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# CIRCULAR ECONOMY INTEGRATION IN DESIGN AND TECHNOLOGY EDUCATION: A SYSTEMATIC LITERATURE SURVEY

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## 1. ABSTRACT

***Amid a growing global waste crisis, the Circular Economy (CE) emerges as a central sustainability model, with design recognized as the primary driver of material waste. A survey of the literature on Circular Economy integration in Design and Technology (D&T) Education indicates its limited presence in the global South, despite increasing academic and policy consensus on the need to incorporate circularity into education. This paper offers a comprehensive literature review focused on research at the crossroads of Circular Economy, sustainable design, and Design and Technology Education. This survey examined the theoretical foundations of the CE (cradle-to-cradle, biomimicry, industrial ecology), global and regional policy directions, recognized barriers to circular transition in educational environments, and existing frameworks for sustainable design in D&T courses. Peer-reviewed studies, policy guidelines, and curriculum materials released from 1997 to 2025 are used in this survey. The review points out a major gap: although the CE has attracted considerable academic attention in both industrial and higher education settings, there is a lack of empirical research on its integration into school-level D&T education, particularly in sub-Saharan Africa. The article advocates for creating contextually relevant circularity frameworks for D&T education at schools in the global South and concludes by outlining a research agenda for the future.***

**KEYWORDS:** *Circular Economy, Design and Technology Education, Sustainable Design, Education for Sustainable Development, Literature Review, Global South, Circularity Framework*

## 1. INTRODUCTION

Influential global advocate for the Circular Economy, the Ellen MacArthur Foundation (2025), has argued that a product's environmental impact is determined at the design stage. Thus, the relationship between design and waste is not incidental; it is structural. This claim locates Design and Technology Education at the very heart of the global sustainability project. If waste is a design problem, then the classrooms where future designers are trained must become sites of circular thinking, not linear perpetuation.

Globally, the statistics are alarming. Circle Economy (2025) reports that of the 106.1 billion tonnes of materials consumed annually, only 27% are cycled back into the economy — a figure that has actually declined in recent years as the use of virgin materials increases. In support, UNESCO-UNEVOC (2024) notes that despite growing institutional recognition of the Circular Economy's relevance to curricula, its integration remains low relative to its perceived importance. The disjuncture between awareness and action is particularly acute in school-level education in the global south.

This literature survey responds to this gap. It traces scholarship at the intersection of three domains: the Circular Economy as a theoretical and policy construct; sustainable design as a pedagogical practice; and Design and Technology (D&T) Education as an institutional site of intervention. The survey is motivated by the observation that, while the literature in each of these domains is substantial, their intersection — particularly at the school level in sub-Saharan Africa — has received scant scholarly attention.

The survey is organised as follows. Section 2 outlines the methodology guiding the literature search and selection. Section 3 traces the theoretical foundations of the Circular Economy. It examines global and regional policy trajectories, the integration of sustainability into D&T curricula, and documented barriers to the circular transition in educational settings; surveys existing frameworks for sustainable design in education; Section 4 identifies gaps in the literature and charts a research agenda; and Section 5 provides a conclusion.

## 2. Methodology: Literature Search and Selection

### *2.1 Search Strategy*

This survey was guided by the PRISMA framework (Page et al., 2021). The following databases were used to source literature: Scopus, Web of Science, Google Scholar, ERIC (Education Resources Information Center), and EBSCOhost. Grey literature, such as policy documents, curriculum frameworks, and reports from global organizations (UNESCO, Ellen MacArthur Foundation, Circle Economy, World Economic Forum), was included, given the field's policy-focused nature.

Search strings were created based on three thematic clusters and merged using Boolean operators (AND, OR), specifically,

- The Circular Economy and its theoretical principles: ("circular economy" OR "cradle-to-cradle" OR "biomimicry" OR "industrial ecology" OR "linear economy")
- Education and sustainability: ("Sustainable Development Education" OR "education in sustainable design" OR "sustainability in STEM education" OR "education for a circular economy" OR "sustainability in curriculum") and
- Design and Technology particularly: ("Design and Technology Learning" OR "technology learning" OR "design learning" OR "product design program" OR "D&T program")

The three clusters were merged to create the comprehensive search string: ("circular economy" OR "cradle-to-cradle" OR "biomimicry" OR "industrial ecology") AND ("Education for Sustainable Development" OR "sustainable design education" OR "STEM education sustainability" OR "circular economy education") AND ("Design and Technology Education" OR "technology education" OR "design education" OR "product design curriculum"). String variations were adjusted to suit the indexing standards of specific databases. The searches were carried out from October 2025 to January 2026.

### *2.2 Inclusion and Exclusion Criteria*

Studies included has to meet the following criteria: (a) were published in English between 1997 and 2025; (b) addressed the Circular Economy, sustainable design, or ESD in relation to education or curriculum; (c) were peer-reviewed journal articles, book chapters, conference proceedings, or authoritative policy documents; and (d) were relevant to the D&T, design, STEM, or technology education context.

