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Case studies

C-Waste: Environmental education for sustainable development in urban communities

C-Waste: educación ambiental para el desarrollo sustentable en comunidades urbanas

Edgar Armando Chávez Moreno[1], María Virginia Flores-Ortiz[2]

[1]Facultad de Ciencias de la Ingeniería y Tecnología, Universidad Autónoma de Baja California, Blvd. Universitario 1000, Unidad Valle de Las Palmas, 22260 Tijuana, Baja California, México.
[2]Facultad de Ciencias Administrativas, Universidad Autónoma de Baja California, Blvd. Río Nuevo, Eje Central y, Río Nuevo, 21330 Mexicali, Baja California, México.

Corresponding author: Edgar, Armando Chávez Moreno, Facultad de Ciencias de la Ingeniería y Tecnología, Universidad Autónoma de Baja California, Blvd. Universitario 1000, Unidad Valle de Las Palmas, 22260 Tijuana, Baja California, México. E-mail: gared74mx@uabc.edu.mx. ORCID: 0000-0002-9305-3595.

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Abstract. - *Municipal solid waste management is a critical global challenge, necessitating a transition from traditional disposal methods to circular economy approaches and behavioral change. This article presents the development and analysis of C-Waste, an environmental education mobile application designed to foster sustainable waste management and responsible consumption in urban communities, specifically in Tecate, Baja California, Mexico. The objective is to evaluate how digital technologies can facilitate behavioral change and environmental awareness. Adopting a case study methodology based on a pilot test carried out at the El Florido IV Section Community Center aimed at a population of 500 users, the research encompasses four stages: the design of a Business Model Canvas (BMC), the development of the mobile application, multi-channel public dissemination, and preliminary impact analysis. The results demonstrate the successful structuring of a viable BMC that aligns technological capabilities with socio-environmental objectives, ensuring economic sustainability. The app effectively translates complex ecological data into an accessible tool featuring gamification and the 5R framework (refuse, rethink, reduce, reuse, recycle). Furthermore, a robust omnichannel digital strategy (YouTube, Instagram, Facebook) was deployed to maximize community engagement. In conclusion, the C-Waste initiative illustrates that integrating digital engagement, structured pedagogical models, and strategic multisectoral alliances effectively bridges the information-action gap, empowering citizens to adopt sustainable habits and contributing significantly to urban environmental education.*

Keywords: Sustainable development; Environmental education; Urban solid waste.

Resumen. - *La gestión de residuos sólidos urbanos es un desafío global crítico que requiere una transición hacia enfoques de economía circular y educación ambiental. Este artículo presenta el desarrollo y análisis de C-Waste, una aplicación móvil de educación ambiental diseñada para promover prácticas sostenibles de gestión de residuos y consumo responsable en comunidades urbanas, específicamente en Tecate, Baja California, México. El objetivo principal es evaluar cómo las tecnologías digitales pueden facilitar el cambio de comportamiento ecológico. Adoptando una metodología de estudio de caso a partir de una prueba piloto llevada a cabo en el Centro Comunitario El Florido IV Seccion dirigida a una población de 500 usuarios, la investigación abarca cuatro etapas: el diseño de un Modelo Canvas (BMC), el desarrollo de la aplicación móvil, su difusión pública multicanal y un análisis preliminar. Los resultados demuestran la estructuración de un BMC viable que alinea los recursos tecnológicos con los objetivos socioambientales. La aplicación traduce eficazmente los datos ecológicos en una herramienta que integra ludificación y el marco de las 5R (rechazar, repensar, reducir, reutilizar, reciclar). Además, se implementó una estrategia digital en plataformas como YouTube, Instagram y Facebook para maximizar la participación social. En conclusión, la iniciativa C-Waste ilustra que integrar herramientas digitales, modelos pedagógicos y alianzas multisectoriales cierra efectivamente la brecha entre información y acción, empoderando a los ciudadanos para adoptar hábitos sostenibles.*

Palabras clave: Desarrollo sustentable; Educación ambiental; Residuos sólidos urbanos.

1. Introduction

Municipal solid waste (MSW) management has become a critical challenge for cities worldwide due to population growth, urbanization, and increased consumption patterns. According to recent sustainability research, the transition toward a circular economy requires new approaches to waste reduction, resource efficiency, and citizen participation [1], [2], [15], [16]. Traditional waste management strategies have focused primarily on end-of-pipe solutions such as landfills and recycling systems. However, contemporary sustainability research emphasizes the importance of behavioral change and environmental education to reduce waste generation at the source [3] - [6], [11].

Environmental education initiatives are essential for promoting responsible consumption habits and increasing awareness about environmental impacts. Universities play a key role in fostering sustainability competencies among students and communities [20], [27]. In recent years, digital technologies have become important tools for sustainability communication and environmental learning. Mobile applications, in particular, provide accessible platforms for disseminating environmental information and engaging users in sustainability practices [3], [8], [19].

