2026
volume 23 | issue 1

ENQ
The ARCC Journal for Architectural Research

Curriculum, Pedagogy, and Application: An Analysis of Sustainable Design Education Gaps in Indian Architecture Programs

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Abstract

The global furniture industry generates approximately 300–450 million tonnes of waste annually, directly undermining UN Sustainable Development Goals, particularly SDG 11 (Sustainable Cities) and SDG 12 (Responsible Consumption). The Circular Economy offers a structured response to this problem by prioritising material loops that reduce extraction and extend value. For design education and practice, this translates into Circular Design Principles that operationalise circularity at the scale of furniture, material assemblies, and interior fit-outs. Despite their significance, architecture and interior design education programs inadequately prepare students to address these challenges through circular spatial strategies. This study presents a comprehensive three-component investigation examining circular design integration in Indian design education. First, a curricular analysis of 30 leading architecture and interior design programs was conducted to establish the instructional context for circular design in India. This was followed by a detailed examination of 17 studio briefs, using content analysis to assess how sustainability is incorporated into the learning objectives. Lastly, an empirical study with 23 third-year architecture students, using a sequential mixed-methods approach, was conducted to evaluate knowledge-practice gaps in the integration of circular strategies. The findings reveal critical deficiencies across the curriculum, pedagogy, and stages of student learning. While sustainability terminology appears in 93% of architecture programs, no institution explicitly integrates circular design as a core competency. Studio brief analysis reveals that sustainability appears in some learning outcomes but remains operationalised through material substitution only. Student assessment shows only 28% naturally incorporate sustainable strategies, achieving 34.8% accuracy in identifying circular principles, while 65% demonstrating severe perception-reality gaps. The study demonstrates that current educational approaches treat sustainability as secondary, rather than integral. These findings necessitate systematic curriculum integration of circular design principles to develop specialised competencies in future designers. These systemic deficiencies, triangulated across curriculum, pedagogy, and student outcomes, orient this research to identify specific leverage points for reform. It offers a replicable framework for examining student understanding and provides curriculum designers, educators, and policymakers with evidence-based recommendations for effective circular design integration.

Keywords: sustainable design education; circular design principles; architecture curriculum; design pedagogy; furniture waste

Stable URL: https://arcc-journal.org/index.php/arccjournal/article/view/1322

DOI 10.17831/enq:arcc.v23i1.1322

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1. INTRODUCTION

The contemporary global furniture industry faces a severe environmental crisis of waste management due to intense consumer demand, affordability, and mass accessibility. This industry generates around 10–15% of total global waste, amounting to approximately 300–450 million tonnes annually (Ellen MacArthur Foundation 2023). In India, the situation is particularly acute. The IGBC reports that the country generates approximately 150 million tonnes of construction and demolition waste annually, while ASSOCHAM (2024) estimates that urban households discard 20–25% of their furniture within 5–7 years. This contributes to a 40% increase in furniture waste over the past decade, with only 5–8% being effectively recycled or repurposed. This shift reflects a growing perception of furniture as a disposable commodity rather than a durable investment, directly violating core principles of resource conservation and environmental responsibility.

This societal shift toward disposability contrasts sharply with historical practices where communities across India, Africa, and pre-industrial Europe developed sophisticated material conservation strategies, emphasising modular construction, repair, and intergenerational reuse. Looking back, the Industrial Revolution fundamentally disrupted these sustainable traditions, establishing economic models that prioritised consumption over longevity and durability. Contemporary furniture waste management thus presents complex challenges requiring comprehensive strategic interventions.

Circular Economy offers a structured response to concerns of disposability and waste utilisation by prioritising material loops that reduce extraction and extend value. For design education and practice, this translates into Circular Design that operationalises circularity at the scale of furniture, material assemblies, and interior fit-outs (Almelhem et al. 2025; Chirumalla et al. 2024; Kotyal 2023). In this study, the term Circular Design Principles (CDPs) is used to refer specifically to application-level circular strategies that enable material value retention in furniture and interior design contexts, while the broader concept of circular design encompasses system-level approaches such as lifecycle assessment, design-for-disassembly, and adaptive reuse.

In interior design education, the opportunity and responsibility to address furniture waste through circular strategies are particularly acute. Interiors cycle faster than buildings, entail intensive material decisions, and therefore offer powerful leverage points for circular interventions, provided students are trained to recognise, select, and implement them. Furniture waste alone represents a significant portion of global material waste (approximately 300-450 million tonnes annually), with Indian urban households discarding 20-25% of furniture within 5-7 years and only 5-8% being effectively recycled or repurposed (ASSOCHAM, 2024; IGBC, 2021). This rapid disposal cycle, combined with the material intensity of interior fit-outs, positions furniture and interiors as a critical intervention point for circular design education. Yet, across many programs, sustainability is still delivered as fragmented content (a single course, brief module, or elective) rather than as an integrated, cross-curricular design lens. The result is that key topics such as material lifecycles, waste minimisation, and durability, when taught, are taught in isolation, with limited scaffolding to help students connect them during design decision-making.

This study focuses specifically on four material transformation strategies: recycling, upcycling, downcycling, and repurposing, as application-level competencies that operationalise circular design principles within furniture and interior contexts. These end-of-life strategies directly address the furniture waste challenge by providing alternatives to landfill disposal and extending the value of materials. While broader circular design frameworks encompass system-level approaches such as Design for Disassembly (DfD), Life Cycle Assessment (LCA), and design for adaptability—each embedding circularity during the design phase—these four strategies represent the operational skills through which students apply circular thinking to material decisions, furniture specifications, and end-of-life planning. Each strategy can be mapped to foundational circular design principles as shown in Table 1. By assessing student competency in these application-level skills, this study evaluates whether design graduates possess the operational capacity to implement circular strategies in practice, beyond theoretical awareness of sustainability principles

In this context, educating and training future architects and designers becomes critical, as they are not only the creators of built environments, but also key agents in re-establishing sustainable material and spatial practices that have been displaced by industrial-era models of disposability. The competencies required to implement circular design strategies extend beyond general environmental awareness and require specialised skills in design thinking, material adaptability, spatial planning, and contextual innovation. Sustainable practices are increasingly recognised as essential in architecture education: however, research indicates that specialised training is necessary to bridge the gap between theoretical knowledge and practical application (Lotfabadi and Iranmanesh 2025).

Fundamentals of Circular Design (System-level Approaches)	Recycling	Upcycling	Downcycling	Repurposing
Design for Disassembly				
Life Cycle Assessment				
Design for Adaptability				
Material Loops				

Table 1. Mapping of system-level circular design principles to application-level spatial strategies in interior design.

A persistent gap remains between what is taught in design curricula and what is required in professional practice, particularly regarding innovation and forward-thinking approaches (Ahmad et al. 2024; El-Kholei and Yassein 2023; Lotfabadi and Iranmanesh 2025). Consequently, students may graduate with a conceptual understanding of sustainability but lack the technical and strategic competencies required to integrate circular design principles (CDPs) into real-world design solutions. This educational gap constitutes a significant barrier to preparing design professionals capable of addressing the challenges of environmental degradation, material waste, and resource scarcity. Addressing this limitation requires targeted pedagogical interventions that integrate conceptual understanding with applied circular spatial strategies.

This paper presents findings from a study examining the competency gap in interior design education, specifically investigating whether students possess the knowledge and skills required to integrate circular design strategies into spatial design solutions. The study focuses on circular design principles, including recycling, upcycling, downcycling, and repurposing, as key strategies to address furniture waste.

To explore this gap, the paper first examines undergraduate curricula from leading architecture and interior design programs in India to assess the extent to which Circular Design Principles (CDPs) are embedded within program structures. This is followed by an examination of studio design briefs from diverse schools to assess how sustainability and circular design concepts are operationalised in actual studio training exercises. Finally, the study evaluates students' baseline understanding and applied competency in circular design through a structured group exercise, assessing their ability to apply circular strategies both before and after minimal theoretical input.

By mapping curricular content, pedagogical translation, and student performance, the research identifies gaps in both educational structure and applied competency. The findings aim to inform the development of targeted pedagogical interventions that strengthen student capabilities in sustainable spatial design through circular methodologies. The study contributes to design education research, supports curriculum development in sustainability-focused pedagogy, and provides industry stakeholders with insight into the preparedness of graduates to apply circular economy thinking in practice.