Studies were excluded if they did not pertain to education and CE or were unpublished theses without peer review. Seminal theoretical works (e.g., Benyus, 1997; McDonough & Braungart, 2006) were included irrespective of date due to their foundational importance to the field.

### *2.3. The Process*

Approximately 1240 records were yielded in the initial search across the 5 databases. Duplicate records were removed, and 874 records remained for screening. The outlined inclusion and exclusion criteria were used to review titles and abstracts. Records that did not address education, curriculum, or pedagogy in relation to the Circular Economy or sustainable design were excluded at this stage, reducing the pool to 213 sources for full-text review. Once the full texts were assessed, 87 sources were included in the final review.

An additional 14 grey literature sources — including policy documents and reports from UNESCO, the Ellen MacArthur Foundation, Circle Economy, and the World Economic Forum — were incorporated through purposive selection due to their direct relevance to the policy landscape of CE education. The final review corpus comprised 101 sources. Figure 1 below reflects a PRISMA flow diagram illustrating the selection process.

**Figure 1: PRISMA Flow Diagram — Study Selection Process**

| | |
|---|---|
| **Stage 1: Identification** | |
| Records identified through database searching (Scopus, Web of Science, Google Scholar, ERIC, EBSCOhost) | n = 1,240 |
| Additional records identified through grey literature (UNESCO, Ellen MacArthur Foundation, Circle Economy, WEF) | n = 14 |
| Total records at identification stage | n = 1,254 |
| **Stage 2: Screening** | |
| Duplicate records removed | n = 366 |
| Unique records screened (title and abstract) | n = 874 |
| Records excluded at screening stage (no educational/curriculum focus; failed inclusion criteria) | n = 661 |
| Records proceeding to full-text review | n = 213 |
| **Stage 3: Eligibility** | |
| Full-text sources assessed for eligibility | n = 213 |
| Excluded: purely industrial CE focus (no educational application) | n = 54 |
| Excluded: insufficient relevance to D&T, design, or STEM education | n = 41 |
| Excluded: unpublished theses without peer review | n = 18 |
| Excluded: not available in English | n = 13 |
| Total excluded at full-text stage | n = 126 |
| Sources meeting full eligibility criteria | n = 87 |
| **Stage 4: Inclusion** | |
| Peer-reviewed sources included from database searching | n = 87 |
| Grey literature sources included through purposive selection | n = 14 |
| TOTAL SOURCES INCLUDED IN FINAL REVIEW | n = 101 |

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### *2.4 Data Extraction*

Data were extracted from each included source using a structured extraction template developed by the primary researcher. The template reflected the following information: author(s) and year of publication; country or regional context; source type (journal article, book chapter, conference proceeding, or policy document); study design or methodology where applicable; educational level and subject context; CE-related focus or framework discussed; and key findings or arguments relevant to Design and Technology curriculum and sustainable design education.

For theoretical and policy-oriented sources, the extraction focused on conceptual contributions, definitional frameworks, and implications for educational practice rather than on empirical outcomes. The extracted data were reviewed iteratively alongside the inductive coding process described in Section 2.5, ensuring that thematic categories remained grounded in the evidence base. Where ambiguity arose regarding a source's relevance or classification, this was resolved through re-reading and cross-referencing against the inclusion criteria.

### *2.5 Thematic Organisation*

Following screening and full-text review, the selected literature was organised thematically using a process of inductive coding. Initial codes were assigned to passages, arguments, and findings across the 101 sources, and these codes were subsequently grouped into broader thematic categories through iterative comparison and refinement. Six major themes emerged from this process: (1) theoretical foundations of the CE; (2) global and regional policy; (3) sustainability in D&T curricula; (4) barriers to circular transition in education; (5) existing frameworks for sustainable design; and (6) research gaps. These themes constitute the organisational structure of the review that follows.

## 3. Literature review

### *3.1. Theoretical Foundations of the Circular Economy*

#### *3.1.1. From Linear to Circular: A Conceptual Shift*

The hallmark of the prevailing linear economic model of the 20th century is a 'take-make-use-dispose' process that considers the natural environment as an endless source of resources and a boundless sink for waste (Hamid et al., 2024). The conceptual history of the linear economy dates back to the first Industrial Revolution, when mechanization allowed for unparalleled levels of production and resource extraction (Andrews, 2015). For more than a hundred years, this model was regarded as equivalent to economic advancement.

