Circular Economy in Architectural Education: Pedagogical Approaches and a Proposed Framework

Cirkularna ekonomija u arhitektonskom obrazovanju: Pedagoški pristupi i prijedlog okvira

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Abstract The transition from linear to circular models is increasingly recognized as essential for reducing resource depletion and environmental impacts in the built environment. Because early design decisions shape the material, environmental, and lifecycle performance of buildings, architectural education plays a pivotal role in preparing future practitioners to support this shift. Yet despite the growing presence of circular economy (CE) frameworks in policy and practice, their integration into architectural curricula, particularly within design studios, remains fragmented and inconsistent. This paper addresses this gap by reviewing recent scholarship, analyzing emerging pedagogical models, and examining case studies that explore how circular thinking is taught in architecture programs worldwide. The findings reveal recurring challenges, including limited material literacy, insufficient life-cycle reasoning, and a lack of structured assessment methods capable of evaluating circular design outcomes. At the same time, the design studio emerges as a uniquely productive setting for cultivating systemic thinking, material awareness, and regenerative design skills through experiential, collaborative, and evidence-based learning. Building on the analysis, the paper proposes a pedagogical framework for Circular Design Studios (CDS) that operationalizes CE principles through lifecycle thinking, material traceability, systems mapping, and regenerative design strategies. By outlining transferable pedagogical strategies and competency-based assessment criteria, the study aims to support architectural schools in embedding circularity more systematically across curricula and to equip future designers with the skills necessary to contribute to a circular and sustainable built environment.

Keywords architectural education; circular economy; design studio.

Sažetak Prelazak sa linearnog na cirkularni model sve se više prepoznaje kao ključan za smanjenje iscrpljivanja resursa i negativnih uticaja na okoliš u izgrađenom okruženju. Budući da rane projektantske odluke oblikuju materijalne, okolišne i životnociklusne performanse zgrada, arhitektonsko obrazovanje ima važnu ulogu u pripremi budućih stručnjaka za podršku ovoj tranziciji. Međutim, uprkos sve većoj prisutnosti okvira cirkularne ekonomije (CE) u politikama i praksi, njihova integracija u nastavne planove arhitekture, posebno unutar projektantskih studija, i dalje je fragmentirana i nedosljedna. Ovaj rad razmatra navedeni jaz kroz pregled recentne literature, analizu novih pedagoških modela i analiziranje primjera koji istražuju na koji se način cirkularno razmišljanje podučava u arhitektonskim programima širom svijeta. Rezultati ukazuju na ponavljajuće izazove, uključujući ograničenu materijalnu pismenost, nedovoljno razumijevanje životnog ciklusa zgrada te nedostatak strukturiranih metoda evaluacije koje mogu procijeniti ishode cirkularnog dizajna. Istovremeno, predmet arhitektonsko projektovanje se pokazuje kao posebno produktivno okruženje za razvoj sistemskog razmišljanja, svijesti o materijalima i regenerativnih dizajnerskih vještina kroz iskustveno, kolaborativno i na dokazima zasnovano učenje. Na osnovu provedene analize, rad predlaže pedagoški okvir za Circular Design Studios (CDS), koji operacionalizira principe cirkularne ekonomije kroz razmišljanje o životnom ciklusu, mogućnost praćenje toka materijala, mapiranje sistema i regenerativne strategije projektovanja. Definiranjem prenosivih pedagoških strategija i kriterija evaluacije zasnovanih na kompetencijama, istraživanje nastoji podržati arhitektonske škole u sistematičnijem uključivanju cirkularnosti u nastavne planove te osposobiti buduće projektante vještinama potrebnim za doprinos cirkularnom i održivom izgrađenom okruženju.

Ključne riječi arhitektonsko obrazovanje; cirkularna ekonomija; arhitektonsko projektovanje.

1 Introduction

The growing urgency of climate change, resource depletion, and environmental degradation has intensified global interest in transitioning from linear production models toward regenerative, circular systems (Wöhler et al., 2024; UNEP, 2021). Within this global shift, the built environment holds a central role due to its substantial contribution to material extraction, waste generation, and both operational and embodied carbon emissions (Wöhler et al., 2024; Pierzchlewicz et al., 2025). Architecture, positioned at the intersection of spatial design, material use, and technological innovation, is uniquely responsible for mediating these impacts. Early design decisions profoundly influence a building's long-term environmental performance, its adaptability, and its capacity to reintegrate materials into future cycles (Pomponi & Moncaster, 2017; Motiei et al., 2024). As a result, the architectural discipline is increasingly called upon to adopt approaches that extend beyond traditional sustainability measures toward circular strategies capable of maintaining material value, reducing waste, and supporting ecosystem regeneration (Ghisellini et al., 2016; Durmisevic, 2016).

Despite the rapid evolution of circular economy (CE) frameworks in policy and practice, ranging from the EU Circular Economy Action Plan to emerging digital material-tracking infrastructures (European Commission, 2015; Przepiórkowska et al., 2025), the integration of CE principles into architectural education remains fragmented and uneven. Many architectural curricula continue to prioritize form-making, aesthetic exploration, and isolated technical considerations, leaving life-cycle thinking, material literacy, and multi-scalar systems analysis insufficiently addressed (Vergani et al, 2024; Stoiljković et al., 2023). At the same time, design studios, as the core pedagogical spaces within architectural programs, offer significant potential to cultivate the competencies, tools, and value systems needed for circular practice. Recent studies underline the studio's capacity to combine experiential learning, research-by-design, stakeholder collaboration, and digital workflows, enabling students to test circular strategies such as design for disassembly, adaptive reuse, modular construction, and evidence-based environmental assessment (Vrontissi et al., 2023; Patil et al., 2025; Çolakoğlu et al., 2023).