2. BACKGROUND

As with other material products, furniture has a finite lifespan determined by use, functionality, and aesthetic relevance. Once it is no longer required or considered suitable for continued use, it is commonly discarded and ultimately enters the waste stream, often ending up in landfills. The environmental impact of this disposal process is significant. The scale of furniture waste generation is substantial, with some regions reporting over 150 tons per day from the furniture sector alone

(Pringle et al. 2018). Moreover, the downstream phases of the furniture lifecycle—particularly transportation and end-of-life processing—account for the majority of greenhouse gas emissions associated with the sector (Coloma-Jiménez et al. 2022). These findings indicate that furniture waste is not merely a disposal issue but a significant contributor to climate-related environmental impacts.

In response to these challenges, the circular economy has emerged as a compelling framework that rethinks traditional linear consumption models. By promoting the reuse, recycling, and transformation of materials, circularity seeks to reduce both resource extraction and waste production. This approach involves new forms of coordination across processes, actors, and scales (Nikolaou and Stefanakis 2022). In the context of furniture and interior design, strategies such as upcycling, recycling, repurposing, and the use of biodegradable or composite materials are gaining traction. These approaches not only reduce dependence on raw materials and landfill waste but also present economic and social benefits(Fekry Gamal 2022; Ofori-Agyei et al. 2023; Wang et al. 2023). Among these, upcycling is particularly notable for enabling community engagement and innovation. Design in the circular economy is complex and requires a transformation in thinking to shift from the current product-centric focus towards a more system-based design approach.

Circular design operates on the principle of delivering products or services that are not only functional and high-performing but also optimised in terms of materials to minimise environmental impact over their entire lifecycle (see Fig. 1). It moves the design process from a product-centric orientation toward a systems-based approach. This means designing with a lifecycle mindset—reducing the use of virgin raw materials, planning for product longevity, and ensuring that components can be recovered or repurposed at end-of-life. Such thinking requires a paradigm shift in how designers conceive, specify, and evaluate materials and forms.

Despite growing recognition of the environmental implications of furniture waste and the potential of

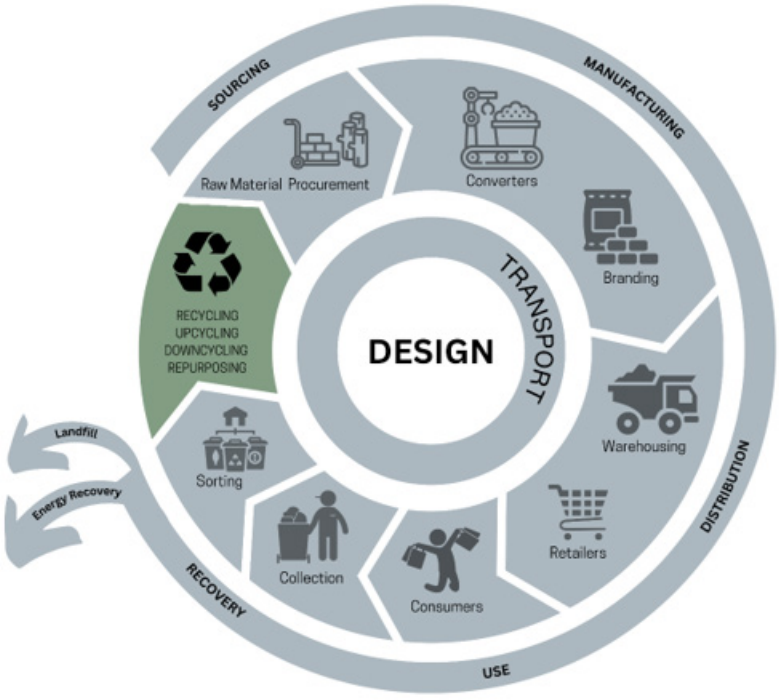

Figure. 1 Augmented Circular Design Diagram (Adapted from Goel, 2018)

circular strategies, architectural and interior design education often treats sustainability in isolated fragments rather than through integrated, holistic approaches. Most university-level programs offer dedicated courses on sustainability only as electives or brief modules within other courses, rather than embedding these principles across the curriculum(Watkins et al. 2021). As a result, concepts such as energy efficiency, material lifecycle management, and waste minimisation are taught as separate topics without adequate linkage to show their interdependencies and cumulative environmental impact. This disjointed delivery limits students' ability to approach sustainability as an inherent design lens rather than an optional consideration.

In the Indian context, there is a further deficit in targeted curricular scaffolding that explicitly builds competencies in circular design (Sinha et al. 2025). Across Indian architecture and interior programs, sustainability typically appears as broad environmental content (e.g., climatology, energy, green-rating awareness) rather than as a mandated, competency-based circular design component. The Minimum Standards of Architectural Education (2020) set overall structures and outcomes for B.Arch but do not require explicit training in circular design principles such as LCA, DfD, furniture redesign, or waste management (recycling, upcycling, downcycling, and repurposing), leaving integration to institutional discretion. At the system level, the UGC requires an undergraduate Environmental Studies course, which reinforces general awareness but is not a substitute for practice-oriented circular design skill (UGC 2023). Parallel skill ecosystems exist—industry frameworks and trainings such as GRIHA learning resources for green buildings, and the Ellen MacArthur Foundation's circular design tools for higher education—but these are typically optional add-ons rather than embedded curricular scaffolds (Ellen MacArthur Foundation, 2023). Even where sustainability is mentioned, it is rarely operationalised through structured, experiential learning opportunities that train students to select, adapt, and apply strategies such as recycling, upcycling, downcycling, and repurposing based on project-specific contexts. By contrast, the international state of the art emphasises project-based integration of circular design methods: reviews synthesise effective approaches (systems thinking, PBL, challenge-based learning) for education for the circular economy; studios that teach LCA within design projects show measurable learning gains; and DfD pedagogy is documented through dedicated modules and scoping reviews that outline competencies and assessment (Gomes et al. 2022; Ostapska et al. 2024; Renfors 2024).

3. METHODOLOGY

This study employed a sequential mixed-methods design with two components: (1) a desk analysis of Indian design education to establish curricular context and (2) an empirical classroom study to probe students' understanding and application of Circular Design Principles (CDPs).

Curricular Component: As the preliminary step to this study, we analysed undergraduate curricula from leading architecture and interior design programs in India to assess the extent to which Circular Design Principles (CDPs) are explicitly incorporated and operationalized in training. We sampled 15 architecture programs from the NIRF India Rankings: Architecture & Planning (NIRF 2024) and 15 interior programs from the IIRF Design Colleges Rankings (IIRF 2025), filtering for institutions offering Interior/Furniture Design specializations. Further, we collected design studio briefs across schools of architecture and design to assess the extent to which CDPs are integrated into studio pedagogy. A total of 17 briefs were collected.

Pedagogy and Student Application Components: We then conducted a synchronous session with 23 third-year B.Arch students in their design studio. This cohort was selected because, by the third year, students typically demonstrate foundational proficiency in user-centric design considerations (e.g., market analysis, contextual assessment, visualization, ergonomics). Although the study has implications for architecture, interior, and furniture design disciplines, the diagnostic phase engaged architecture students as the primary participant group. The main research question addressed in this paper is: To what extent do students integrate Circular Design Principles in design solutions?

The primary objectives of this study were:

- To assess the explicit integration of CDPs within leading Indian curricula—tracking the presence of circular design terminology, LCA, design for disassembly, adaptive reuse, and furniture-waste–related assessment—and to identify how these competencies are being emphasised in design studios.

- To assess students' natural design inclinations, highlighting whether sustainability or circularity emerges organically in early-stage conceptualisation.

- To assess the depth and specificity of sustainability knowledge—beyond superficial mention—to examine if students understand how to implement environmentally responsible choices (e.g., material sourcing, lifecycle thinking, spatial reuse).

