report says reuse and remanufacturing save money, resources, and the environment.

Table 4: Life Cycle Costing (LCC)

Cost Category	Disposal	Reuse	Remanufacturing	Units
Material Costs	N/A	N/A	Recycled materials ($20/kg) vs. Virgin materials ($30/kg)	$/kg
Energy Consumption (EoL)	Low (transportation: 100 kWh)	Low (transportation: 200 kWh + minor cleaning: 50 kWh)	Moderate (disassembly: 500 kWh, remanufacturing: 1,000 kWh)	kWh
Transportation Costs	Moderate (landfill distance: $1/km)	Low (reuse distance: $0.5/km)	Moderate (remanufacturing distance: $1/km)	$/km
Disposal Fees	High ($100/ton)	N/A	N/A	$/ton
Potential Cost Savings	N/A	Reduced material costs ($10 per unit of furniture)	Reduced material costs ($30 per unit) + Potential revenue from reuse ($20 per unit)	$/unit
Total LCC	$250	$130	**$220 (potentially lower than disposal)** \$	****

Figure 4 may include all eco-friendly furniture materials. These aspects determine furniture materials' longevity, sustainability, and environmental impact. Key factors include renewability. The substance's replenish ability is shown here. Wood, bamboo, and cork are sustainable furniture materials. Other important figure properties include recyclability. Create new goods from end-of-life resources. Recycling aluminum, steel, and some plastics cuts furniture manufacture waste and resources. Whether discarded goods spontaneously decompose to reduce environmental impact may also be asked. Cotton, wool, and hemp are used in eco-friendly furniture design. Durability impacts material choice. Material durability and environmental resilience. Durable hardwoods, metals, and synthetic fibers are common furniture materials. The graphic also shows VOC-free, low-toxicity products. Untreated textiles and non-toxic solid wood improve indoor air quality and occupant health, making them pleasant. Promoting ethically managed woods, eco-friendly manufacturing, and fair labor are also options. Display FSC or GOTS-certified materials. Figure 4 provides an overview of material properties to help designers and manufacturers choose sustainable furniture materials. It emphasizes furniture's environmental, social, and functional impacts from material choices.

Figure 4. *Material Properties for Sustainable Furniture Design*

Environmental furniture manufacturing material selection variables are shown in Figure 4. First column rates cloth, metal, plastic, and wood. Each material has furniture-making and environmental needs. For sustainable sourcing, the second column lists material origin. Materials from ethically managed forests, recycled, or renewable sources lessen environmental impact and encourage supply chain ethics. This column evaluates material toxicity. Natural textiles and solid wood improve indoor air quality and manufacturer and customer health. Durable materials are needed for furniture. Woods, metals, and some polymers wear less, decreasing replacements. End-of-life disassembly ease for repair, reuse, or recycling is examined in this column. Modular design, standardized fasteners, and replaceable parts boost circular economy and resource efficiency.

Table 5: Material Properties for Sustainable Furniture Design

Material	Source	Toxicity	Durability	Ease of Disassembly	Additional Considerations
Wood (Oak)	Virgin or Recycled	Low (if properly treated)	High	Moderate (depends on joinery techniques)	Slow-growing hardwood, consider fast-growing alternatives for virgin wood
Steel	Virgin or Recycled	Moderate (requires proper handling)	High	Low (welded joints difficult to disassemble)	Heavy material, transportation impacts
Aluminum	Virgin or Recycled	Low	High	Moderate (riveted joints easier to disassemble than welded)	Energy-intensive production for virgin aluminum
Adhesives	Virgin or Bio-based	Varies (check specific product)	N/A	Low (often creates permanent bonds)	Look for low-VOC (volatile organic compound) adhesives for better indoor air quality
Natural Fibers (e.g., Cotton, Wool)	Virgin or Recycled	Low	Moderate to High (depends on quality)	High (easily separated from frames)	Requires proper care and maintenance
Recycled Plastic	Recycled	Varies (depends on plastic type)	Moderate	Moderate (depends on joining method)	Can be susceptible to UV degradation outdoors