Given these developments, there is a growing need for coherent pedagogical frameworks that embed CE principles across architectural education through structured competencies, integrated teaching methodologies, and transparent assessment mechanisms (Ioannou & Klein, 2022; Schiano-Phan & Soares Gonçalves, 2022). Drawing on an extensive literature review and comparative analysis of global educational models, this paper examines how circular design thinking can be systematically embedded into architectural learning. It synthesizes insights from existing pedagogical approaches, emerging tools, and institutional practices to propose a comprehensive framework for Circular Design Studios (CDS). By reframing studio-based education through lifecycle-oriented and regenerative principles, the study aims to support the development of architects capable of contributing meaningfully to the circular transition of the built environment.

2 Circular Economy in Architectural Practice

The circular economy (CE) offers a regenerative alternative to the linear "take–make–dispose" model by reducing resource use, waste, emissions, and energy losses through narrowing, slowing, and closing material loops (Wöhler et al., 2024). It aims to maintain material value over time, supported by frameworks such as the 10R hierarchy and models like ReSOLVE and the EU waste hierarchy (Pešta et al., 2023; Ellen MacArthur Foundation, 2021; Soliu et al., 2024). The built environment is central to CE transitions, accounting for roughly one-third of global energy use, CO_2 emissions, and material consumption (UNEP, 2021; Wöhler et al., 2024). While aligned with sustainability, CE focuses more specifically on material circularity and value retention (Stoiljković et al., 2023), requiring strategies such as design for disassembly and adaptability, modular construction, and adaptive reuse, often supported by digital tools (Durmisevic, 2016; Timm et al., 2023; Motiei et al., 2024). At the policy level, CE is a key instrument for climate neutrality and resource efficiency, exemplified by the EU Circular Economy Action Plan and its integration with the European Green Deal (European Commission, 2015, 2020; Przepiórkowska et al., 2025; The Circular City Centre – C3, 2025). Global initiatives such as UNESCO, UNEP, OECD further stress the need to embed CE in education, linking it to SDGs and promoting systems thinking, lifecycle reasoning, and digital skills (UNESCO, 2022; OECD, 2023; Pierzchlewicz et al., 2025). In practice, CE in architecture involves rethinking buildings as multi-life-cycle systems, using approaches such as reversible design, material passports, and circular procurement, enabled by BIM, LCA/LCC, digital twins, IoT, and blockchain (Arup & Ellen MacArthur Foundation, 2021; Aral et al., 2024). However, integrating these concepts into architectural education remains challenging due to rigid curricula strucutre and diverse institutional contexts, prompting the need to examine existing pedagogical models, competencies, and assessment methods for preparing students for circular practice.

3 Architectural Education and the Need for Transformation

Architectural education plays a critical role in shaping future designers' environmental values, competencies, and approaches to design. However, prevailing pedagogical models often remain grounded in linear conceptions, prioritizing novelty, form, and aesthetics over material performance, adaptability, and long-term value retention. Traditional studio culture has emphasized visual and conceptual creativity, while environmental and material considerations have typically been treated as secondary or technical concerns addressed later in the design process.

In response to escalating global challenges, architectural education has begun to shift toward sustainability, resilience, and climate adaptation. The UNESCO-UIA Charter for Architectural Education (UNESCO & UIA, 2023) reflects this transformation, emphasizing the need for environmentally responsible, lifecycle-oriented, and interdisciplinary approaches. It acknowledges that the built environment is shaped by complex environmental, social, economic, and technological forces, and calls for architects to be equipped to address 21st-century societal demands. However, while the Charter establishes a strong foundation for sustainability, it does not explicitly address the integration of circular economy principles into architectural curricula.

Although many programs have introduced themes related to ecological design, energy performance, and social sustainability, these efforts often remain focused on efficiency and technological optimization rather than systemic resource circularity. As a result, current curricula frequently lack lifecycle and systems thinking, limiting students' understanding of how design decisions influence material flows, carbon emissions, and long-term resource use. In addition, limited engagement with disciplines such as environmental engineering, material science, and data analytics constrains the ability to address the complexity of the built environment. Consequently, few programs explicitly incorporate circular economy frameworks, leaving graduates underprepared for emerging professional demands.

Within this context, the architectural design studio offers significant transformative potential. As a microcosm of professional practice, the studio supports experiential, project-based, and collaborative learning. Integrating circular economy principles into studio teaching enables students to engage with strategies such as adaptive reuse, design for disassembly, and material lifecycle assessment through applied experimentation and critical reflection. Embedding these approaches within the studio environment, where design, making, and evaluation intersect, can foster the competencies required for a transition toward a regenerative and circular built environment.

These opportunities highlight the need to rethink not only curricular content but also pedagogical approaches. Advancing from fragmented sustainability topics toward an integrated, systems-oriented framework requires innovative teaching methods, interdisciplinary collaboration, and new assessment models. The following section therefore examines emerging pedagogical strategies for incorporating circular economy principles into architectural education.

4 Methodology

Building on the conceptual background discussed above, the study examines how CE principles are integrated into architectural education through a literature review, analysis of existing curricula, and exploration of educational case studies. The literature review was conducted across academic databases, Scopus, Web of Science, and ScienceDirect, focusing on publications from 2020 to 2025 that address the incorporation of circularity and circular economy strategies in architectural education.