Step	Objective	Data Source(s)	Instruments & Analysis Method used
Desk Research: Curricular Component			
Curricula Study	To establish the instructional context for circular design in India.	Syllabi of 15 Architecture and 15 Interior Design Schools	● Comparative Analysis ● Structured Thematic Coding (Deductive) ● Competency Mapping
Design Brief Study	To assess the extent of Circular Design Principles (CDPs) integration in existing pedagogy.	17 Design Briefs	● Comparative Analysis ● Structured Thematic Coding (Deductive)
Student Interaction: Pedagogy and Student Application Components			
Pre-Session Survey and Baseline Assessment	To establish baseline understanding by assessing familiarity with circular material concepts and recording initial design priorities before targeted instruction.	Form Responses Design Drawings (which were created before the interaction)	Instrument - Pre-Session Survey Questionnaire ● Content Analysis ● Descriptive Statistical Analysis to calculate frequencies ● Comparative Analysis ● Thematic Coding (Deductive)
Synchronous Interaction	To test students' ability to apply freshly acquired concepts to design problems with minimal instructional assistance.	Form Response	Instrument - Design Approach Questionnaire (DAQ) Scaffold - Basic Conceptual Explanation of each strategy ● Perception vs. Implementation Mapping ● Knowledge Assessment Analysis

Table 2. Overview of Research Components, Data Sources, Instruments, and Analytical Methods

The student-focused study adopted a two-phase approach (see Fig. 2) consisting of a pre-session baseline assessment followed by a classroom interaction, each designed to probe different dimensions of students' understanding and application of circular design principles (CDPs).

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4. PROCEDURE

4.1. Curricular Component: Curricula and Studio-Brief Study

Desk research on undergraduate curricula was conducted to establish the instructional context for circular design in India. We reviewed 30 programs: 15 B.Arch programs sampled from the NIRF India Rankings – Architecture & Planning (2024) and 15 Interior programs sampled from the IIRF Design Colleges Rankings (2025), filtered to institutions offering Interior/Furniture Design

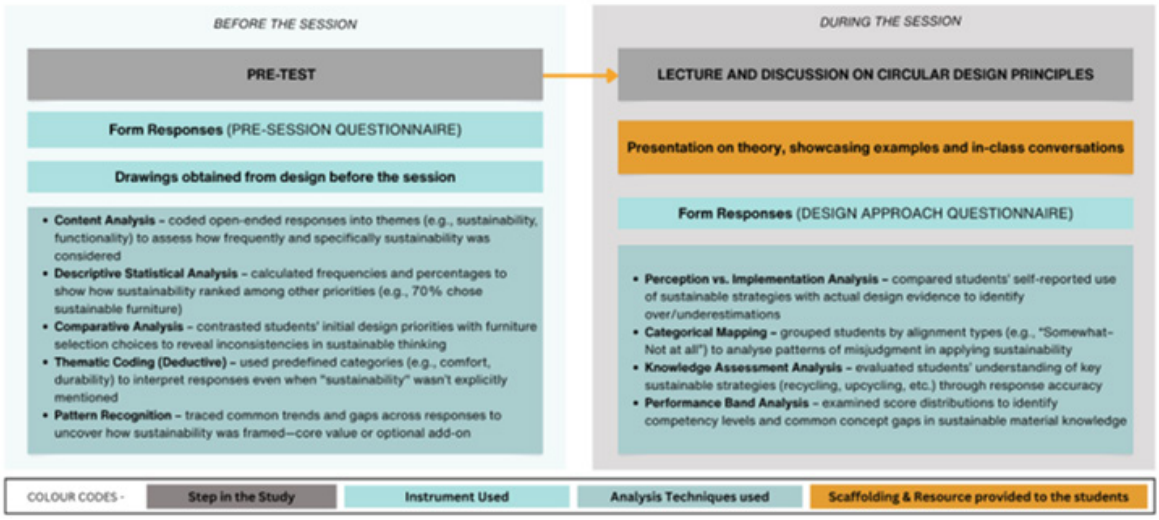

Figure 2. Study Methodology Diagram

specialisations. For each program, the latest publicly available scheme of study, syllabi, handbooks, and studio/course descriptions were compiled.

In addition to program syllabi, we aimed to analyse studio briefs across schools of architecture and design to assess the extent to which CDPs are integrated into design pedagogy. To do so, faculty members from different schools were contacted and requested to share any design briefs that they formulated where sustainability was explicitly listed as a criterion (core or elective). 17 semester-long studio briefs were examined to understand how sustainability is operationalised in design teaching.

4.2. Pedagogy and Student Application Components

This part of the study operationalises circular design competency using four material transformation strategies: recycling, upcycling, downcycling, and repurposing, selected for their direct relevance to furniture waste management and end-of-life decision-making. These strategies represent application-level skills that translate these principles (such as Design for Disassembly, Life Cycle Assessment, and adaptability) into tangible design actions. By focusing on these four strategies, the study assesses whether students can recognise circular opportunities in existing material flows, evaluate appropriate transformation pathways based on material condition and context, and implement this approach in furniture specification and detailing decisions. These competencies are essential for addressing the furniture waste challenge documented in the Background section. This approach enables measurement of students' operational capacity to apply circular thinking, which serves as a foundation for more complex system-level competencies (e.g., LCA, designing complete disassembly sequences) that can later be built.

Phase 1: Pre-Session Survey and Baseline Assessment

Prior to any formal instruction in sustainable or circular design, students were given a pre-session survey (see Fig. 3 for sample questions) to capture their baseline understanding, intuitive responses, and cognitive framing. This was done when they first encountered a context-based design challenge, in this case, a community library. The instrument was grounded in principles of situated cognition (Brown et al. 1989) to assess prior knowledge, reveal implicit assumptions, and identify conceptual gaps in sustainability thinking.

The session was scheduled midway through the semester, when students had already completed an initial design for a community library. The original design brief embedded implicit opportunities for sustainable strategies (for example, a rural site that might naturally suggest the use of local materials) but did not explicitly require consideration of sustainability principles. This allowed the researchers to assess whether students, without prompting, would naturally incorporate CDPs into their design processes or outputs.

The pre-session survey was intentionally designed to:

- Probe the extent to which sustainability considerations emerge unprompted.
- Assess familiarity with concepts such as recycling, upcycling, downcycling, and repurposing.
- Record students' initial design priorities and strategies before exposure to targeted instruction.

Phase 2: Synchronous Interaction

Following the survey, a synchronous, in-person interaction was conducted. The physical environment was designed following Duh & Nemanič's (2020)

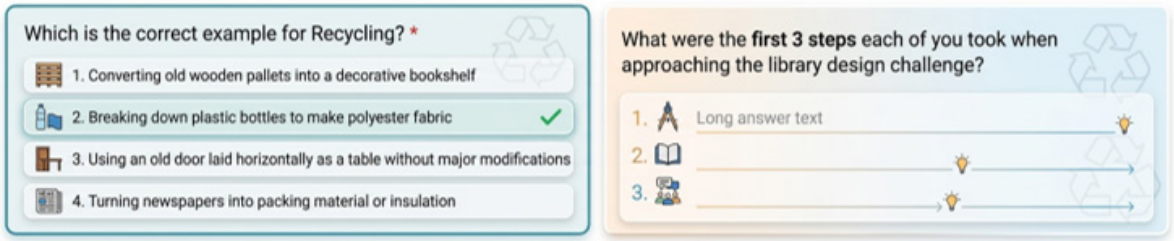

Figure 3. Sample questions from the Pre-Session Survey assessing baseline knowledge of circular design strategies (left) and initial design priorities (right).

approach and was arranged to support both didactic (lecture-based) segments and interactive, collaborative design activities, enabling a fluid transition between conceptual instruction and applied design exercises. All activities and discussions were conducted in groups of three students. During the interaction, students completed a second instrument—the Design-Approach Questionnaire (DAQ)—to capture changes in conceptual understanding and immediate application skills following instruction.

The session began with a facilitator-led discussion highlighting furniture waste issues at global and Indian scales, situating the topic within broader environmental and resource challenges. Students were prompted to reflect on why furniture waste represents a critical sustainability concern, activating prior knowledge and encouraging contextual reasoning. This was followed by an introduction to Sustainable Development Goals (SDGs) relevant to design practice, with explicit focus on four key circular design strategies: Recycling, Upcycling, Downcycling, and Repurposing. For each strategy, the facilitator:

- Provided concise conceptual explanations
- Offered illustrative examples relevant to furniture and interior design
- Conducted 5-minute micro-activities with basic scaffolding, allowing hands-on engagement with each concept through guided practice and structured support

These applied exercises were intended to test the transfer of learning through basic theoretical scaffolding—students' ability to apply freshly acquired concepts to design problems with minimal instructional assistance. The combined theoretical instruction and scaffolded micro-activities occupied approximately 1.5 hours.