Table 5 lists eco-friendly furniture materials. The source, toxicity, durability, disassembly ease, and other features of wood (oak), steel, aluminum, adhesives, natural fibers (cotton, wool), and recycled plastic are evaluated. Oak wood is nontoxic after treatment. Joinery is robust but difficult to disassemble. Fast-growing wood alternatives must be considered to reduce slow-growing hardwood's environmental impact. Unsafe to handle raw and recycled steel. Steel is robust but hard to disassemble due to welded seams. Weight impacts transport. Aluminum, created from virgin or recycled resources, is robust and non-toxic. Riveted connections break easier than welded ones. Virgin aluminum manufacturing is energy-intensive. The toxicity of virgin or bio-based adhesives varies by product. Although adhesives do not affect durability, they can produce persistent connections that hamper disassembly. Low-VOC adhesives improve indoor air. Some cotton and wool are non-toxic and durable. They may be removed from furniture frames but are sturdy. Recycled plastic may be harmful. Connection mechanism helps disassembly, moderate durability. Outdoor recyclable plastic furniture may need UV protection. In conclusion, Table 5 provides material property insights to help designers and manufacturers construct sustainable furniture designs that promote environmental responsibility, durability, and easy disassembly throughout the product lifecycle. Innovation in TRIZ-based sustainable furniture design is shown in Figure 5. These photographs illustrate furniture designers using TRIZ for sustainability. Sketches can demonstrate creativity, problem-solving, circular economy, user-centricity, and environmental impact reduction. These pictures inspire sustainable furniture design with their creative design, problem-solving, and sustainability stories.

Figure 5. *Sustainable Furniture Design Using TRIZ*

Sustainable Furniture Table 6 compares the pros and downsides of DfD methods for each furniture component. Oak chair frames are checked for seat screws and leg and backrest dowel joints. Dowel joints and screws are robust and adaptable, but drilling and disassembly require accuracy. Self-centered dowel jigs improve accuracy; however screw type depends on wood and load. Designs use cam locks to link the table's recovered wood top and base allowing tool-free removal. Cam locks can loosen and wobble, so select robust ones with dowel pins and latches.

Groove and dado joints give plywood cabinet doors sturdy, clean connections. The technique is accurate and time-consuming, so routers speed groove carving and improve connections. Maintaining solid wood drawers is easy with quick-release slides and dovetail connectors. However, carpentry skills and consideration for lighter quick-release levers are crucial, as is practicing dovetail joints on scrap wood before integration and picking slides based on drawer needs. Finally, zippered cushion borders make fabric sofa cushions easy to replace, wash, and repair. Visible zippers can be unattractive, requiring fabric reinforcement or hidden zippers. For maximum functionality, zipper size and strength should match cushion and fabric weight. Sustainable furniture designers and manufacturers employ DfD to promote careful material selection and assembly throughout the design process to ensure product durability, simplicity of maintenance, and sustainability.

Table 6: DfD Technique Selection for Sustainable Furniture Design

Furniture Component	Function	DfD Techniques	Advantages	Disadvantages	Considerations
Chair Frame (Oak)	Structural support	- Dowel joints (for legs and backrest) - Screws (for seat attachment)	- Strong and secure for structural support - Disassembly possible for repair or remanufacturing - Screws allow for some adjustability	- Requires precise drilling for dowel joints - Screws require tools for disassembly	- Use self-centering dowel jigs for accurate drilling -- Select screw type based on wood type and load (e.g., coarse thread for oak)
Table Top (Recycled Wood)	Surface, support	- Cam locks (connecting top to base)	- Easy disassembly without tools - Allows for potential future top replacements	- Cam locks might loosen over time, impacting stability	- Choose high-quality cam locks with locking mechanisms - Consider adding dowel pins for additional strength

Cabinet Doors (Plywood)	Enclosure, access	- Groove and dado joints	- Strong and stable connection - Clean aesthetic with hidden joinery	- Requires precise woodworking skills - Time-consuming to assemble/disassemble	- Ensure tight-fitting joints for a secure closure - Consider using a router for faster and more precise groove cutting
Drawer (Solid Wood)	Storage	- Dovetail joints (for drawer front and sides) - Slides with quick-release levers	- Very strong and durable joint - Easy drawer removal for cleaning or repairs	- Requires advanced woodworking skills for dovetails - Quick-release levers might have lower weight capacity	- Practice dovetail joints on scrap wood before applying to final design - Choose slides based on drawer size and weight
Sofa Cushions (Fabric)	Comfort	- Zippers (along cushion edges)	- Easy removal and replacement of cushions - Allows for cleaning or future reupholstery	- Zippers might require additional fabric reinforcement - Visible zippers might affect aesthetics	- Use concealed zippers for a cleaner look - Select zipper size and strength based on cushion size and fabric weight

Figure 6 shows DfD strategy selection for sustainable furniture design. Examples show DfD on furniture parts. These examples may demonstrate DfD testing and implementation of dowel joints, screws, cam locks, groove and dado joints, dovetail joints, and zippers. Each example likely shows DfD furniture, its purpose, and its pros and downsides. This visual guide shows designers and manufacturers how DfD can maintain furniture by enabling disassembly, repair, and recycling. Figure 6 shows how DfD may be used to create durable, practical, and environmentally friendly furniture by considering material selection, assembly, and end-of-life.