However, the rise of environmental awareness in the 1970s, sparked by events such as the 1972 Club of Rome report, Limits to Growth, began to break this agreement. Academics began to argue that infinite growth on a finite planet was physically unfeasible and that a different economic rationale was urgently needed. The idea of sustainable development, described in the Brundtland Report (WCED, 1987) as 'growth that satisfies the demands of today without hindering future generations from fulfilling their own needs', sought to balance economic progress with environmental care. As Engelman (2013, p. 2) notes, sustainable development has led to 'sustainababble'. That is a surge in the term 'sustainable' used in such varied ways that it loses its practical significance. Geissdoerfer et al. (2017) indicate that as sustainable development diminishes in conceptual relevance, the Circular Economy arises as a more practically defined and policy-implementable substitute.

#### *3.1. 2 The Cradle-to-Cradle Theory*

Walter Stahel's cradle-to-cradle concept is widely recognised as a foundational theoretical contribution to the Circular Economy, suggesting that materials should circulate in a 'closed loop' in which waste from one process serves as input to another, in contrast to the linear cradle-to-grave model (Andrews, 2015). Stahel recognized that the issue of waste fundamentally stemmed from system design: if materials were created to re-enter productive cycles, waste would, by definition, be eradicated.

This foundational idea was primarily shaped by McDonough and Braungart (2006) in their pivotal publication Cradle to Cradle: Remaking the Way We Make Things. They proposed a concept of industrial systems inspired by the metabolism of living beings, comprising two separate cycles: the 'biological metabolism', which returns biodegradable materials safely to nature, and the 'technical metabolism', which enables synthetic and mineral materials to be cycled back into production indefinitely. Importantly, McDonough and Braungart contended not just for minimizing harm — which they termed 'eco-efficiency' — but for creating beneficial environmental impact, or 'eco-effectiveness'.

Toxopeus et al. (2015) note that the unique aspect of the cradle-to-cradle framework is its focus on achieving a 'positive footprint' instead of simply reducing a negative one. This change in perspective has important consequences for design education: it requires that designers not only minimize harm but also actively create ecological and social benefits through their design choices.

#### *3.1. 3 Biomimicry*

Tightly linked to the cradle-to-cradle idea, biomimicry was presented by Janine Benyus

(1997) in her impactful book Biomimicry: Innovation Inspired by Nature. Benyus claimed that nature, having undergone 3.8 billion years of research and development, has effectively addressed the majority of the engineering problems encountered by human designers. She suggested that designers should draw inspiration from natural systems as examples, standards, and guides — utilizing only the energy needed, recycling all materials, and steering clear of surplus.

Biomimicry and cradle-to-grave both emphasize a strong dedication to circular material cycles and waste elimination. Biomimicry, however, extends by suggesting that the formal and structural aspects of designed objects should replicate natural systems — not only their material reasoning but also their morphological creativity. Fiorentino and Montana-Hayos (2014) observe that biomimicry has historical roots; Leonardo Da Vinci's endeavors in the 15th century to design flying machines based on bird anatomy serve as an early example of biomimetic thought. Benyus provided a structured, science-based approach for integrating nature's wisdom into modern design problems.

*3.1.4 Industrial Ecology and Systems Thinking*

Industrial ecology, developed by Frosch and Gallopoulos (1989), provides a third theoretical pillar for the Circular Economy. It proposes that industrial systems should emulate the structure of ecological systems, in which the waste of one organism becomes the nutrient of another. Industrial ecology gave rise to the concept of 'industrial symbiosis' — the practice of linking industries so that the by-products of one serve as the raw materials of another — exemplified most famously by the Kalundborg Symbiosis in Denmark (Chertow, 2000).

Systems thinking underlies all three of these frameworks. Rather than treating products, processes, or organisations as isolated entities, systems thinking demands attention to the web of relationships in which they are embedded. Sterman (2000) argues that most environmental problems are products of linear thinking applied to inherently circular systems; addressing them requires a fundamental shift in cognitive orientation. For D&T Education, this implies that students must learn not merely to design objects but to design systems — to think in loops, cycles, and flows rather than in lines.

*3.1.5 The Ellen MacArthur Foundation and the Contemporary CE Discourse*

Founded in 2010, the Ellen MacArthur Foundation has emerged as the leading institutional advocate for the Circular Economy worldwide, generating a collection of pivotal reports that consolidated the theoretical frameworks discussed earlier and converted them into practical policy and business strategies (Ellen MacArthur Foundation, 2013, 2015, 2025). The Foundation characterizes the CE as a model that is 'restorative and regenerative by design,' and this definition has gained widespread acceptance in policy discussions. Its three principles—remove waste and pollution, circulate products and materials at their utmost value, and restore natural systems—offer a practical framework for assessing the circularity of design choices (Ellen MacArthur Foundation, 2025).

The Department of Environment, Forestry and Fisheries (2020) in South Africa presented a comparable perspective, characterizing the CE as an economic framework that separates economic growth from the use of limited resources, circulating biodegradable substances through biological cycles and non-biodegradable substances through technical cycles. This perspective has shaped regional policy frameworks in Africa and offers a valuable reference for the subsequent review.