The collected materials were analyzed using an analytical framework structured around the five key dimensions of: pedagogical approaches, competencies, teaching methods, assessment strategies, and institutional context. Based on these insights, the study proposes a conceptual framework to guide the integration of circular design thinking and regenerative approaches into architectural pedagogy, preparing future professionals to contribute effectively to a circular built environment.

5 Results

Below is a structured, comparative analysis of research articles using an analytical framework with five thematic categories: (1) pedagogical approaches, (2) targeted competencies, (3) teaching methods, (4) assessment strategies, and (5) institutional contexts. The analysis is presented in Table 1.

5.1 Pedagogical Approaches

Research literature stresses the need for a paradigmatic shift in architectural pedagogy. Integration of CE principles should move from a peripheral or elective status to a transversal, system-oriented orientation that reshapes course aims, studio pedagogy, and stakeholder relations (Ioannou & Klein, 2022; Vergani et al, 2024). Authors converge on several overlapping pedagogical orientations.

First, studio-centered, experiential learning is widely advocated. Patil, Butt, Rigoni, and Salama (2025) propose embedding CE into project-based studios using their 'Circular Commons Framework' to translate theory into practice through industry collaboration and real-world cases. Scott and Seddiki (2025) position a studio-centered, case-based reasoning approach grounded in scaffolded constructivism; they operationalize CE via six assessable criteria (design, materials, construction, life-cycle, disassembly, and biodiversity) to make sustainability legible in standard studio reviews. Vrontissi, Rinke, and Vandyck (2023) and the ERASMUS+ Crafting Circularity consortium push the didactic value of design-and-build workshops and "learning-through-making," arguing that hands-on fabrication, material harvesting, and full-scale mock-ups promote authentic learning about modularity, disassembly, and the logistical frictions of circular supply chains.

Second, situated and transdisciplinary learning is emphasized. Wandl, Balz, Qu, Furlan, Arciniegas & Hackauf, (2019) and the REPAiR project describe Peri-Urban Living Labs (PULLs) and collaborative studios where students engage communities and stakeholders, linking CE to urban metabolism and territorial design. Such situated labs are promoted as venues in which socio-spatial resource flows and governance constraints become legible and actionable (Wandl et al., 2019; Gajanayake & Iyer-Raniga, 2025).

Third, design-by-research and scenario-based learning feature as mechanisms for integrating theory and practice. Vergani et al. (2024) recommend design-by-research and scenario exercises (including village-scale projects) and identify gamification/serious games as effective pedagogies for systems thinking. Dabaieh and Lundgren (2025) demonstrate a pilot course that combines interdisciplinary project work with LCA/LCC, blurring research and design as an educational stance.

Fourth, lifelong learning and diversified formats are foregrounded by TU Delft's CBE Hub (Ioannou & Klein, 2022). The Hub advocates MOOCs, professional education, and short collaborative formats to disseminate technical knowledge while cultivating imaginaries of circular futures across professions and publics. This framing relocates universities as experimental safe spaces that co-produce knowledge with non-academic actors.

Fifth, teacher and tutor development is identified as essential: multiple authors stress that educators must, themselves be trained in CE frameworks, tools, and policy contexts to properly mentor students (Wandl et al., 2019; Vergani et al., 2024; Ioannou & Klein, 2022). Tiippana-Usvasalo et al, 2023) extend this to teacher-led, bottom-up rollouts across all education levels.

Finally, authors highlight institution-level pedagogical strategies, from curriculum mainstreaming to creation of "circular programs" that reuse student outputs (McGinley & Karlshøj, 2022), positioning pedagogy not as an isolated course matter but as an institutional trajectory requiring scaffolding across bachelor, master, and Continuing Professional Development (CPD) tiers (Vergani et al., 2024; McGinley & Karlshøj, 2022).

5.2 Targeted Competencies

The literature defines multi-dimensional competency sets for implementing CE in the built environment, grouped into technical, digital/analytical, systemic, and socio-professional domains. Technical skills, such as LCA, design for disassembly, adaptive reuse, modular systems, industrial symbiosis, and material passports, are core, but must be embedded in studio practice rather than isolated in lectures to ensure practical integration (Çolakoğlu et al., 2023; Ryńska, 2020; Vrontissi et al., 2023). Digital competencies, including BIM, GIS, parametric design, AR/VR, IoT, big data, and AI-enabled tools, support material traceability, predictive modeling, and data-driven decision-making, reinforcing LCA literacy and cradle-to-cradle thinking (Çolakoğlu et al., 2023; Patil et al., 2025; Tabrizi et al., 2023). Systemic competencies emphasize systems thinking, urban metabolism, multi-scalar reasoning, and scenario planning to understand lifecycle impacts across supply chains and urban contexts (Wandl et al., 2019; Vergani et al., 2024; Campbell et al., 2024). Socio-professional skills, including stakeholder engagement, participatory processes, policy literacy, and ethical reasoning—are equally critical, as CE practice requires collaboration with diverse actors beyond traditional architectural roles (Ioannou & Klein, 2022; Durán-Navarrete et al., 2024), alongside reflective and research-based practices that foster critical thinking, collaboration, and awareness of trade-offs in circular design processes (Vrontissi et al., 2023).