Figure 6. *DfD Technique Selection for Sustainable Furniture Design Samples*

4.1 Discussion

We used TRIZ and DfD to build sustainable furniture. We wanted to improve furniture sector environmental challenges by increasing resource efficiency, waste minimization, and product lifespan. Using imaginative problem-solving, TRIZ increased furniture sustainability while maintaining usability and beauty. We created a furniture circular economy by making components easy to disassemble, repair, and recycle using DfD. We achieved our aim using a systematic approach with key phases. A thorough literature review helped us understand sustainable furniture design processes, challenges, and opportunities. TRIZ theory helped us innovate furniture manufacturing sustainability solutions. Our DfD design approach covered material selections, joinery methods, and end-of-life situations. We improved our real-world furniture design with iterative design and prototyping. Designers and manufacturers can create sustainable furniture that meets environmental, consumer, and commercial standards with our strategy.

Table 1 shows the life cycle impact of sustainable furniture design and its environmental effects. The table depicts important procedures, material kinds and quantities, energy consumption, transportation distances, and waste generation during raw material acquisition, manufacturing, distribution, use, and end of life. Table 1 methodically maps these aspects to assess each stage's environmental impact, allowing designers and manufacturers to improve. This table illustrates how transportation distance and waste affect the environmental impact of acquiring furniture raw materials. Table 1 examines the environmental impact of furniture design by calculating carbon footprint, water usage, air pollution, energy consumption, transportation emissions, and disposal costs. Throughout the furniture life cycle, quantitative analysis assists stakeholders in prioritizing environmental initiatives. The table shows that manufacturing is energy-intensive and polluting, emphasizing the need for energy-efficient technologies and emission reductions. The table demonstrates how discarding, reusing, and remanufacturing are sustainable beyond furniture use. Table 1 demonstrates how sustainable furniture makers improve circularity and environmental efficiency.

Table 2 shows a full life-cycle Environmental Impact Assessment (EIA) for sustainable furniture design. The table shows the carbon footprint, water usage, air pollution, energy consumption, and transportation emissions for furniture manufacturing. Table 2's metrics and structures assist decision-makers in minimizing their environmental impact. The environmental impact parameters in the table allow for environmental solutions tailored to each step of the life cycle. Because of their high carbon footprint and water consumption, wood harvesting and metal extraction necessitate sustainable raw material sourcing and conservation. Manufacturing process assessments prioritize energy-efficient manufacturing and pollution control in order to reduce air pollution and energy consumption. Table 2 examines environmental implications across the furniture life cycle to help designers and manufacturers prioritize environmental actions. Table 2 allows participants to compare the environmental consequences of disposal, reuse, and remanufacturing. Decision-makers could weigh disposal and material costs against environmental effect reduction. The table also demonstrates how circular economy remanufacturing conserves energy and resources. Table 2 demonstrates how sustainable furniture design benefits the business.

Table 3 lists TRIZ Inventive Principles for Sustainable Furniture Design for Disassembly. Through design disputes, imaginative concepts, and examples, the table presents novel furniture disassembly efficiency and sustainability solutions. A systematic presentation explains how TRIZ may improve furniture design and disassembly for faster end-of-life management. The chart defines design inconsistencies by System Incompleteness, Strength and Disassembly Difficulty, Universality and Specialization, and Resource Utilization to inspire creativity. The System Incompleteness table describes disassembling Composite Materials and Pneumatic or Hydraulic Drives. Strong joints prevent disassembly. Variable parameters and phasing are innovative. The table offers new concepts and DfD examples to help designers use TRIZ for sustainable furniture design. In TRIZ design for manufacture, Table 3 emphasizes material quality, joinery, and end-of-life scenarios. Furniture disassembly is easier by choosing materials with inherent disassembly qualities and appropriate connecting ways. The table's TRIZ resource efficiency and circular economy design enhance furniture sustainability. Table 3 illustrates designers and manufacturers how to use TRIZ to DfD plans for furniture circularity and sustainability.