5. INSTRUMENTS

Before the interaction: Pre-session Survey: This survey served as a comprehensive assessment tool to evaluate students' existing knowledge and approach to sustainable design strategies before the session. It was conducted in two phases: an initial questionnaire distributed one day prior to the session, followed by a second component administered immediately before the session began. It contained 12 primary questions divided into two main areas: Design Approach Assessment (6 questions) - examining students' initial design steps, rationale behind their decisions, furniture selection priorities, and sustainable strategy incorporation in their library design work, and Conceptual Knowledge Assessment (6 questions) - testing students' ability to correctly identify and distinguish between key sustainability concepts: recycling, upcycling, downcycling, and repurposing.

This survey was designed to establish baseline knowledge[GG2.1] of fundamental sustainable design concepts, identify existing design approaches and priority hierarchies in student decision-making processes, assess the knowledge-action gap between theoretical understanding and practical implementation of sustainable strategies and evaluate the accuracy of students' self-assessment by comparing their perceived incorporation of sustainable strategies with evidence from their actual design work. The instrument was validated through expert review by three design faculty.

During the interaction: The Design Approach Questionnaire (DAQ) was developed based on established circular design frameworks (Ellen MacArthur Foundation, 2023) and validated through consultations with two sustainability experts. This questionnaire consisted of four practical application questions administered after each concept-based interaction on recycling, upcycling, downcycling, and repurposing. This section was structured as a set of interactive learning exercises rather than traditional assessment questions. Each question followed a consistent pedagogical approach: a 10-minute concept discussion led by the facilitator, followed by a 5-minute practical exercise where each group of three students worked together to brainstorm, sketch, and articulate specific sustainable solutions for different contexts. This scaffolded structure was designed to immediately reinforce the theoretical concepts through application while encouraging peer-to-peer knowledge exchange. The exercise served as a post-test, allowing facilitators to gauge students' grasp of the concept and identify areas requiring additional scaffolding during the main session.

6. DATA SOURCES

Three complementary data sources were collected during the study :

Pre-session Survey Responses captured students' self-reported design priorities, furniture selection criteria, and baseline conceptual understanding of circular design strategies (recycling, upcycling, downcycling, and repurposing) prior to formal instruction.

Design Drawings, produced early in the semester, served as a supplementary data source (see Fig. 4). They provided tangible evidence of students' instinctive design approaches. These drawings were completed prior to any formal introduction of sustainability in the project brief, allowing for an authentic examination of whether CDPs were incorporated instinctively. The analysis compared students' perceived use of

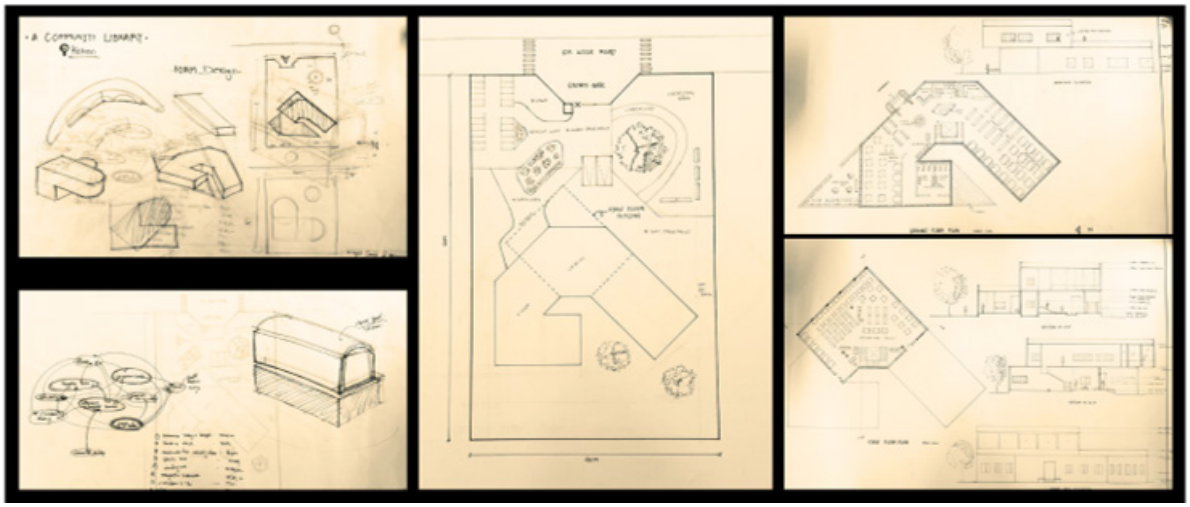

Figure 4. Sample student design drawings (furniture concepts, site plans, and floor plans) for the community library project, produced prior to the interaction.

sustainable strategies with evidence in their design work.

Design Approach Questionnaire (DAQ) Responses collected during the synchronous session documented students' immediate application of circular design concepts after scaffolded micro-activities, serving as a post-instruction assessment of knowledge transfer and problem-solving capability.

7. ANALYSIS

This study uses a sequential mixed-methods design to address the research question comprehensively. The analysis integrated multiple datasets collected at key stages of the study—preliminary, pre-session, and during-session—as outlined in the research methodology diagram (see Fig. 2). The overall strategy combined diagnostic and evaluative components to assess how students prioritised sustainable strategies in their design decision-making processes. The analysis drew on five primary data sources: curricula from architecture and interior design programs, a collection of studio design briefs, pre-session survey responses, pre-session drawings, and Design Approach Questionnaire (DAQ) responses.

A desk-based content analysis was first conducted on the architecture and interior design program curricula of established schools in India. Thirty curricula were collected and examined for this purpose. Using a structured coding process, we recorded the presence or absence of six indicators across these curricula applying a binary coding scheme (1=present, 0=absent): explicit use of the terms sustainability or circular design/ circular economy; LCA; DfD; adaptive reuse/renovation (core or elective); general sustainability/green building/environment coursework; and assessment components that could reasonably evaluate furniture or fit-out waste strategies (e.g., reuse/upcycling briefs, disassembly criteria, salvage/material passports). Each indicator required explicit textual evidence from course descriptions, learning outcomes, or assessment criteria; mere mention of related terms without an operational definition was coded as absent. For example, if a school's (coded A10) course curriculum included a module titled "Sustainable Architecture Practices" or "Green Building Design," it was coded as present (1) for the term sustainability. Frequencies were summarised by program type and visualised in a single grouped bar chart. To establish reliability, 30% of curricula (n=9) were dual-coded, achieving Cohen's kappa $\kappa = 0.87$, indicating strong inter-rater agreement.

This was followed by a second desk-based study of Design Briefs collected from schools of architecture and interior design across India. Each brief, which included learning outcomes, deliverables, context, and general specifications, was analysed using a structured coding framework that captured positioning (where sustainability appears–programme outcomes, studio aims, or evaluation criteria), extent of integration (emphasis across briefing, concept development, schematic design, detailing, and documentation); depth of application; and assessment criteria . For example, Brief INTD_002 mentioned sustainability 8 times and allocated 8% marks, but focused exclusively on "eco-friendly material selection" without requiring lifecycle analysis or disassembly documentation (coded as MATERIAL only). Two reviewers independently coded all 17 briefs using a structured rubric. Initial inter-coder agreement was 91% (Cohen's kappa $\kappa = 0.89$). The remaining 9% of discrepancies were resolved through consensus discussion.

For pre-session data, the following method was applied: Open-ended responses were systematically coded into thematic categories (e.g., sustainability, functionality, comfort) to interpret responses even when “sustainability” was not explicitly named, allowing implicit sustainability indicators to be captured. Frequencies and percentages were calculated for each design priority, and these were used to determine sustainability's rank relative to other priorities (e.g., the proportion of students selecting 'sustainable furniture' among their top choices, which determined its relative rank position). Students’ stated design priorities were contrasted with their reported furniture-selection criteria to reveal potential misalignments in their sustainable thinking. Trends and recurring omissions were mapped to identify whether sustainability functioned as a core design value or was treated as a secondary/optional add-on. Additionally, students were grouped into alignment categories (e.g., somewhat to not at all) to analyse misalignments[GG3.1] between stated intentions and actual application of sustainability strategies.