5.3 Teaching Methods

The literature identifies a range of teaching methods that support CE competency formation, with the design studio positioned as a central "living laboratory" integrating literature review, fieldwork, stakeholder engagement, and design development grounded in frameworks such as the 10R principles, as seen in projects like proximate briefs in Aberdeenshire and the "Circular Village" master level studio in Türkiye (Scott & Seddiki, 2025; Çolakoğlu et al., 2023). Complementary approaches include living labs and place-based projects that connect students with real contexts and external actors (Wandl et al., 2019; Gajanayake & Iyer-Raniga, 2025), and design-build or learning-by-making models using reclaimed materials, prototyping, and full-scale mock-ups to develop practical skills and expose logistical challenges (Vrontissi et al., 2023). Interdisciplinary and transdisciplinary collaborations across fields such as engineering, management, and policy further reflect real-world CE complexity (Vergani et al., 2024; Salas et al., 2021; Bakırlıoğlu et al., 2021), while digital tools, including BIM, LCA platforms, and parametric modeling, enable evidence-based design and analysis of material flows (Patil et al., 2025; Dabaieh & Lundgren, 2025). Additional methods include gamification and scenario-based learning to support systems thinking (Vergani et al., 2024), workshops, field trips, and stakeholder co-production to address real constraints (Ryńska, 2020; Ioannou & Klein, 2022), and lifelong learning formats such as MOOCs and professional education programs that extend CE knowledge beyond academia and align it with practice and policy (Ioannou & Klein, 2022).

5.4 Assessment Strategies

Assessment remains one of the most contested and underdeveloped areas in CE education, combining emerging innovations with persistent gaps. Approaches include rubric-based studio assessment with explicit CE criteria. These include: six-dimensional frameworks covering design, materials, construction, life cycle, disassembly, and biodiversity, as well as metrics like disassembly potential, material inventories, and embodied carbon (Scott & Seddiki, 2025; Ryńska, 2020; Vrontissi et al., 2023). Evidence-based deliverables (e.g., LCA reports, adaptability diagrams, assembly sequences, and mock-ups) shift evaluation toward traceability and measurable circular performance (Vrontissi et al., 2023; Dabaieh & Lundgren, 2025), while mixed-method models combine quantitative analysis with reflective writing and stakeholder-informed evaluations (Dabaieh & Lundgren, 2025; Çolakoğlu et al., 2023). Living labs and external collaborations introduce multi-actor assessment formats such as juries, stakeholder scoring, and public reviews (Wandl et al., 2019; Gajanayake & Iyer-Raniga, 2025), alongside portfolio-based and reflective methods capturing iterative learning and ethical reasoning (Kirchherr & Piscicelli, 2019). On a broader scale, programmatic and formative evaluation, exemplified by Finland's Sitra initiative and TU Delft relies on iterative feedback, surveys, and professional alignment rather than single-point exams (Tiippana-Usvasalo et al.2023; Ioannou & Klein, 2022). Despite these developments, key challenges persist, including the lack of standardized benchmarks, limited integration of CE indicators into formal curricula, and insufficient assessment of social and digital competencies, prompting calls for competency-based frameworks aligned with accreditation and quality assurance systems (Patil et al., 2025; Faitani et al., 2025; Galle et al., 2022; Khajuria, 2025).

5.5 Institutional Contexts

Institutional configurations and external ecosystems play a key role in shaping circular economy (CE) uptake in architectural education, with diverse models including policy-led national roadmaps, NGO-driven pilots, and STEM/industry-aligned programs across contexts such as the UK, Sweden, the Netherlands (TU Delft), Türkiye (Çolakoğlu et al., 2023), Poland (WUT), Argentina (Faitani et al., 2025), Australia (Gajanayake & Iyer-Raniga, 2025), and Latin America (Salas et al., 2021). Fragmented approaches are evident, for example in Sweden where CE is embedded within existing curricula but lacks systemic integration, limiting transversal skills (Vergani et al., 2024), while Finland's Sitra roadmap demonstrates how coordinated national policy, cross-sector funding, and lifelong learning strategies can accelerate capacity building (Tiippana-Usvasalo et al., 2023). Similarly, Latin American HEIs act as cultural change agents linking teaching, research, and local practice (Salas et al., 2021). Transformative models such as TU Delft's CBE Hub position universities as knowledge brokers through MOOCs, professional education, and collaborative platforms (Ioannou & Klein, 2022), while partnerships with industry, municipalities, and NGOs, seen in WUT studios and TU Delft regional initiatives enhance realism and expose students to practical constraints (Ryńska, 2020; Ioannou & Klein, 2022). Additionally, EU-funded and networked initiatives (e.g., ERASMUS+ Crafting Circularity, H2020 REPAiR) enable living labs and cross-national exchange beyond the capacity of single institutions (Vrontissi et al., 2023; Wandl et al., 2019), though accreditation frameworks, employability narratives, and uneven access to material labs, digital tools, and staff expertise continue to shape and often limit full CE integration (Campbell et al., 2024; Schiano-Phan & Soares Gonçalves, 2022).

Table 1 Analysis of CE in Architectural Education based on a structured framework. Source: Author, 2026.