Table 4 uses sustainable furniture design LCC characteristics to indicate environmental sustainability economics across the product's life cycle. To evaluate end-of-life scenarios and design modifications, the chart classifies material prices, energy usage, transportation expenses, disposal fees, and potential cost savings. This organized presentation helps stakeholders evaluate sustainability projects' economic pros and cons and plan actions. The table's disposal, reuse, and remanufacturing costs demonstrate circular economy furniture design's financial impact. While disposal costs money and shipping, reuse and remanufacturing save resources and may produce income from reused components. The table calculates each end-of-life scenario's total LCC, helping stakeholders assess methodology's economic viability and choose the most cost-effective furniture design sustainability options. In Table 4, LCC calculation priority include material selection, energy use, and transportation logistics. Recycling is cheaper than virgin resources, and the graphic explains ways to reduce energy use during end-of-life processing. The table also shows how circular economy furniture design cuts reuse and remanufacturing expenses. Table 4 advises stakeholders on sustainable furniture design to maximize environmental and economic performance throughout the product's life cycle.

Table 5 contrasts sustainable furniture design resources with production materials. The chart helps designers and manufacturers find sustainable furniture materials by source, toxicity, durability, disassembly, and more. This methodical presentation lets stakeholders evaluate material choices' environmental, health, and practical impacts on furniture design sustainability and utility. Finally, the chart lists wood, steel, aluminum, adhesives, natural fibers, and recycled plastic. The analysis recommends oak for furniture structural components due to its low toxicity and durability. The table indicates that wood and natural fibers are easier to disassemble than steel and aluminum furniture frameworks. Table 5 shows material qualities, supply, toxicity, and recycling. The table indicates that virgin aluminum manufacturing is energy-intensive and environmentally harmful, underlining the need for recycled materials. The chart shows material disassembly ease and challenges to help furniture designers increase circularity and end-of-life management. Using Table 5, furniture designers and manufacturers choose useful and appealing sustainable materials.

Design for Disassembly (DfD) strategies for sustainable furniture component design are listed in Table 6 with their advantages, cons, and difficulties. The table categorizes furniture components, functionality, DfD technique, and pros and disadvantages to enable designers and manufacturers pick sustainable and circular disassembly methods. To help furniture designers enhance disassembly efficiency and end-of-life management, stakeholders can evaluate many DfD approaches' trade-offs and practical implications in this organized presentation The table shows how difficult and harmful disassembling chair frames, table tops, cabinet doors, drawers, and sofa cushions is. The study indicated that chair frame dowel joints and screws are strong and easy to disassemble for repair or remanufacturing. Precision drilling and equipment may complicate disassembly. Beyond DfD, Table 6 emphasizes carpentry, materials, and aesthetics. Routers cut plywood cabinet door grooves faster and more accurately, saving assembly/disassembly time. A graphic shows DfD pros and cons to help furniture designers manage end-of-life and reduce environmental impact. Table 6 helps furniture designers and manufacturers choose sustainable, useful, elegant, and affordable DfD processes. DfD can help stakeholders improve furniture sustainability and circularity by examining component attributes and disassembly.

TRIZ for Furniture DfD results are shown in Figure 2. First, it solves system incompleteness, strength, and disassembly problems creatively. The examples demonstrate how TRIZ increases DfD furniture disassembly efficiency and sustainability. For holistic sustainable design, TRIZ furniture design must include material quality, joinery techniques, and end-of-life. Complete findings include reuse, remanufacturing, recycling, and disposal at the end of the furniture product life cycle (Figure 3). The picture shows circular economy benefits like energy savings, resource conservation, and money reuse/remanufacturing. EoL efficiency and sustainability depend on transit logistics and local processing. Sustainable furniture design requires consideration of prevalent furniture manufacturing materials (Figure 4). Low-toxicity, durable, and disassembleable materials must be used in furniture design to increase sustainability and circularity. When choosing materials, it considers source, recyclability, energy intensity, and transportation.

Figure 5 depicts sustainable furniture design DfD approach selection and the pros, disadvantages, and concerns of various furniture component DfD methods. To increase furniture disassembly efficiency and end-of-life management, consider woodworking abilities, material properties, and aesthetics while adopting DfD techniques. Figure 6 shows practical implementations of DfD technique selection for sustainable furniture design samples. DfD methods for furniture components are illustrated, with benefits and cons. It promotes DfD in furniture design for circularity and sustainability.