For the during-data session, the following analytical techniques were employed: Students’ self-reported use of sustainable strategies was compared to tangible evidence found in their pre-session design drawings, revealing overestimating and underestimation[GG4.1] in their actual practice. Students’ conceptual understanding of the four sustainable strategies (recycling, upcycling, downcycling, and repurposing) was measured using accuracy scores from the DAQ responses. The distribution of scores was examined to identify competency levels and common conceptual gaps, particularly in the application and selection of sustainable materials. Lastly, the quick design exercises were analysed to evaluate whether students could integrate sustainability strategies into spatial and material decision-making processes. The evaluation process was deliberately kept straightforward, focusing solely on whether a sustainability-oriented strategy appeared in any stage of the student’s design process. This provided a clear, binary indicator of CDPs presence or absence, enabling a direct alignment check between self-reported intentions and the tangible design outcomes.

This multi-layered analytical framework was developed for a nuanced interpretation of students’ sustainability integration—capturing what the curricula orient them to learn, what they believe they know, what they claim to know and do, and how closely these perceptions align with their demonstrable design outputs.

8. FINDINGS

Across curricula, sustainability is widely referenced, but explicit, scaffolded training in circular design and furniture-waste assessment remains essentially absent, indicating a lack of practice-ready competencies.

Fifteen architecture programs were selected from the NIRF India Rankings - Architecture & Planning (NIRF, 2024) published by India’s Ministry of Education. A further 15 interior programs were selected from the IIRF Design Colleges Rankings (IIRF, 2025), filtered to institutions offering Interior/Furniture Design specializations. Reviewing these 30 publicly available curricula shows broad use of the term sustainability across programs, but no integration of circular design in either program type. Not a single program explicitly names “circular design/circular economy” as a required strand. Method-level competencies central to circularity—LCA and design for disassembly (DfD)—are likewise absent as explicit content (see Fig. 5).

Sustainability courses are widespread in architecture (14/15 programs list environment/energy/green building content) but less consistently visible in interior design (5/15). Where circular-adjacent ideas surface, they appear as isolated modules or electives rather than a scaffolded progression across studios. For example, adaptive reuse/renovation is clearly listed in only 1/15 interior curricula and 6/15 architecture curricula.

No program publishes explicit, furniture-waste–focused assessment criteria in the documents reviewed. However, 24/30 curricula include applicable terms (e.g., Sustainable Design courses, Material Studios, Renovation/Alteration projects) that could be used to evaluate repairability, reuse, disassembly, or material salvage—yet these opportunities are not formalised into outcomes or rubrics tied to furniture and fit-out waste.

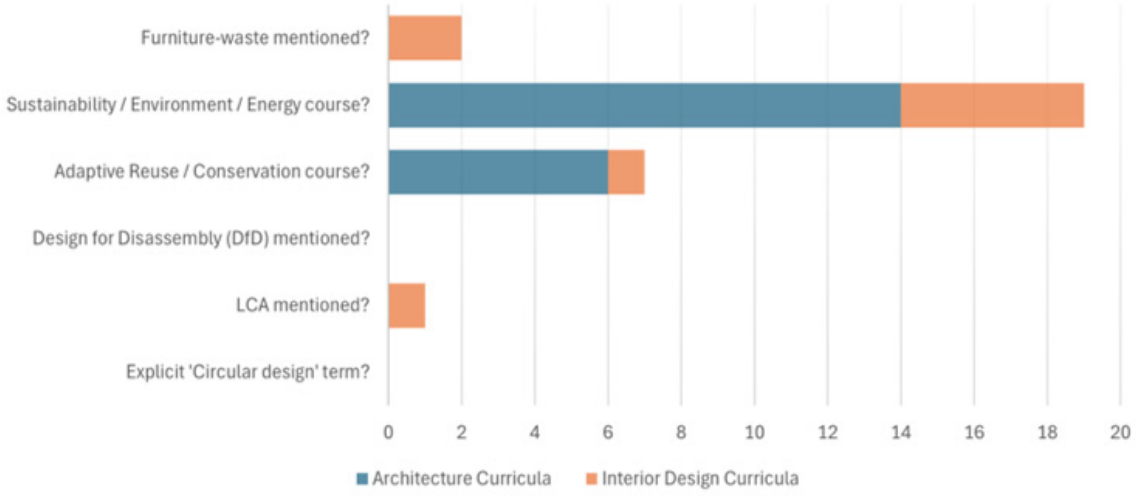

Figure 5. Graph showing presence/absence of CD indicators across 30 Indian undergraduate curricula (n = 30)

Taken together, the evidence indicates a structural gap: sustainability is present as knowledge about environmental issues, but competency-based training for circular practice is not embedded. The result is students graduating with awareness but limited operational capacity to address furniture and interior waste.

The design briefs lack actionable skill requirements and generalise sustainability to material selection, with no demand for methods or strategies like LCA, design-for-disassembly, or waste planning.

Across briefs, sustainability appears frequently in text but is rarely structured as a competency. Learning-outcome language leans on awareness verbs ("appreciate," "be mindful," "consider"), and no brief specifies actionable skills (e.g., conducting LCA boundaries, planning disassembly, repurposing, reusing, and other end-of-life strategies). In practice, sustainability is collapsed into material substitution: 13/17 briefs frame it as "material choice" (with 3/17 briefs showing "partial mentions" and 1/17 showing "no mention"), while lifecycle consideration, disassembly documentation, and waste reduction strategies are all absent.

Sustainability is typically allocated token marks, clustered between 1–10%, with several briefs at 0% and none above 20%, which communicates that applying circular strategies is peripheral to overall performance as shown in Fig. 6. Such low, dispersed weightings are misaligned with the briefs'own pedagogical intent[GG5.1] to ensure students have learned to apply sustainability: they reward mention rather than method, and they provide too little incentive for evidence-based outputs (e.g., disassembly diagrams, reuse schedules, end-of-life plans).

Overall, briefs signal sustainability but seldom scope it into method or evaluate it as performance, which explains why application tends to stop at materials rather than inform spatial strategy, assembly logic, adaptability, or circular workflows.

Sustainability is not among the primary design considerations

An analysis of students' initial design approaches reveals that sustainable design principles do not emerge as intuitive or automatic considerations for interior design students (see Fig. 7). The pre-test questionnaire responses show that only 9% (2) of students prioritised sustainability in their initial approach, despite libraries being long-term community assets where sustainable design can offer significant benefits in terms of operational costs, environmental impact, and user comfort. Only 26.1% (6) of students explicitly included sustainability or recycling among their top three design considerations. Overall, sustainability-related considerations received only three mentions, placing them well behind other design aspects.

SC01 referenced "sustainable materials" as part of their preliminary design strategy, SC07 identified an "eco-friendly library" as a primary consideration, and SC22 demonstrated the most comprehensive understanding by listing "sustainable material," "eco-friendly environment," and "3Rs" as key approaches.