Article	Pedagogical Approaches	Targeted Competencies	Teaching Methods	Assessment Strategies	Institutional Contexts
Ab Hamid et al. (2024)	Project-based, student-centered, constructivist, experiential	Project-based learning, active learning, problem-based tasks, serious games, case studies	Critical & creative thinking, LCA application, collaboration	Project deliverables, group work, reflective tasks	Global review of CE teaching
Campbell, Niblock, Flood, & Lappin (2024)	Studio-based, constructivist, embodied learning; systems thinking	Linked design projects across scales; expert workshops; live-build 1:1 making; precedent-based learning; critiques; peer feedback	Circular design literacy; systems thinking; design for disassembly; collaboration; cost awareness	Authentic assessment via critiques and presentations; teacher observations; marks logged	UK architecture program
Çolakoğlu et al. (2023)	Design-by-research; studio with digital integration	CE 10R strategies, digital fluency, socio-cultural sensitivity	Fieldwork, project-based learning, stakeholder engagement, BIM/GIS, AR/IoT	Artifact-based evaluation, 10R mapping	Istanbul Technical University, M.Arch studio with municipal links
Dabaieh and Lundgren (2025)	Interdisciplinary, project-based; design + analytics	Circular design, LCA/LCC, critical reflection	Lectures, workshops, site visits, modular shelter project	LCA/LCC reports, reflective essays, group presentations	Malmö University, undergrad program

Article	Pedagogical Approaches	Targeted Competencies	Teaching Methods	Assessment Strategies	Institutional Contexts
Duran-Navarrete et al. (2024)	Experience-based, design-integrated Design-studio approach; technology-mediated	BIM modeling, material circularity, reuse/recycle design BIM/Revit modeling, perception surveys, scenario comparison BIM-enabled circular design, material circularity evaluation, policy literacy	Hands-on BIM modeling, BIM-enabled circular design	Circularity scores, CDW reduction metrics Quantitative metrics	Chilean higher education aligned with EU directives
Faitani, Lopez de Munain, Bielsa (2025)	Non-formal, operational learning in a living lab; CE frameworks (ReSOLVE/ DISRUPT) reframed as governance/ operations pedagogy; scenario-based planning	Diagnose–index–compare–scenario cycle; equipment/ power audit; EMIce indicators (renewables, virtualization, automation, efficiency, structural retrofit, governance); future scenario design	CE operations literacy, indicator design, energy-efficiency planning, institutional stewardship, policy awareness, scenario building	Indicator-based benchmarking across time	Universidad Nacional de General Sarmiento (Argentina)
Gajanayake and Iyer Raniga (2025)	Flexible, context-sensitive, case-based Non-formal, participatory, community-based learning	Conceptual clarity, R-strategies, systemic thinking	Case studies, interactive exercises, co-learning, stakeholder engagement; problem framing; transdisciplinary teamwork	Formative assessments, reflective exercises Diagnostic surveys (conceptual understanding, behaviors); reflections	Global collaboration (RMIT, TERI SAS, AIT, AKSU)
Giannoccaro et al. (2021)	Outcome-based, Bloom's taxonomy; limited active learning	Technical (eco-design, LCA), managerial, analytical; social underrepresented	Lectures, flipped classroom, challenge-based learning	Knowledge checks, project design, application tasks	Italian universities; postgraduate programs
Haase et al. (2024)	Interdisciplinary, collaborative, transdisciplinary	Sustainability governance, CE management, financial modeling, stakeholder engagement	Project-based learning, interdisciplinary teamwork, guest lectures	Simulated board presentations, portfolio evaluation	Zurich University of Applied Sciences
Ioannou & Klein (2022)	Transdisciplinary, lifelong learning; constructivist approach fostering dialogue and communities of practice	Technical + transversal: systems thinking, collaboration, critical reflection; policy literacy	MOOCs for global awareness; ProfEd for sector-specific skills; PCPs for industry-driven learning	Formative assessment via peer feedback, project reviews, no standardized testing	TU Delft
Ioannou, Geldermans, Klein, & Wandl, (2020)	Transformative, systems / complexity-aware pedagogy; Scales-Aspects model; Circular Learning Objectives (CLO); research- and practice-based learning; connectivist ethos and ethical decision-making	Modular curriculum integration (plug-ins, MOOCs/ ProfEd), inter-department studios and living lab exchanges, program-wide alignment to CLOs	Systems thinking, CE vocabulary, multi-scalar reasoning, interdisciplinary and transdisciplinary collaboration, accountability / ethics in design	CLO-aligned outcomes; evaluation of actionable knowledge and judgment under uncertainty; program-level synthesis across courses	TU Delft Faculty of Architecture & Built Environment; Circular Built Environment Hub