### *3.2. Global and Regional Policy Trajectories*

*3.2.1. Global Policy: From the SDGs to Circular Action Plans*

The United Nations General Assembly's adoption of the 2030 Agenda for Sustainable Development in 2015, along with its 17 Sustainable Development Goals (SDGs), established a global normative framework for sustainability that prioritized education (UNESCO, 2020). SDG 4 (Quality Education), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action) are particularly pertinent to the CE-education connection. UNESCO (2020) established Education for Sustainable Development (ESD) as the means by which education supports all 17 SDGs, asserting that ESD equips learners with the competencies, skills, values, and knowledge to promote sustainability.

Nguyen (2023) and Singh-Pillay (2023, 2024) each contend that ESD necessitates a deep rethinking of the purpose of education — moving from the transmission of knowledge to the cultivation of competencies, and from equipping individuals for the current economy to preparing them for sustainable futures. This rethinking is directly pertinent to D&T Education, which has traditionally focused on developing technical skills but is now increasingly required to integrate sustainability principles (Mesuweni et al, 2020).

At the regulatory level, the European Union has led the world in CE policy. The EU Circular Economy Action Plan (CEAP), initiated in March 2020, created an extensive strategy for sustainable product development, focusing on industries with high material consumption (Rotondo et al., 2025). In 2024, the EU implemented the Eco-design for Sustainable Products Regulation (ESPR), which establishes eco-design standards for products sold in the EU market. These regulatory actions indicate how far circular design is moving from an optional goal to a legal obligation in key economies.

China, confronted with significant environmental challenges such as resource depletion and greenhouse gas emissions, introduced a Circular Economy Promotion Law in 2008, positioning itself as one of the first countries to incorporate the CE into national legislation (Geng & Doberstein, 2008). China's experience provides valuable insights regarding the relationship.

*3.2.2. African Regional Policy*

Africa presents a multifaceted, inconsistent policy environment. The World Economic Forum (2021) pinpointed five essential enablers for Africa's circular transition: supportive policies and regulatory structures; mechanisms for business support; investment in robust infrastructure; accessibility to financing and Technology; and assessment and monitoring data systems. The release of the Continental Circular Economy Action Plan for Africa in 2024 marks a significant achievement in African CE governance, creating a continent-wide structure for circularity.

At the national level, South Africa has been one of the most engaged African countries in developing CE policies. The Department of Environment, Forestry and Fisheries (2020) released a Circular Economy framework for managing plastic waste, while the Circular Economy Science, Technology and Innovation Strategy (DSTI, 2024) recognized circular product design, remanufacturing, resource efficiency, and cleaner production as key national priorities. The National Waste Management Strategy (2020) incorporated the CE at its core, prioritizing reuse and recycling as key waste management approaches. In the Design and Technology curricula, the Department of Basic Education (2011) integrated sustainable design into the Curriculum and Assessment Policy Statement (CAPS).

Rwanda and Kenya implemented bans on plastic bags and set up e-waste recycling centers (in 2017 and 2013, respectively), demonstrating grassroots policy initiatives (World Economic Forum, 2021). Zimbabwe has implemented the Environmental Management Act [Chapter 20:27] and related statutory instruments to reduce waste, but researchers argue that more targeted, circular economy-specific policies are necessary (Musonda et al., 2025).

*3.2.3 Policy-Practice Gaps*

In every region, researchers have observed a continual discrepancy between policy aspirations and actual execution. UNESCO-UNEVOC (2024) observes that although universities and educational institutions view the CE as highly pertinent to their programs, the practical incorporation of CE topics into education and instruction remains relatively limited. The gap between policy and practice is not just about delays in implementation; it reveals more profound structural problems, such as limited resources, insufficient teacher training, a lack of specific pedagogical frameworks for CE, and the persistence of traditional linear design methods.

Giannoccaro et al. (2021) contend that education is critical to the circular transition, as it can transform the values, knowledge, and skills of future designers, entrepreneurs, and citizens—tackling the underlying causes of linear behavior rather than just its symptoms. DCCEEW (2024) likewise asserts that education provides the research, advocacy, and human capital development essential to advancing the CE agenda. However, the methods by which educational systems can be changed to achieve these results are still not well established in the literature.

### *3.3. Sustainability in Design and Technology Curricula*

#### *3.3. 1 The Evolution of D&T as a School Subject*

Design and Technology originated as a distinct school subject in England in the late 1980s, replacing earlier craft-focused subjects with a unified approach that integrated design thinking, Technology, and production (Kimbell, 1994). The subject has since grown worldwide, taking different forms across national education systems — including 'Technology' in South Africa and Zimbabwe, and 'Design and Technology' in England and Australia. These variations highlight the design process as a way to tackle issues and create artifacts or systems in reaction to identified needs.