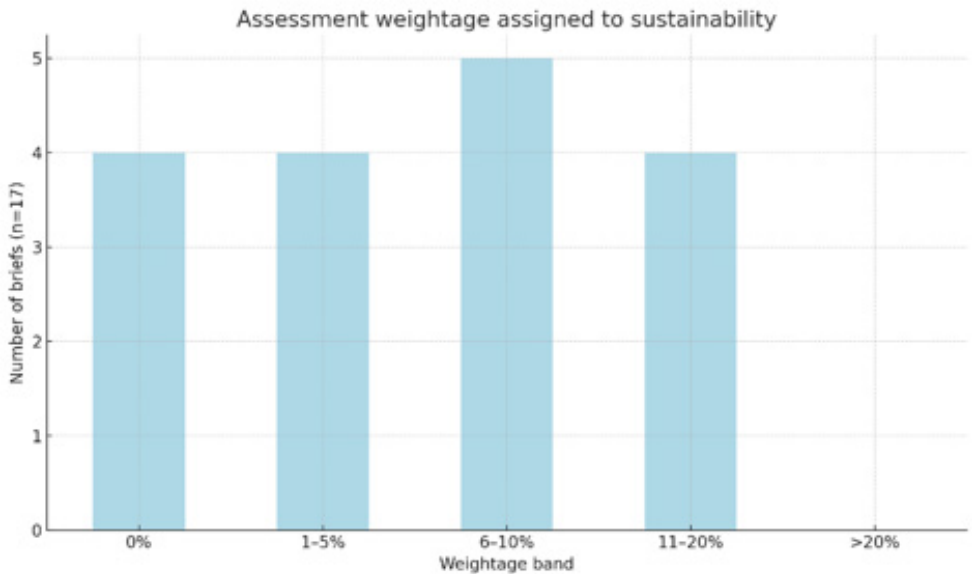

Figure 6. Distribution of Assessment Weightage Assigned to Sustainability Across Design Studio Briefs (n=17)

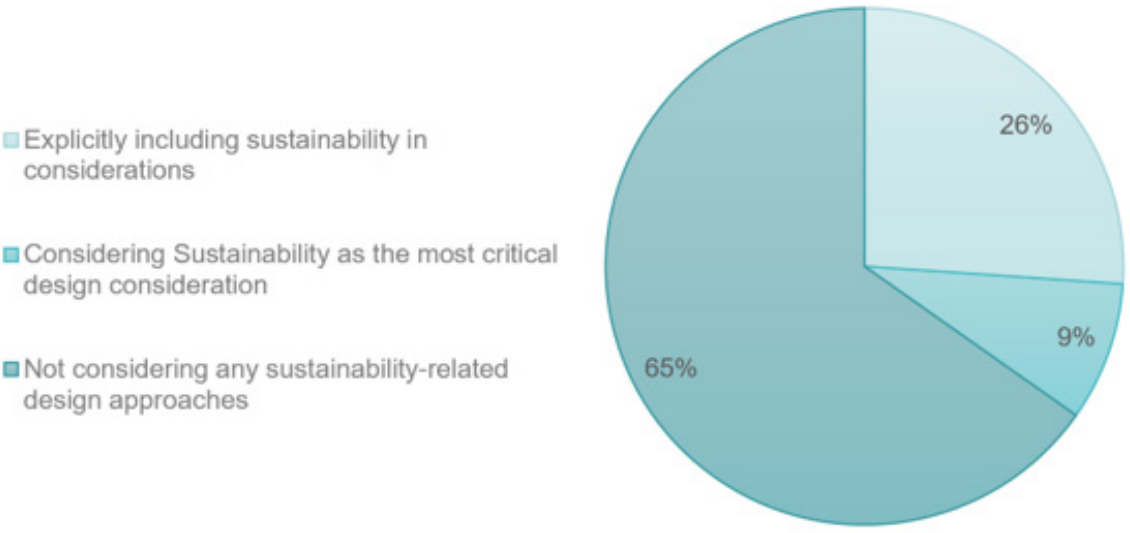

Figure 7. Students' Consideration of Sustainability in Design

This pattern is consistent with the broader emphasis on functional design priorities (accessibility, comfort, ergonomics) over sustainability. It was also noted that references to sustainability lacked specificity, typically appearing as generic statements ("Sustainability is important" or "Furniture[GG6.1] must be sustainable/ recycled") without detailed implementation strategies or concrete applications.

When asked to identify their primary considerations for selecting library reading area furniture, students prioritised:

i. "User comfort and body-friendly seating" - 23/23 students (100%)

ii. "Aesthetic harmony with the overall design concept" - 19/23 students (83%)

iii. "Flexibility to accommodate different user groups and activities" - 17/23 students

Sustainable and eco-friendly materials tied for 4th place (along with "Durability and maintenance requirements" and "Tactile qualities and material experience"), with 16 out of 23 students (70%) selecting it as a primary consideration (see Fig. 8).

This indicated that while sustainability is important to most students (70%), it is not yet considered as essential as comfort, aesthetics, or flexibility. Interestingly, considerations that might complement sustainability, such as "Durability and maintenance requirements" (also 70%) and "Cost-effectiveness" (52%), received varying levels of attention. This suggests students may not be fully connecting how these aspects interrelate in sustainable design practice. The data reveals an opportunity to strengthen education on integrated sustainable design thinking, where sustainability isn't just about materials but encompasses durability, maintenance, cost over time, and other factors that contribute to truly sustainable furniture solutions.

Further, as part of a collaborative group activity (Question 1, DAQ: furniture selection for library reading areas), sustainability and its associated concepts ranked only sixth in priority (see Fig. 9), far behind other considerations such as anthropometry and ergonomics, accessibility, and functionality. This positioning further reinforces that sustainability is not perceived as a primary driver in students' design decision-making and tends to be overshadowed by functional and aesthetic concerns.

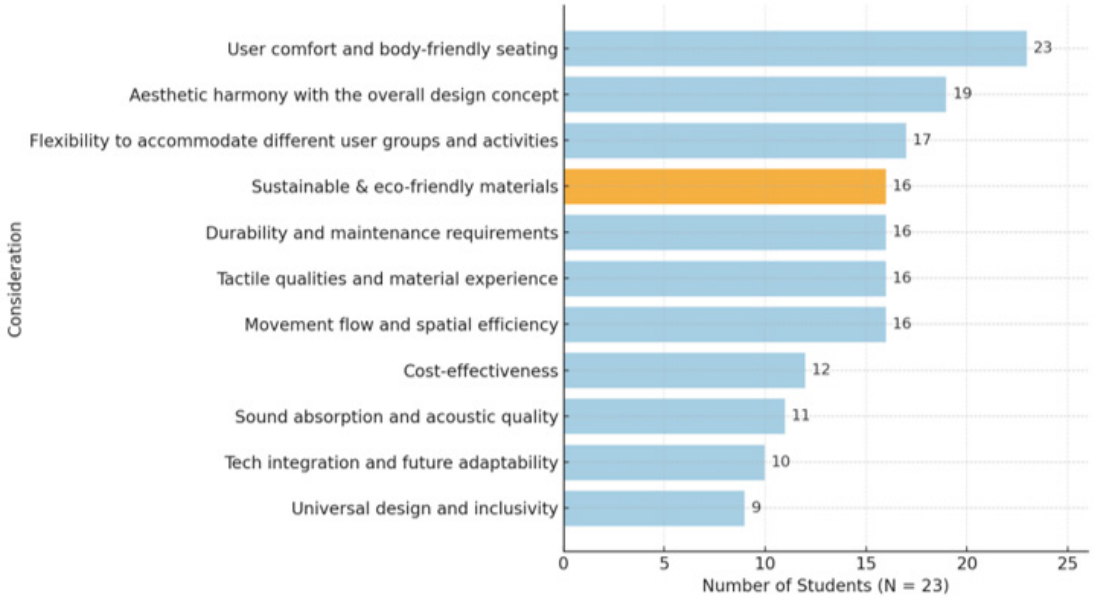

Figure 8. Graph showing primary considerations for library furniture selection in individual pre-session responses.

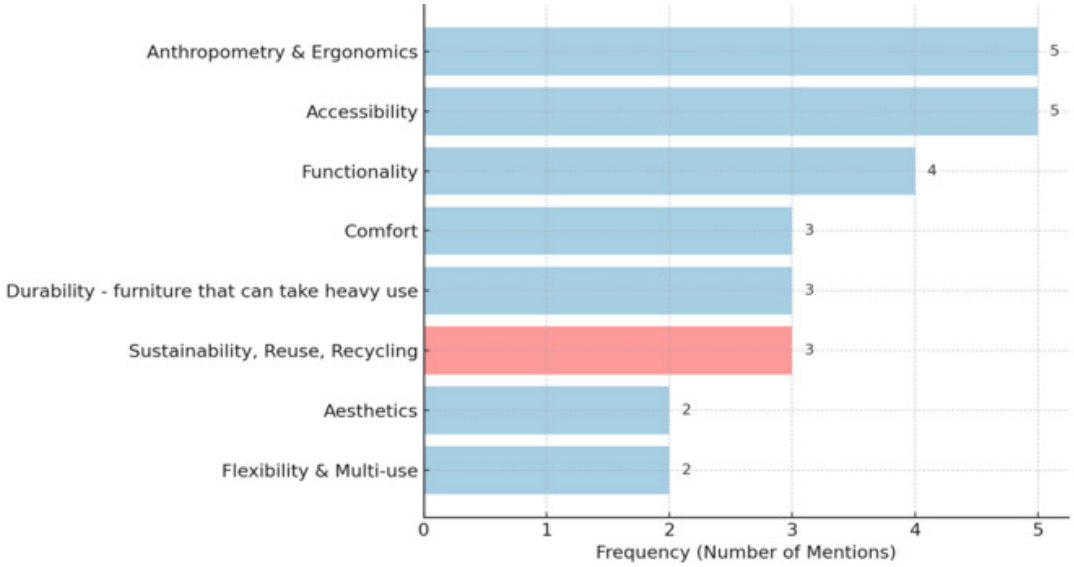

Figure 9. Primary considerations for library furniture selection in group responses from DAQ

This mirrors the earlier finding: even in group discussion, functional criteria took precedence, with sustainability considerations not emerging as a defining factor (only 3 mentions).