Article	Pedagogical Approaches	Targeted Competencies	Teaching Methods	Assessment Strategies	Institutional Contexts
Khajuria (2025)	CE as transversal, cross-curricular theme, Multi-level (K–12, VET, HE) CE integration, Place-based, policy-informed pedagogy	Systems thinking, Collaboration & problem-solving, Ethical reasoning & sustainability citizenship, Workforce-relevant CE skills in VET/HE	Project-based learning, Place-based and community engagement, Internships & industry partnerships, Micro-credentials and modular CE units	Authentic assessments (projects, portfolios), Competency-based evaluation, Context-specific assignments (e.g., place-based tasks)	National-level education systems (Finland, Greece, Vietnam)
Kirchherr & Piscicelli (2019)	Constructive alignment; problem-based learning; interactivity	CE foundations; eco-design & repair; industrial symbiosis; macro policy & rebound; critical reflection	7 interactive exercises (teardown, EIP simulation, policy design, futures) + 2 excursions; curated readings	In-class presentations with rubrics; module & final evaluations	Utrecht University,
McGinley and Karlshøj (2022)	System-level redesign; circular courses/programs	Process circularization, open BIM, coding for reuse	Multi-course integration, live design, tool development	Course evaluations + C0–C5 circularity rubric	Technical University of Denmark, UG & PG courses
Patil, Butt, Rigoni, & Salama (2025)	Systems-oriented, studio-based CE pedagogy, "Circular Commons" framework integrating technical + socio-cultural dimensions, Experiential, participatory, and transdisciplinary learning	Technical CE literacy (DfD, LCA, material loops), Community engagement & participatory design, Governance, equity, social-cultural competencies, Systems and multi-scalar thinking	Design studios & labs, Live-builds using reclaimed materials, Stakeholder workshops, role-play, systems mapping, Transdisciplinary teamwork with municipalities/NGOs	Combination of qualitative & quantitative evaluation, Use of simple circularity calculators, Peer review + stakeholder feedback, Reflective narratives to connect technical and social dimensions	Architecture schools with limited resources
Pradhananga & Elzomor (2023)	Combination learning (PBL + CMD)	Systems thinking, communication, CE principles	Group projects, concept maps, real-world problems	Pre/post surveys, Wilcoxon test, rubric	Florida International University
Renfors (2024)	Systems-integrative, co-learning with stakeholders	Resource management; systems thinking; circular design/LCA; business models; collaboration	Team-based, case-based, project-based, simulations	Assignments and presentations	European HEIs
Ryńska (2020)	Interdisciplinary studio, client-driven project-based learning (PBL), experiential workshops	Circular design, life-cycle awareness, teamwork	Client kick-offs; site analysis; expert critics; performance simulations	Critiques and client presentations	Warsaw University of Technology (WUT)
Sadowski (2021)	Design studio + RTD	Technical sustainability, LCA, optimization	Expert lectures, iterative design, digital tools	Quantitative indicators, radar charts, surveys	Wrocław University of Science and Technology
Salas, Criollo & Ramirez (2021)	HEIs as cultural change agents; bibliometric + narrative synthesis	CE policy/business literacy; inclusive engagement with informal sectors; technology transfer; localized CE framing	Campus living labs, outreach, frugal innovation, stakeholder co-design	Bibliometric indicators; mapping drivers/barriers; call for evaluating inclusion, rebound, and limits to circularity	Latin America; Brazil-led outputs
Scott & Seddiki (2025)	Studio-centered, project-based and case-based reasoning (CBR); constructivism and scaffolding aligned with Zone of Proximal Development	Systems thinking for circular design; life-cycle and embodied-carbon literacy; design for adaptability/disassembly	Real sites and briefs in coastal Aberdeenshire; iterative project reviews; use of BIM, IES, OneClick LCA; independent study and peer knowledge sharing	Thematic coding of student outputs into six CE criteria (Design, Material, Construction, Life-cycle, Disassembly, Biodiversity); reflective feedback from stakeholders	Undergraduate Architectural Technology program at Robert Gordon University; embedded in UKGBC frameworks and regional needs

Article	Pedagogical Approaches	Targeted Competencies	Teaching Methods	Assessment Strategies	Institutional Contexts
Shooshtarian, Caldera, Ryley, Maqsood, Zaman, & Wong (2022)	Sectoral training taxonomy; program evaluation framework (logic models; staged evaluation)	Waste minimization; resource recovery; site operations & compliance; design for circularity	VET Certificates II–IV; HE courses; CPD by GBCA/ISC; industry platforms (EduPortal, Greenius); government programmes (ecologiQ, SESA, Circular360)	external evaluation, indicators, pilots, accreditation	Australia
Tabrizi, Gocer, Sadrieh, Globa, (2023).	Theoretical, tool-mediated pedagogy using AI (KBS + LLM)	AI tool for LCA-lite (automation, prediction, optimization, visualization); planned short workshops	LCA literacy; cradle-to-cradle thinking; data-driven decision-making; environmental performance optimization	Planned evaluation post-pilot; currently conceptual	University of Sydney
Taraszkiewicz & Taraszkiewicz (2024)	Experiential, NEB-based	Sustainability, social inclusion, aesthetics	Lectures, design exercises, surveys	Qualitative survey analysis	Gdańsk University of Technology
Tiippana-Usvasalo, et al. (2023).	National curriculum integration; "learning by doing" for teachers; bottom-up teacher-led development; lifelong learning emphasis	CE mindset across society; policy and business model literacy; capacity to identify drivers/ barriers; sector-specific CE skills	Country-wide teacher workshops; 21 funded consortia; university lectures	Qualitative analysis of open-ended student responses; programmatic validation via nationwide roll-out steps and iterative feedback	Finland's national CE roadmap (Sitra); UBC & Aalto examples; cross-sector coverage from pre-school to adult education
Trevisan et al. (2025)	Competency-based, multimethod Skills-backward curriculum design; competency-based	Technical, digital, and soft skills for CE Mixed methods: design studios, AR/ VR, digital twin labs, data-driven exercises	Lectures + recommended digital labs, industry collaboration	Resilience soft skills (communication, negotiation), digital skills (data analytics, robotics), technical CE skills	European Higher Education & VET
Vergani et al. (2024)	Traditional, discipline-based studio	Technical: LCA, DfD, material reuse; limited transversal skills.	Lectures, limited project work; few participatory workshops or living labs.	Mostly implicit; CE rarely formalized as learning outcomes.	Five HEIs under Swedish Universities of the Built Environment
Vrontissi et al. (2023)	Learning-through-making; availability-based design; design-and-build	Disassembly, adaptability, resource-framed thinking, collaboration	Full-scale mock-ups; site visits; public exhibitions; local studios	Public reviews/exhibitions; reflective critique	ERASMUS+ consortium (5 universities)
Wandl, Balz, Qu, Furlan, Arciniegas, Hackauf (2019)	Situated learning within Living Labs; research-education integration; transdisciplinary studio	Spatial metabolism literacy; ability to model resource flows at multiple scales; collaborative problem framing; eco-innovation design	Workshops on urban metabolism, multi-scale assessment; stakeholder co-reviews	Mid-term and final juries with stakeholders; external surveys rating poster reviews	TU Delft (Faculty of Architecture); Horizon 2020 REPAiR project; Amsterdam Metropolitan Area case with living labs
World Green Building Council (2023)	Experiential and problem-based learning; emphasizes real-world case studies and collaborative design challenges	Technical + socio-economic: circular business models, material passports, stakeholder engagement.	Case-based learning, simulation tools, design studios; promotes industry-academia collaboration.	Suggests performance-based metrics (e.g., circularity indicators) but not formalized academically.	Global network of Green Building Councils