5. Conclusion

TRIZ and DfD increase furniture design sustainability in this study. This study investigates the intricate interaction between environmental, economic, and design factors in furniture. Results show that circular economy concepts, material selection, and optimal end-of-life management reduce environmental impact and maximize resource efficiency. Holistic and integrated sustainable design and TRIZ and DfD processes in furniture manufacturing innovation and circularity are stressed in the study. Combining TRIZ with DfD creates innovative sustainable furniture designs. TRIZ principles enable furniture makers identify unique environmental solutions throughout the product life cycle. TRIZ principles help designers eliminate discrepancies and maximize sustainability without losing beauty or usability. For environmental sustainability, circular economy and material selection are emphasized. Reusing and remanufacturing save money and resources. Furniture designs' environmental impact depends on material toxicity, durability, and disassembly.

The research emphasizes holistic design, which considers environmental, economic, and social concerns. TRIZ and DfD assist designers make eco-friendly, profitable, and socially responsible furniture. Finally, sustainable furniture design should use TRIZ and DfD to maximize environmental, economic, and social impacts. Innovative design and circular economy practices can make furniture more resilient and sustainable. This initiative uses TRIZ and DfD to develop sustainable furniture. This unique combination solves furniture manufacturing sustainability challenges. Combining TRIZ problem-solving with DfD to increase furniture design sustainability improves the field. Environmental issues throughout the furniture product life cycle are carefully studied in this research. Through tables, statistics, and arguments, the study highlights furniture manufacturing and usage environmental footprints, impact evaluations, and end-of-life possibilities. This extensive analysis helps stakeholders identify key areas for intervention and improvement, supporting sustainable design. This research helps create sustainable furniture. The study reveals material qualities, life cycle costing, and DfD approach choices to help furniture designers and manufacturers improve environmental, economic, and social outcomes. With this information, stakeholders may make sustainable decisions without sacrificing functionality or beauty. Our study enhances the furniture industry's circular economy. Through new design ideas, the study creates a more sustainable and resilient furniture manufacturing future by improving resource efficiency, waste reduction, and product durability. This research improves sustainable furniture design with in-depth analysis and practical guidance.

This comprehensive analysis has *limitations*. The study's focus on TRIZ and DfD may overlook other sustainable design principles. More study could improve sustainable furniture design in numerous ways. Regional boundaries, commercial variables, and technical constraints may limit research generalizability. To apply the study's conclusions to other sectors or locations requires caution. Environment and design methods are covered in the study, however social and economic sustainability in furniture design may not be. Studying these factors can help determine furniture sector sustainability. Psychologists, sociologists, and economists could investigate furniture design sustainability and solve the above problems. In *future researches*, several concepts help researchers create more complete sustainable design frameworks. Sustainable furniture design could be studied longitudinally. Researchers can evaluate furniture sector sustainability by examining environmental, economic, and social impacts. Scientific, corporate, and government collaboration can scale sustainable design. Partners and information sharing can change furniture manufacture and achieve sustainability. Beyond this study, sustainable furniture design requires more research and ingenuity. Addressing restrictions and adopting future recommendations will help researchers save the furniture industry and make it more robust and equitable.

5.1 Research Implications

This research aids green furniture design and manufacturing. Furniture makers can improve environmental, economic, and social consequences via TRIZ and DfD problem-solving and design. This research can help sustainable furniture designers choose materials, fabrication processes, and end-of-life. The study's circular economy focus impacts furniture sales. Manufacturing should use a circular business model to enhance resource efficiency, waste minimization, and product lifetime to reduce environmental impact and resource consumption. Circularity saves money, advances environmental goals, and differentiates enterprises in green markets. Sustainable furniture design can be informed by this research. The study's recommendations can help stakeholders innovate in material procurement and end-of-life management. Sustainability improves furniture companies' competitiveness, brand awareness, and industry sustainability.

Practical and theoretical consequences of sustainable furniture design are important. DfD and TRIZ help green design. This study uses these two methodologies to create new product design sustainability solutions. Furniture industry and circular economy theories are covered in this subject. For circularity-based sustainable development, research stresses resource efficiency, waste reduction, and product longevity. To support furniture manufacturing circular economy claims, the study investigates end-of-life, material, and life cycle costs. Research shows how design promotes sustainable consumption and behavior. Holistic design, material selection, and end-of-life management emphasize design's theoretical impact on society and the environment. This philosophy emphasizes how sustainable design empowers and equalizes societies. This practice-based study supports circular economy, sustainability, and design innovation by demonstrating sustainable furniture design's theoretical foundation and environmental and social benefits.

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