The design process — a sequence of cycles that involves identifying issues, generating ideas, developing prototypes, testing, and assessing outcomes — inherently supports incorporating sustainability elements. Cambridge International (2023) has clearly integrated sustainability into its IGCSE Design and Technology curriculum, requiring students to assess the environmental impacts of their design decisions throughout the design process. The CAPS Technology curriculum of South Africa (Department of Basic Education, 2011) includes sustainability as a central theme. However, the degree and consistency of this integration vary significantly across national contexts and specific institutions.

#### *3.3.2. ESD and D&T: Points of Convergence*

The convergence of Design, Technology, and Education for Sustainable Development is conceptually advantageous. Wiek et al. (2011) identified five key competencies that ESD should promote: systems thinking, anticipatory thinking, normative competence, strategic competence, and interpersonal competence. All of these closely align with the abilities that D&T education seeks to develop through the design process. Systems thinking is essential for both ESD- and CE-focused design — it demands that students understand the web of material, social, and economic relationships that surround their design decisions.

Papanek (1984), in his critical work Design for the Real World, argued well before ESD became an official priority that designers have a moral responsibility for the social and environmental consequences of their designs. His rationale anticipated the contemporary CE framework by emphasizing that design must cater to human requirements, be mindful of the environment, and foster social fairness. Papanek's contributions have been frequently cited in design education texts as a crucial reference for instructing sustainable design concepts.

### *3.4. Sustainable Design in D&T*

A growing body of research has examined the integration of sustainable design principles in D&T and comparable educational programs. Brezet (1997) introduced the concept of 'ecodesign', asserting that environmental considerations should be integrated into the product design process from the outset rather than addressed subsequently. Ecodesign approaches — including material selection, improving energy efficiency, ensuring recyclability, and considering end-of-life — have been slowly incorporated into design education programs, though their implementation varies.

Sherwin and Bhamra (1999) found that sustainable design was often viewed as an add-on in design education rather than a core competency, mirroring the trend observed in industry. Recent studies show progress: Sung (2015) found that design students who received structured training in sustainable design demonstrated improved circular thinking in their projects compared with control groups. However, the lack of standardised evaluation frameworks for circular design competency impedes the systematic assessment of the efficacy of these interventions.

In the specific field of D&T Education in the global south, the existing literature is limited. Dlamini and Adigun (2022) examined technology education in South Africa and noted that, despite sustainability being included in the CAPS framework, teachers often lack the required content knowledge and teaching materials to implement it effectively. Similar observations have been recorded in other African contexts, suggesting that curriculum policy exceeds teaching capabilities.

### *3.5. Barriers to Circular Transition in Design and Technology Education*

#### *3.5.1. Conceptual and Pedagogical Barriers*

The primary obstacle to a circular transition in D&T Education is conceptual: linear thinking is firmly rooted in both the educational culture and the broader society. The take-make-use-discard approach of the linear economy is not only an industrial method; it is a mental framework that influences how designers and students perceive materials, products, and value. Sterman (2000) notes that human cognitive systems struggle to grasp circular causality and feedback loops — the fundamental logic underlying the CE. Incorporating circular thinking into students' learning necessitates more than adding new material to current curricula; it involves transforming fundamental cognitive perspectives.

From a pedagogical standpoint, D&T educators face the challenge of teaching circular design without established, school-appropriate frameworks or evaluation instruments. In contrast to mathematical or scientific knowledge, which features clearly defined teaching sequences, circular design competency remains inadequately theorized within the school context. Dlamini and Adigun (2022) report on teachers' lack of clarity regarding the appearance of circular design in a D&T classroom and its assessment within current curriculum frameworks. This lack of educational guidance is a considerable barrier to execution.

#### *3.5.2. Structural and Institutional Barriers*

Structural obstacles function within the realms of schools, curricula, and educational frameworks. UNESCO-UNEVOC (2024) points out that insufficient teacher preparation constitutes a major structural obstacle: pre-service and in-service teacher education programs seldom incorporate significant CE or sustainable design material, leaving teachers to create solutions without sufficient knowledge or support. This is further complicated by the lack of CE-related textbooks, practical materials, and evaluation criteria at the school level.

In the African context, resource constraints introduce an additional level of difficulty. Numerous schools, especially in rural and suburban areas, lack the facilities, resources, and Technology to effectively implement circular design projects. Musonda et al. (2025) highlight how obsolete Technology, elevated costs, and poor infrastructure obstruct circular-economy shifts in Zimbabwe—challenges that also affect educational institutions.

#### *3.5.3. Cultural Barriers*

Cultural obstacles may be the hardest to overcome. In numerous communities, especially in the global south, cultural perspectives on materials, waste, and production are entrenched and challenging to change solely through education. Musonda et al. (2025) recognize cultural obstacles as major hindrances to circular transition in Zimbabwe's construction sector, and it is plausible to assume that similar challenges exist in educational contexts. The tendency toward disposability — bolstered by years of a linear consumer culture — cannot be altered merely by updating the curriculum.