Digital platforms can support sustainability transitions by facilitating access to information, encouraging participation, and enabling behavioral change [13], [31]. Research has demonstrated that mobile-based sustainability tools can influence pro-environmental behavior by providing users with practical information and interactive learning experiences [26]. In this context, the C-Waste initiative was developed as an environmental education platform designed to promote sustainable waste management practices through a mobile application [5]. The project integrates principles of the circular economy and the 5R framework to encourage responsible consumption and waste reduction behaviors [22], [25].

Based on gaps identified in the literature and the analyzed community context, this research is guided by the following central question:

RQ: How do the design and implementation of a gamified mobile platform, integrated with a multi-channel dissemination strategy, influence knowledge acquisition, attitudes, and the adoption of sustainable municipal solid waste (MSW) management practices among urban community residents?

To address this question, this article is structured into five logical sections. Section 2 (Theoretical Framework) examines the foundations of Education for Sustainable Development (ESD), the "5Rs" pedagogical framework (refuse, rethink, reduce, reuse, and recycle), and the role of persuasive technologies and gamification in behavioral change. Section 3 (Methodology) details the mixed-methods case study design, structured in four stages: business modeling using the Business Model Canvas (BMC); the architecture and development of the C-Waste application; the multi-channel communication strategy; and the analytical design for empirical evaluation (participant characterization, variables, and instruments). Section 4 (Results and Discussion) presents and analyzes the quantitative and qualitative findings from the pilot phase, comparing C-Waste with existing solutions and identifying key barriers to local adoption. Finally, Section 5 (Conclusions) synthesizes the study's main theoretical and practical contributions, its implications for municipal public policy, the work's limitations, and avenues for future research.

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2. Background (Theoretical framework, state of the art)

A. Environmental Education for Sustainability

Environmental education has been widely recognized as a key strategy for achieving sustainable development goals [11]. Educational initiatives aimed at sustainability seek to promote environmental awareness, critical thinking, and responsible decision-making [34]. A foundational contribution in this area is the competence framework proposed by Wiek, Withycombe, and Redman, who argue that sustainability education should cultivate systems-thinking, anticipatory, normative, strategic, and interpersonal competences [36].

Universities and educational institutions are increasingly incorporating sustainability education into their curricula to prepare future professionals to address environmental challenges [27]. Brundiers et al. later refined this line of thought by seeking an agreed-upon reference framework for higher education, demonstrating that sustainability competences had become central not only to curriculum design but also to the evaluation of academic programs and professional outcomes [37]. Taken together, these authors frame EES as a mode of empowerment rather than as a body of static knowledge.

Digital learning environments can enhance environmental education by enabling interactive learning experiences and increasing accessibility to sustainability knowledge [28]. Mobile learning platforms allow users to access information anytime and anywhere, making them effective tools for environmental awareness campaigns [19]. However, the competence perspective does not exhaust the educational problem. Rieckmann argues that future-oriented higher education must foster key competences through learning processes that explicitly address uncertainty, participation, and social responsibility [38]. His work complements the earlier competence literature by underscoring that sustainability learning is inseparable from the temporal and ethical dimensions of decision-making.

In other words, it is not enough for learners to understand environmental systems; they must also become capable of acting under conditions of incomplete information and competing values. This concern is reinforced by Corres, Rieckmann, Espasa, and Ruiz-Mallén, whose systematic review of educator competences shows that sustainability education requires teachers who can facilitate transformational, interdisciplinary, and participatory pedagogies [39]. Their review is especially important because it moves the discussion from student outcomes to educator capabilities, thereby showing that the success of EES depends on institutional investment in teaching capacity.

A further layer of complexity appears when one considers whether environmental education actually changes behavior. Van de Wetering et al. offer a major meta-analysis showing that environmental education significantly improves knowledge, attitudes, intentions, and—though more modestly—behavior among children and adolescents [40]. This is an important empirical corrective to skepticism about the effectiveness of education, yet the authors also reveal substantial heterogeneity in outcomes. Their findings suggest that education has real potential, but that its effects vary across contexts, methods, and evaluation designs. Monroe et al. make a related contribution in their systematic review of climate change education strategies, identifying pedagogical approaches—such as local relevance, active engagement, and solution-oriented framing—that are more likely to promote meaningful learning and agency [41]. Compared with van de Wetering et al., who synthesize outcome effects, Monroe et al. focus more directly on what kinds of educational strategies produce those effects. Together, these studies

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support the argument that EES is effective when it is interactive, context-sensitive, and oriented toward action.