6 Towards a Framework for Circular Design Studios

Building on the comparative analysis in Section 3, this section proposes an integrated framework for embedding CE principles into architectural design studios. This framework proposes Circular Design Studios (CDS) as the core pedagogical engine for embedding CE logics across architectural education, translating systemic, lifecycle-oriented thinking into auditable design practice. A CDS proposes reframing the studio from producing one-off proposals to designing for multiple service lives, future recoverability, and value retention across materials, components, buildings, and urban systems.

6.1 Practical Implications

Across the five thematic areas, the following conclusions and practical implications emerge from the analyzed literature:

1. CE should be embedded as a transversal curricular scaffold – research literature advocates moving CE out of elective silos into vertical and horizontal curricular integration across studios, technical modules, and professional practice. Doing so supports longer-term competency formation and prevents superficial exposure.
2. CE should be operationalized through evidence, tools, and rubrics. To make circular intentions teachable and assessable, studios should require quantifiable evidence, material inventories, LCA outputs, adaptability diagrams, assembly sequences, and use explicit rubrics.
3. The integration of CE should be scaled through situated, networked learning and staff development. Where large grants or national strategies are unavailable, lightweight situated methods, such as structured stakeholder workshops, mid-semester external reviews, design-and-build intensives, can replicate many living lab benefits. Vertical pathways (micro-credentials, staff development, MOOCs) help build institutional memory and scale CE literacy beyond pilot studios.

These implications also highlight persistent research and practice gaps such as: lack of standardized assessment frameworks, systematic evaluation of social and digital competencies, and institutional strategies for sustaining living labs and cross-faculty collaboration.

6.2 Core Principles

The framework builds upon four interrelated principles that translate CE concepts into pedagogical terms. Each principle aims to cultivate specific competencies and design sensibilities relevant to circularity.

a. Lifecycle Thinking: Students are encouraged to evaluate buildings as dynamic systems that evolve over time rather than as static artifacts. Design projects should incorporate the full material and operational life cycle, from sourcing and assembly to disassembly, reuse, and regeneration. This approach promotes long-term thinking and accountability for design consequences beyond project completion.

b. Material Awareness: Circular design education requires a shift from abstract form-making to material intelligence. Students should engage directly with materials, understanding their origins, transformation processes, and potential for reuse. Incorporating material passports, digital databases, or physical reuse libraries can strengthen this awareness and encourage decisions based on traceability and embodied value.

c. Systems and Feedback Thinking: Circularity demands comprehension of complex interdependencies among design, construction, and urban systems. The studio becomes a space for simulating these interactions through

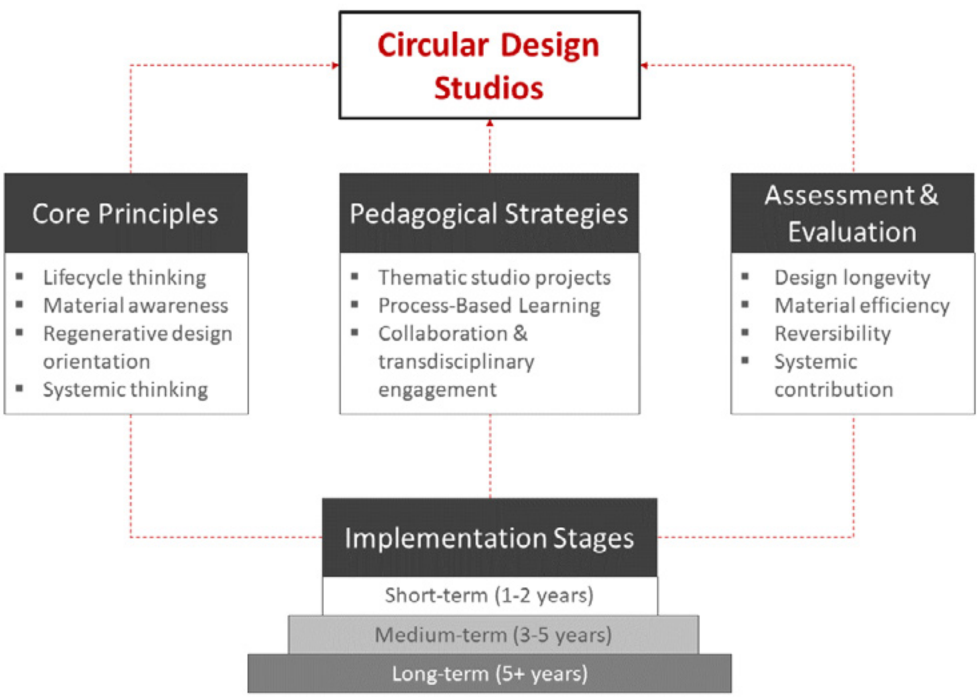

Figure 1 Diagram of a proposed framework for Circular Design Studios. Source: Author, 2026.

interdisciplinary collaboration and digital modeling (e.g., BIM integrated with LCA tools). Students should learn to map resource flows, anticipate feedback loops, and design interventions that minimize waste and energy losses.
d. Regenerative Design Orientation: Beyond minimizing harm, circular design education should foster a regenerative mindset that restores ecological and social systems. Studio projects can incorporate strategies such as designing for biodiversity, ecosystem repair, or social reuse of spaces. This principle expands the scope of circularity toward positive contribution rather than mere efficiency.