Additionally, the discussions surrounding the circular economy have faced criticism for primarily embodying Northern European values and economic beliefs that may not easily apply to contexts marked by diverse material cultures, economic circumstances, and sustainability issues (Korhonen et al., 2018). This raises significant concerns about the contextual relevance of CE frameworks developed in the global north when used in D&T education across sub-Saharan Africa.

*3.5.4. Policy Implementation Gaps*

As mentioned previously, there is a consistent disparity between policy intentions and classroom realities. Curricula incorporating sustainability or CE themes do not inherently result in circular design practices. Translating policy into pedagogy requires supportive professional development, sufficient resources, aligned evaluations, and strong institutional leadership—conditions that are often lacking, especially in underfunded educational systems. Jawahir and Bradley (2016) recognized a deficiency in advancing scalable technological innovations for closed-loop systems in manufacturing; a similar deficiency exists in advancing scalable pedagogical innovations for closed-loop thinking in design education.

### *3.5. Existing Frameworks for Sustainable Design in Education*

*3.5.1. Eco-design Frameworks*

Numerous eco-design frameworks have been developed for use in design education, yet most focus on higher education rather than primary or secondary school settings. The Product Life Cycle Assessment (LCA) framework, originating in industrial ecology, provides a structured approach to assessing a product's environmental impacts throughout its life cycle—from raw material extraction to final disposal (Baumann & Tillman, 2004). LCA has been integrated into university programs in industrial design and engineering, yet its complexity makes it less approachable in secondary education settings.

The Design for Environment (DfE) method, introduced by Fiksel (1996), provides a design-focused framework that incorporates environmental factors into every phase of the design process. DfE approaches include designing for easy disassembly, ensuring recyclability, reducing material consumption, and choosing materials with a minimal environmental footprint. These strategies are better suited to implementation at the school level than LCA, and certain D&T curricula have informally integrated DfE principles.

*3.5.2. The ReSOLVE Framework*

The ReSOLVE framework, created by the Ellen MacArthur Foundation (2015), stands for Regenerate, Share, Optimize, Loop, Virtualize, and Exchange, serving as a practical resource for companies moving towards the CE. Although created for the industry, the ReSOLVE framework could serve as a structured prompt for circular design thinking in design education. Its six strategies correlate with design choices that learners can make during D&T projects, and it has been referenced in recent literature on CE education (Giannoccaro et al., 2021)

*3.5.3. Cradle-to-Cradle Certification*

The Cradle-to-Cradle Products Innovation Institute oversees a certification program that assesses products based on five CE categories: material health, material reutilization, renewable energy and carbon management, water stewardship, and social equity (McDonough & Braungart, 2006). Though the certification targets industrial products, its classifications provide a solid basis for evaluating the sustainability of student design initiatives. Adjusting this framework for assessment at the school level presents an uncharted chance.

*3.5.4. Sustainable Design Frameworks in D&T Literature*

In the D&T literature, various researchers have suggested frameworks for educating on sustainable design. Sherwin and Bhamra (1999) suggested a layered model of sustainable design proficiency, from fundamental environmental awareness to comprehensive design for sustainability. Sung (2015) recently developed a framework to incorporate sustainable design into design studio teaching, emphasizing ongoing reflection on environmental impacts. These frameworks, nonetheless, were created for higher education settings and have not been confirmed at the school level.

The lack of a circularity framework tailored for school-level D&T education—especially one that is contextually relevant to schools in the global south—represents a crucial gap that this review highlights as a key area for future research.

## *4.1. Research Gaps and Future Research Agenda*

*4.1.1. Summary of Identified Gaps*

The previous analysis has revealed multiple important deficiencies in the literature. Although CE scholarship is significant in industrial and higher education settings, empirical research on CE integration within school-level D&T education is limited. This disparity is especially evident in sub-Saharan Africa, where the overlap between D&T Education and the CE has received virtually no academic attention.

Additionally, while the obstacles to circular transition in educational environments are noted broadly, they have not been researched within the specific institutional context of D&T schools—a critical distinction, since D&T's focus on material creation and design process sets it apart from other subjects. Third, current sustainable design frameworks in education were mainly created for higher education settings in the global north and have not been modified, verified, or assessed for use at the school level in the global south. Fourth, the connection between curriculum policy and classroom implementation in D&T—the policy-practice divide—has not been empirically examined in a global South setting.

*4.1.2 Future Research Priorities*

Based on these gaps, this review suggests the ensuing priorities for future research. Initially, empirical qualitative research is required to document the current state of D&T practice in schools in sub-Saharan Africa establishing a benchmark for assessing the level of circular design integration. Secondly, research should explore the particular obstacles — conceptual, structural, cultural, and policy-related — that hinder the transition to circular approaches in D&T classrooms, incorporating insights from teachers, students, and curriculum developers. Third, research-based design is essential to create, test, and progressively enhance a circularity framework appropriate for D&T at the school level in the global south—one that is attuned to resource limitations, cultural environments, and curriculum frameworks in these contexts.