This action orientation also helps explain the historical shift from conventional environmental education to education for sustainable development. Bolscho and Hauenschild, writing on the German case, show that this transition involved more than a terminological update; it marked a move from topic-based environmental instruction toward a broader project of social transformation [42]. A similar historical and institutional transition is documented by Acosta-Castellanos and Queiruga-Dios in their systematic review of higher education, which demonstrates how universities have increasingly reframed environmental education in terms of sustainable development, interdisciplinarity, and institutional integration [43]. These two studies are particularly useful in combination: the former emphasizes the paradigm shift, while the latter shows how that shift has been concretized in higher education structures, programs, and discourse.

Another important debate concerns what students themselves perceive as relevant competences. Cebrián and Junyent, studying student teachers, found that sustainability education is often interpreted through a strong emphasis on knowledge and practical skills, but less consistently through ethical reflection, emotional engagement, and value-based learning [44]. This observation is highly revealing because it suggests that even within sustainability-oriented programs, the educational imagination may remain narrower than the transformative ambitions of the field. Barth, Godemann, Rieckmann, and Stoltenberg likewise argue that higher education must cultivate key competences through pedagogies that cross disciplinary boundaries and engage students in active problem-solving [45]. Their contribution aligns with Cebrián and Junyent in recognizing that sustainability learning should not be reduced to information acquisition, yet it also pushes further by linking competence development to curricular innovation and institutional learning.

Recent empirical work strengthens these concerns. Hammer and Lewis show, in their evaluation of sustainability-oriented study programs at the University of Bern, that students, graduates, and internship supervisors broadly converge around the importance of competences such as systems thinking, communication, and responsible participation [46]. Their findings are notable because they provide evidence that stakeholder groups beyond faculty perceive competence-oriented sustainability education as valuable. Lozano et al. complement this by explicitly connecting competences with pedagogical approaches in higher education, arguing that different teaching strategies activate different sustainability outcomes [47]. Where Hammer and Lewis provide evaluative evidence from a specific institutional setting, Lozano et al. provide a broader conceptual framework linking pedagogy and competence. The implication is clear: EES is most effective when institutions intentionally align learning outcomes, pedagogies, and assessment strategies.

Overall, literature converges on a powerful point. EES should be understood as transformative learning that combines knowledge, values, practice, and institutional support. Yet the authors do not agree on the exact balance among these elements. Wiek et al. and Brundiers et al. emphasize structured competence frameworks [36], [37]; Corres et al. and Lozano et al. stress educator capacity and pedagogy [39], [47]; van de Wetering et al. and Monroe et al. foreground evidence on learning outcomes and effective strategies [40], [41]. Rather than treating these as competing views, this article interprets them as complementary. Competences define the direction of learning, pedagogy shapes the process, and empirical evaluation clarifies what changes. That synthesis is essential if sustainability education is to contribute to real socio-ecological transformation.

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B. Circular Economy and the 5R Framework

The circular economy paradigm emphasizes resource efficiency, waste reduction, and the creation of closed-loop systems in which materials are reused and recycled rather than discarded [1], [2]. Within this framework, the 5R model has been widely adopted as a practical approach to encourage sustainable consumption behaviors [7]. The 5R principles include refusing unnecessary products, rethinking consumption patterns, reducing waste generation, reusing materials, and recycling resources.

These strategies are designed to minimize environmental impacts and promote sustainable production and consumption patterns [24], [32]. The adoption of circular economy principles is increasingly recognized as a key pathway toward sustainable urban development [12]. If EES addresses the question of how people learn to think and act sustainably, the Circular Economy addresses how production and consumption systems can be reorganized to reduce environmental pressure. Geissdoerfer, Savaget, Bocken, and Hultink define the circular economy as a regenerative system that minimizes resource input, waste, emissions, and energy leakage by slowing, closing, and narrowing loops [48]. Their article has become a landmark because it positions CE as more than a waste-management strategy; it frames circularity as a systemic alternative to linearity. Ghisellini, Cialani, and Ulgiati, in contrast, emphasize the expected transition to a balanced interplay of environmental and economic systems, providing a broader historical and policy-oriented review [49]. Although both contributions are foundational, they differ in emphasis: Geissdoerfer et al. focus on conceptual clarity and the relation between circularity and sustainability, whereas Ghisellini et al. are more concerned with implementation pathways across micro, meso, and macro levels.

The practical language through which CE is often operationalized is the 5R framework: reduce, reuse, recycle, recover, and redesign. This framework is useful because it orders strategies according to how early they intervene in resource flows. Su et al., reviewing the circular economy in China, show how policy rhetoric evolved toward implementation through industrial ecology, cleaner production, and resource efficiency measures [50]. Their work is particularly valuable because it demonstrates that circularity is not an abstract aspiration but a state-led development strategy that can shape industrial systems. At the same time, Kirchherr, Reike, and Hekkert show that CE definitions vary widely, and that many definitions reduce circularity to combinations of reuse, recycling, and reduction without adequately addressing systemic change, social dimensions, or business models [51]. When read together, these studies reveal both the utility and the risk of the 5R framework: it provides a recognizable operational grammar but can become conceptually thin if treated as a checklist rather than as a systems framework.