These findings clearly indicate that the concept of sustainable design remains peripheral to students' core design thinking and only surfaces when specifically mandated or following prior exposure to sustainability-focused instruction, highlighting the need to incorporate more comprehensive education on sustainable design strategies that position sustainability as an integral, rather than supplementary, component of the design process.

Perception–-Reality Gap in Sustainable Design Implementation

When students were asked whether they incorporated any sustainable strategies to design the library, a significant discrepancy emerged between their self-perception and actual evidence. Student responses were divided into six categories, as shown in Table 3, based on the alignment between students' self-reported use of a sustainable strategy (SS) and the actual evidence of that strategy in their pre-session drawings. To examine the accuracy of these self-reported perceptions, these pre-session drawings were analysed and mapped against their survey responses to identify whether the claimed incorporation of circular design thinking was evidenced in their design considerations and representations.

The data revealed distinct patterns of alignment and misalignment in students' assessment of their sustainable design integration. Students demonstrating matched perceptions included those in the "Somewhat–Somewhat" category (3) who demonstrated conceptual awareness of sustainable strategies but limited or surface-level application of them in their drawings, "Not at all–Not at all" students (4) who correctly identified their lack of sustainable strategies, and the "Significantly–Significantly"(1) student who recognised their detailed implementation efforts.

However, the more concerning pattern involved misaligned perceptions across multiple categories (see Fig.10). Students in the "Somewhat–Not at all" group (11) were overestimating their use of sustainable strategies, claiming basic-level incorporation that was not found in their drawings, while those categorised as "Significantly–Not at all" (2) showed an even greater gap, claiming significant incorporation that was also absent from their actual designs. Some students in the "Not at all–Somewhat[GG9.1]" category (2) were underestimating their implementation efforts.

This misalignment indicates a fundamental gap in understanding of what constitutes meaningful sustainable design implementation, with many students believing they incorporated sustainable strategies when evidence from their work suggests otherwise. The disconnect points to critical educational needs: clearer criteria for what constitutes different levels of

Alignment Pattern	Description
Somewhat–Somewhat	This student's self-reported level of understanding in the pre-session questionnaire (Q1) aligned with the level of incorporation actually shown in their design drawings, with both at a preliminary level.
Somewhat– Not at all	While students believe that they incorporated a sustainable strategy (SS[GG1.1]) in the design at a basic level, it was not found in their primary design considerations and/or in their drawings.
Significantly –- Not at all/Somewhat	While the student believes that he/she incorporated a SS[GG2.1] in the design at a detailed level, it was not found in their primary design considerations and/or in their drawings.
Not at all –Somewhat	While the student believes that he/she didn't incorporate a SS in the design at any stage of the design process, it was found in their primary design considerations and/or in their drawings.
Not at all –Not at all	This student correctly reported not incorporating any sustainable strategy, and none was found in their design considerations (pre-session Q1) or drawings.
Significantly –Significantly	This student accurately reported a high level of sustainable strategy incorporation, which was confirmed by detailed evidence in their drawings.

Table 3. Categories of alignment between student responses and drawings

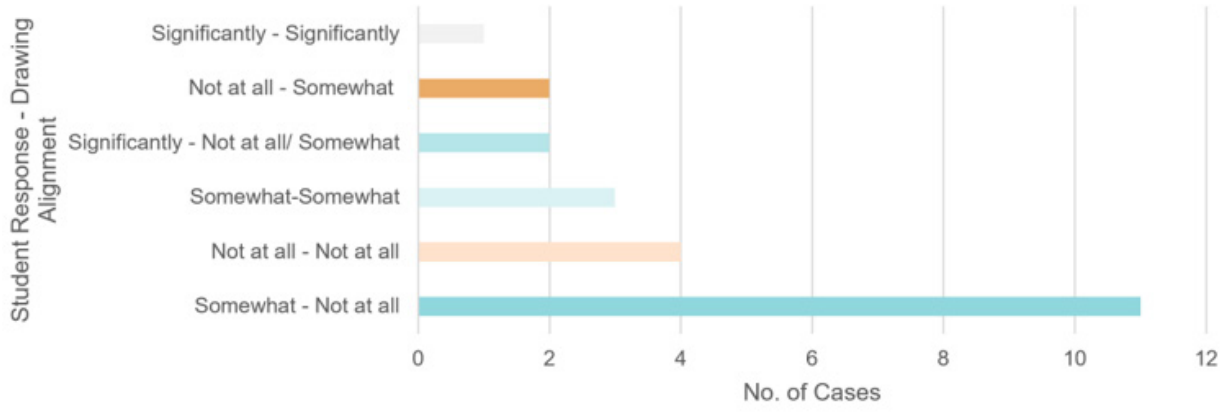

Figure 10. Graph showing the distribution of alignment and misalignment between students' perceived incorporation of sustainable strategies in their library designs and evidence in initial design drawings.

sustainable strategy implementation, more practical education on translating sustainable concepts into actual design elements, and tools for students to self-evaluate their work against sustainable design standards. The pattern suggests many students may have surface-level knowledge about sustainability but struggle to apply it meaningfully in practice, reinforcing previous findings that sustainable design education requires significant strengthening in the curriculum to bridge the theory-practice divide.

Knowledge vs. action in sustainable design education.

When asked to identify the correct sustainable strategy between recycling, upcycling, downcycling, and repurposing in the pre-session survey, students were generally aware of sustainability as a concept but lacked detailed knowledge of specific sustainable material strategies: 8 of 23 students answered none of the four pre-session questions correctly, while only 3 achieved a perfect score (see Fig. 11(a)). Students demonstrate a significant knowledge gap in understanding fundamental sustainable material concepts, particularly in recycling (17.4%) and upcycling (30.4%) (see Fig. 11 (b)). While repurposing concepts were better understood (47.8%), students' average performance across all four pre-session questions (34.8%) indicates an insufficient grasp of circular economy principles essential for sustainable design thinking.

9. DISCUSSION

The findings can be organised in a sequence that moves from curricular framing to student cognition, providing a comprehensive understanding of the educational gaps that must be addressed to improve sustainable design pedagogy.

Systemic Gaps Across Curricular, Pedagogical, and Student Dimensions

Across syllabi, the word sustainability is used frequently, but mostly as a broad theme rather than a structured competency, as defined earlier (see Introduction). Course descriptions and outcomes often signal "awareness," "appreciation," or "sensitivity," yet rarely specify what students must learn to do. As a result, the term appears in many places, but it is not unpacked into assessable skills, nor sequenced across semesters as a progressive learning pathway.

In studio briefs, the practical translation of sustainability is narrowed to material choice—"use eco-friendly/ local/green-rated materials"—with limited attention to spatial and assembly strategies that make interiors genuinely circular (adaptability, modularity, reversible joints, standardisation, design for maintenance, component reuse, and documentation such as material passports). Consequently, students tend to practice material substitution rather than circularity, treating sustainability as a finish or product decision instead of a design logic planning, detailing, and lifecycle scenarios.

Assessment language reinforces this pattern. Rubrics foreground aesthetics, functionality, services, and code compliance, in addition to the basic deliverable-based marking scheme. Sustainability appears, if at all, as a small criterion or a generic note. There is little requirement to evidence circular performance—for example, no expectation of disassembly diagrams, reuse process plans, end-of-life plans, or even conceptual diagrams leading to circularity. Furniture is seldom operationalised as a design problem to be measured or resolved, so it remains invisible to evaluation and, by extension, to students' iterative decision-making.