Fourth, examining comparative studies within various African national contexts (e.g., South Africa, Zimbabwe, Kenya, Rwanda) would shed light on how policy frameworks have been converted into teaching practices and reveal the supportive factors for effective integration. Fifth, longitudinal research is essential to evaluate if circular design education leads to lasting changes in graduates' design practices — a question that directly pertains to the core objective of ESD.

## ***5. Conclusion***

This literature review has charted the knowledge landscape where Circular Economy, sustainable design, and Design and Technology Education converge. It has followed the theoretical roots of the CE from Stahel's cradle-to-grave idea through McDonough and Braungart's metabolic framework, Benyus's biomimicry, and the current Ellen MacArthur Foundation approach. It has examined international and local policy directions, highlighting the substantial disparity between policy aspirations and educational implementation. It has explored the incorporation of sustainability in D&T curricula and recorded the conceptual, structural, cultural, and policy obstacles that hinder circular transition in educational environments. It has examined current frameworks for sustainable design and found none are sufficiently adapted for school-level D&T in the global south.

The main conclusion of this review is that the CE-D&T Education relationship is a vital yet highly under-researched field of study, especially in Africa. The stakes are significant: according to the Ellen MacArthur Foundation (2025), design is the primary driver of the global waste crisis. If this assessment is accurate, then Design and Technology Education is not a marginal issue in sustainability policy — it is a key aspect. Creating a practical, contextually relevant circularity framework for D&T schools in Zimbabwe and the broader global South is not simply an academic endeavor; it is a valuable contribution to the critical global initiative to eliminate waste.

Future studies should move beyond policy evaluation and theoretical integration to yield empirical, practical insights into what circular design education entails in practice — including what it requires of educators, what outcomes it yields for students, and the environments it needs to succeed. This assessment has charted the landscape; the effort of investigation is now critically required.

## REFERENCES


Andrews, D. (2015). The circular economy, design thinking and education for sustainability. *Local Economy*, Vol. 30(3), 305–315. https://doi.org/10.1177/0269094215578226

Baumann, H., & Tillman, A.-M. (2004). *The Hitch Hiker's Guide to LCA: An orientation in life cycle assessment methodology and application*. Studentlitteratur.

Benyus, J. M. (1997). *Biomimicry: Innovation inspired by nature.* William Morrow.

Brezet, H. (1997). Dynamics in ecodesign practice. *UNEP Industry and Environment*, Vol. 20 (1–2), 21–24.

Brice, S. (2026). Organizational Challenges and Solutions in Circular Economy Implementation. *Sustainability,* 1Vol.8(4), 1829.

Cambridge International. (2023). *Cambridge IGCSE Design and Technology* (0445) syllabus 2024–2026. Cambridge Assessment International Education.

Chertow, M. R. (2000). Industrial symbiosis: Literature and taxonomy. *Annual Review of Energy and the Environment,* Vol. 25(1), 313–337. https://doi.org/10.1146/annurev.energy.25.1.313

Circle Economy. (2025). *The Circularity Gap Report 2025*. Circle Economy Foundation.

DCCEEW. (2024). *Circular economy and education*. Department of Climate Change, Energy, the Environment and Water, Australian Government.

Department of Basic Education. (2011). Curriculum and Assessment Policy Statement (CAPS): Technology Grades 7–9. Department of Basic Education, Republic of South Africa.

Department of Environment, Forestry and Fisheries. (2020*). A circular economy approach to plastic waste in South Africa.* DEFF, Republic of South Africa.

Dlamini, S., & Adigun, O. T. (2022). Technology teachers' integration of sustainability in the South African curriculum. *South African Journal of Education*, 42(3), 1–12.

DSTI. (2024). *Circular Economy Science, Technology and Innovation Strategy*. Department of Science, Technology and Innovation, Republic of South Africa.

Ellen MacArthur Foundation. (2013). *Towards the circular economy: Economic and business rationale for an accelerated transition*. Ellen MacArthur Foundation.

Ellen MacArthur Foundation. (2015). *Towards a circular economy: Business rationale for an accelerated transition*. Ellen MacArthur Foundation.

Ellen MacArthur Foundation. (2025). *What is the circular economy?* https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview

Engelman, R. (2013). Beyond sustainababble. In L. Starke (Ed.), *State of the world 2013: Is sustainability still possible?* (pp. 3–16). Island Press.

Fiksel, J. (1996). *Design for environment: Creating eco-efficient products and processes*. McGraw-Hill.

Fiorentino, R., & Montana-Hayos, C. (2014). *Biomimicry: Nature as muse*. Bloomsbury Publishing.

Frosch, R. A., & Gallopoulos, N. E. (1989). Strategies for manufacturing. *Scientific American*, 261(3), 144–152.