6.3 Pedagogical Strategies

To operationalize these principles, the framework integrates circular design into studio teaching through three complementary strategies:
a. Thematic Studio Projects: Studio briefs should be framed around circular challenges such as adaptive reuse, urban mining, or material cycles. For instance, students may redesign an existing structure for disassembly or explore modular housing concepts that enable flexibility and reuse. Real-world contexts and partnerships with local industries can enhance relevance.
b. Process-Based Learning: The design process should be structured to include research, material experimentation, and iterative prototyping. Students should use circular metrics, such as material recovery potential, design adaptability index, or embodied carbon reduction, to guide design decisions.
c. Collaborative and Transdisciplinary Engagement: Circularity requires breaking disciplinary silos. Studios can integrate inputs from engineering, environmental sciences, or business students to explore life-cycle implications and economic models. Collaboration fosters systems thinking and aligns educational practices with real-world circular construction processes.

6.4 Assessment and Evaluation

To reinforce learning outcomes, evaluation criteria should evolve from purely formal or representational qualities toward circular performance indicators. These may include:
- Design longevity (capacity for adaptation and reuse)
- Material efficiency (use of reclaimed or low-impact resources)
- Reversibility (ease of disassembly or reconfiguration)
- Systemic contribution (integration with local material and energy cycles)

Assessment can combine qualitative reflection (design narratives) with quantitative analysis (LCA metrics or circularity indices). This dual approach can foster critical thinking while maintaining creative freedom.

6.5 Implementation Roadmap

Integrating circularity into architectural education requires institutional support and gradual adaptation. The proposed framework suggests gradual implementation in the following stages:

Table 2 Proposed CE implementation Roadmap.
Source: Author, 2026.

Phase	Focus	Actions
Short-term (1–2 years)	Pilot studios and educator training	Development of elective or experimental studios focused on circular design; providing workshops on CE principles for teaching staff.
Medium-term (3–5 years)	Curriculum integration and resource development	Embeding CE themes across design levels; establishing digital/ material reuse databases; creating interdepartmental collaborations.
Long-term (5+ years)	Institutional transformation	Aligning accreditation standards with CE competencies; formation of industry partnerships for circular construction research and practice.

This approach allows gradual cultural change within schools while building educator capacity and institutional infrastructure.

6.6 Expected Learning Outcomes

By implementing this framework, students are expected to develop:
- Systemic and lifecycle awareness – understanding the interrelations of materials, design decisions, and environmental impacts.
- Material literacy – ability to select, evaluate, and design with circular materials.
- Adaptive design competences – capacity to create flexible, reversible, and regenerative architectural solutions.
- Collaborative problem-solving – experience working across disciplines and with real stakeholders.

These competencies position graduates to act as agents of circular transition in professional and societal contexts.

6.7 Contribution of the Framework

By embedding circular principles into design pedagogy, architectural education can move beyond sustainability rhetoric toward actionable frameworks that prepare future architects to design for a regenerative and circular future. The proposed framework contributes to the discourse on architectural education by:
• Providing a structured pedagogical model that connects CE theory with studio practice.
• Offering transferable strategies adaptable to different institutional contexts.
• Highlighting the design studio’s transformative potential as a testbed for systemic change in the built environment.

7 Conclusion

The transition toward a circular built environment necessitates a fundamental transformation of architectural education, extending beyond incremental sustainability measures to embrace systemic, lifecycle-oriented, and regenerative modes of design. This study demonstrates that, while circular economy principles are increasingly prominent within policy agendas and professional practice, their integration into architectural curricula remains limited, inconsistent, or reliant on isolated pilot initiatives. Through a review of pedagogical literature and comparative evaluation of emerging models, this paper identifies the need for cohesive approaches that align CE competencies, studio methodologies, and institutional structures.

The proposed Circular Design Studio (CDS) framework responds to this need by positioning the design studio as the central engine for cultivating material literacy, systems thinking, evidence-based decision-making, and adaptive design competences. By embedding lifecycle thinking, material awareness, feedback loops, and regenerative design orientation into iterative studio processes, the CDS model translates abstract circular principles into auditable design practices. It also foregrounds the importance of assessment strategies that integrate qualitative reflection with quantitative performance indicators, ensuring that circularity is not reduced to rhetorical intentions but becomes measurable and comparable across contexts.

At the institutional level, the study emphasizes the importance of multi-scalar strategies, ranging from staff development and micro-credentials to cross-department collaborations and industry partnerships, to sustain curricular transformation over time. Implementing CE principles requires not only pedagogical innovation but also organizational alignment, resource investment, and long-term cultural change within architectural schools.

By providing a structured and adaptable framework, this research contributes to the ongoing discourse on how architectural education can equip future practitioners to act as resource stewards and agents of systemic change. Future work should focus on empirical validation of the proposed rubrics across diverse educational settings, alignment with accreditation bodies, and the development of feedback mechanisms that link design education with post-occupancy and material-flow outcomes. Ultimately, embedding circularity within architectural pedagogy offers a pathway not only toward minimizing environmental impacts but also toward fostering regenerative, resilient, and equitable built environments for future generations.

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