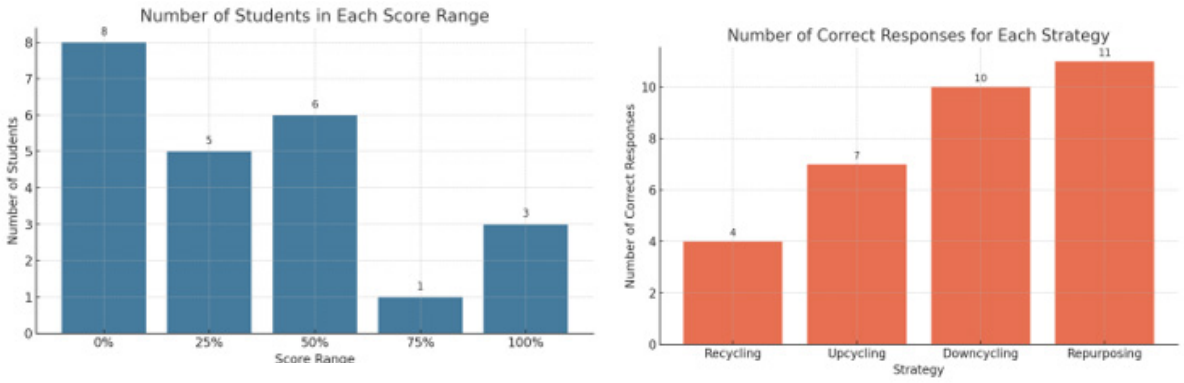

Figure 11. (a) Distribution of student scores across performance ranges for identifying correct sustainable strategies. (b) Number of correct responses for each sustainable strategy.

These curricular and pedagogical patterns have direct cognitive consequences. When sustainability is framed as awareness rather than competency, positioned as material choice rather than design logic, and assessed minimally or generically, students internalise it as peripheral rather than foundational. The student-level findings demonstrate how this structural neglect manifests in actual design thinking and performance. They reveal three interconnected manifestations of this gap:

1. Sustainability is identified as a Prompted Rather Than Intuitive Design Response, which establishes the foundational issue that sustainable thinking does not emerge naturally in students' design processes but requires external prompting or specific project requirements. This finding sets the stage for understanding why sustainability remains peripheral to design education.

2. A significant Perception-Reality Gap in Sustainable Design Implementation, revealing the disconnect between students' self-assessments of their sustainable design integration and the actual evidence of implementation in their work. This finding shows how students may believe they are incorporating sustainability even when their practice suggests otherwise, highlighting issues with metacognitive awareness and the accuracy of self-evaluation.

3. The Knowledge-Action Gap in Sustainable Design Education, which demonstrates that even when students possess theoretical awareness of sustainability principles, they struggle to translate this knowledge into meaningful design decisions and practical applications. This finding reveals the inadequacy of current educational approaches in bridging theory and practice.

Critically, these are not isolated student deficits, but predictable outcomes of the educational environment documented in the curricular and pedagogical analysis. When students are exposed to sustainability primarily through awareness-based language ("appreciate," "be mindful," "consider"), material-focused briefs that collapse circularity into finish selection, and assessment structures that allocate minimal weightages, they develop fragmented rather than integrated sustainability competencies. These educational conditions encourage students to view sustainability as a peripheral consideration rather than an embedded design approach. Without this shift, the gap between theoretical understanding and practical application will persist, limiting students' readiness to address environmental challenges through design.

Scope and Positioning of Circular Design Competencies

This study examined four material transformation strategies: recycling, upcycling, downcycling, and repurposing at the application level to operationalise circular design principles for furniture contexts.

The focus on material transformation strategies serves both pedagogical and contextual purposes. Pedagogically, these represent foundational skills prerequisite to complex system-level interventions. Contextually, they directly address furniture waste by developing students' capacity to see furniture as a material resource rather than end-of-life waste. Each strategy maps to broader principles (Table 1): upcycling applies value retention; recycling operationalises closed-loop flows; repurposing implements functional extension; downcycling demonstrates cascade utilisation.

The findings show that only 28% of students naturally incorporated these strategies, while 65% demonstrated significant perception–reality gaps and 34.8% accurately identified the strategies. Together, these results indicate a fundamental gap in application-level circular design competency and suggest that curriculum reform is needed to integrate both material transformation and system-level competencies in a scaffolded progression.

Future research should examine student competencies across the full spectrum of circular design principles, including design-phase interventions (DfD, LCA, modularity) and their integration with end-of-life strategies. Additionally, investigating how students develop the evaluative judgment to select appropriate strategies based on material condition, context, and circularity potential would provide valuable pedagogical insights.

Study Limitations and Methodological Considerations

This study acknowledges several limitations. Elective offerings can change by semester, limiting the consistency of curricular presence captured. Studio briefs vary in granularity and may not fully reflect in-class guidance, as faculty may provide additional scaffolding beyond documented materials. The student sample (n = 23) was drawn from a single institution, limiting generalizability across program types. Self-reported data may reflect bias, though triangulation with design artefacts partially mitigated this. Furthermore, the binary coding framework (present/absent), while ensuring inter-rater reliability, may not register nuanced degrees of integration.

The study sampled top-ranked programs (NIRF, IIRF), which likely have greater resources than typical

institutions. The absence of circular design integration even in these well-established programs suggests the gap may be wider elsewhere. Findings represent patterns among leading Indian design programs but are limited to a sample of the population. Generalisation to all Indian architecture and design institutions requires further investigation.

Despite these constraints, the convergent evidence across multiple data sources—curricula, briefs, and student performance—helps establish the core finding of systemic gaps in circular design integration.

Implications for Practice: Targeted Interventions Across Educational Levels

The proposed interventions are derived directly from the empirical gaps identified across curricula, studio briefs, and student design outputs in this study. To address the documented gaps, targeted interventions are necessary at multiple levels. At the curricular level, circular design principles (recycling, upcycling, downcycling, repurposing) should be integrated as core competencies rather than electives, supported by method-level tools such as LCA and DfD. At the pedagogical level, studio briefs must shift from awareness-based language to actionable skill requirements, scaffold competencies progressively across semesters, and revise assessment structures to elevate sustainability to 20-25% of grading with evidence-based deliverables. At the student application level, default circular thinking should be encouraged through mandatory integration in every major project. This can be supported by hands-on material literacy workshops that strengthen students' understanding of material use and transformation. In addition, peer- and self-assessment tools can help students evaluate their work against circular performance criteria and refine their design decisions. Early studio exposure could introduce foundational concepts of material reuse and transformation, while advanced studios may engage students with system-level circular strategies such as lifecycle assessment, adaptability, and design-for-disassembly. Taken together, these directions suggest that future work should focus not only on raising awareness of sustainability but on building the conditions—curricular, pedagogical, and experiential—under which sustainability becomes an instinctive part of students' design identity.

10. CONCLUSION

This study examined the integration of Circular Design Principles in Indian architecture and interior design education through a three-level investigation: curricula analysis (30 programs), pedagogical examination (17 studio briefs), and student competency assessment (23 participants). The findings reveal systemic gaps across all three dimensions.

At the curriculum level, while 93% of programs reference sustainability, none mandate circular design as a core competency. Critical methods such as LCA and DfD are absent from formal curricula, indicating sustainability exists as a broad theme rather than structured skill development. At the pedagogical level, studio briefs operationalise sustainability through material substitution only, allocating a minimal assessment weight. At the student application level, only 28% naturally incorporate sustainable strategies, with 65% demonstrating significant perception-reality gaps and 34.8% conceptual accuracy in identifying circular principles, confirming that circular thinking emerges only when explicitly prompted rather than as default design logic.

These convergent findings across institutional structure, instructional delivery, and learner outcomes demonstrate that sustainability is treated as optional awareness rather than a foundational competency. By establishing this baseline understanding, the study provides an evidence-based rationale for rethinking how sustainable design—and particularly circular design principles—are introduced, reinforced, and evaluated in design curricula. This diagnostic framework establishes the empirical foundation necessary for transforming circular design from an aspirational concept into an operational competency in Indian design education.

CONFLICT OF INTEREST STATEMENT

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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