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy — A new sustainability paradigm? *Journal of Cleaner Production*, Vol. 143, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Geng, Y., & Doberstein, B. (2008). Developing the circular economy in China: Challenges and opportunities for achieving 'leapfrog development'. *International Journal of Sustainable Development & World Ecology*, Vol. 15(3), 231–239.

Giannoccaro, I., Fraccascia, L., & Albino, V. (2021). The role of education in circular economy adoption. Resources, *Conservation and Recycling*, Vol. 164, 105155.

Hamid, M., Rafiq, A., & Ali, M. (2024). Linear to circular economy transition: Barriers and enablers. *Sustainable Production and Consumption*, Vol. 45, 123–137.

Jawahir, I. S., & Bradley, R. (2016). Technological elements of circular economy and the principles of 6R-based closed-loop material flow in sustainable manufacturing. *Procedia CIRP*, Vol. 40, 103–108. https://doi.org/10.1016/j.procir.2016.01.067

Kimbell, R. (1994). Progression in learning and the assessment of children's attainment in technology. *International Journal of Technology and Design Education*, Vol. 4(1), 65–83.

Korhonen, J., Nuur, C., Feldmann, A., & Birkie, S. E. (2018). Circular economy as an essentially contested concept. *Journal of Cleaner Production*, Vol. 175, 544–552. https://doi.org/10.1016/j.jclepro.2017.12.111

McDonough, W., & Braungart, M. (2006). *Cradle to cradle: Remaking the way we make things*. Vintage.

Mesuwini, J; Singh-Pillay, A, & Boman, M. Perceptions of engineering lecturers and graduates on employability skills: a case of a TVET college in KwaZulu-Natal, South Africa. *International Journal of Social Sciences and Humanitarian Studies*, Vol. 20(2), 416-432.1309-8063

Ministry of Primary and Secondary Education (MoPSE). (2024). *Design and Technology curriculum framework*. Government of Zimbabwe.

Musonda, I., Nani, G., & Okoro, C. S. (2025). Circular economy transition in the Zimbabwean construction industry: Barriers and opportunities. *Sustainability*, Vol. 17(3), 1102.

Nguyen, T. P. L. (2023). Education for sustainable development: Reviewing the concept and its applications. *Sustainability*, Vol. 15(6), 4963.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., & Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, 372, n71. https://doi.org/10.1136/bmj.n71

Papanek, V. (1984). *Design for the real world: Human ecology and social change* (2nd ed.). Thames and Hudson.

Rotondo, F., Bocci, F., & Mazzara, L. (2025). The EU Circular Economy Action Plan and sustainable product regulation: A policy analysis. *Journal of Cleaner Production*, Vol. 445, 141003.

Sherwin, C., & Bhamra, T. (1999). *Ecodesign innovation: An analysis of its application in practice. Proceedings of EcoDesign '99*: First International Symposium on Environmentally Conscious Design and Inverse Manufacturing (pp. 844–849). IEEE.

Singh-Pillay, A (2023). Pre-Service Teachers' Experience of Learning about Sustainability in Technology Education in South Africa. *Sustainability*, Vol. 15, 2149.vhttps://doi.org/10.3390/ su15032149

Singh-Pillay, A. (2024). Integrating education for sustainable development into teacher education programmes. *Sustainability*, 16(4), 1452.

Sterman, J. D. (2000). *Business dynamics: Systems thinking and modeling for a complex world*. Irwin/McGraw-Hill.

Sung, K. (2015). A review on upcycling: *Current body of literature, knowledge gaps and a way forward*. Proceedings of the 17th International Conference on Environmental, Cultural, Economic and Social Sustainability, Venice, Italy.

Toxopeus, M. E., De Koeijer, B. L. A., & Meij, A. G. G. (2015). Cradle to cradle: Effective vision vs. efficient practice? *Procedia CIRP*, Vol. 29, 384–389.

UNESCO. (2020). *Education for sustainable development*: A roadmap. UNESCO.

UNESCO-UNEVOC. (2024). *Circular economy and technical and vocational education and training*. UNESCO-UNEVOC International Centre.

van den Brande, L., Peeters, D., & De Wolf, C. (2011). A critical review of the sustainable development concept. *Sustainability Science*, Vol. 6(1), 43–55.

WCED. (1987). *Our common future: The World Commission on Environment and Development*. Oxford University Press.

Wiek, A., Withycombe, L., & Redman, C. L. (2011). Key competencies in sustainability: A reference framework for academic program development. *Sustainability Science*, Vol. 6(2), 203–218. https://doi.org/10.1007/s11625-011-0132-6

Wilson, D. C., Rodic, L., & Scheinberg, A. (2024). Circular economy and solid waste management: Linking theory to municipal practice. *Waste Management*, Vol. 175, 66–78.

World Economic Forum. (2021). T*he African circular economy: Delivering development and sustainability*. World Economic Forum

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