The first element, reduced, occupies a privileged position because it prevents resource extraction and waste generation before they occur. In sustainability terms, reduction is often more desirable than downstream treatment. This is consistent with Andersen’s early environmental economics treatment of CE, which emphasized the need to reconsider material throughput and economic assumptions rather than merely improve end-of-pipe efficiencies [59]. Reduction therefore raises questions not only about industrial efficiency but also about sufficiency, demand, and business models. By contrast, recycle and recover are often more visible because they can be measured more easily and institutionalized through waste systems. Yet Ghisellini et al. caution that recycling, while important, remains a lower-order strategy if societies continue generating unnecessary waste at scale [49]. This means the hierarchy implied by the 5R framework is substantive, not cosmetic: upstream strategies generally preserve more value and avoid more impact than downstream ones.

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The second element, reuse, extends product life and delays waste generation. Here, product design becomes decisive. Bocken, de Pauw, Bakker, and van der Grinten argue that companies moving toward circularity must rethink both product design and business model strategies [56]. Their contribution is significant because it shows that reuse is not simply a consumer choice but an organizational and design problem. Products must be durable, maintainable, repairable, and compatible with service-based or take-back models. Moreno et al. make a related point in their conceptual framework for circular design, where they show that design decisions at the earliest stages condition future possibilities for repair, disassembly, refurbishment, and recycling [57]. Compared with Bocken et al., who integrate design with business model innovation, Moreno et al. focus more sharply on the design logic itself. Together, these authors demonstrate that redesign is the enabling condition that makes the other Rs more feasible.

Redesign is especially important because it shifts circularity from reactive management to proactive innovation. Diaz et al. argue that sustainable product development in a circular economy requires coordinated attention to product architecture, actor roles, decision-support tools, and lifecycle information management [58]. Their study adds depth to the circular design debate by showing that redesign is not a one-off technical choice but a multi-actor process involving developers, managers, suppliers, and sustainability experts. This complements Moreno et al.'s conceptual work and illustrates how redesign becomes operational within organizational settings. In this sense, redesign is the strategic R: it embeds circular principles into products and processes before waste or inefficiency is created.

The literature also warns, however, against seeing CE as an uncontested or automatically progressive concept. Korhonen, Honkasalo, and Seppälä argue that the circular economy has conceptual limitations, especially when it is presented as a growth-friendly solution without sufficiently confronting thermodynamic constraints, power relations, and social trade-offs [52]. In another article, Korhonen, Nuur, Feldmann, and Birkie go further by describing CE as an essentially contested concept [53]. This intervention is crucial because it explains why circularity can be used by policymakers, firms, and scholars in markedly different ways. Where Geissdoerfer et al. seek conceptual synthesis [48], Korhonen and colleagues insist on conceptual tension [52], [53]. These positions should not be read as mutually exclusive. Rather, they show that CE must be both sufficiently clear to guide action and sufficiently critical to avoid becoming an empty slogan.

Implementation barriers make this tension even more visible. Kirchherr et al., studying evidence from the European Union, show that cultural and market barriers—not only technical ones—rank among the most pressing obstacles to circular transitions [54]. De Jesus and Mendonça similarly argue that drivers and barriers in the eco-innovation road to CE involve policy, markets, organizational inertia, and innovation ecosystems [55]. Both studies are important because they move beyond idealized circular models and examine why implementation remains uneven. Yet their emphases differ slightly: Kirchherr et al. foreground barriers perceived by businesses and policymakers, while de Jesus and Mendonça frame CE within the broader terrain of eco-innovation transitions. Taken together, they suggest that circularity fails when it is treated as purely technical; successful implementation requires aligned incentives, consumer cultures, institutional support, and organizational learning.

The 5R framework therefore should be interpreted as both a hierarchy of material strategies and a map of socio-technical transformation. Reduce and reuse depend on business model change and user acceptance; recycle and recover depend on infrastructures, policy, and markets; redesign depends on product development capabilities and cross-functional coordination [56]–[58]. This is why circular economy

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research has increasingly shifted from descriptive advocacy to a more critical examination of definitions, barriers, governance, and design. The field has matured from celebrating circularity as a self-evident good to asking under what conditions it actually delivers sustainability.

In summary, CE and the 5R framework offer a compelling structure for sustainability transitions, but only when their technical logic is embedded in broader institutional and cultural change. Geissdoerfer et al., Ghisellini et al., and Su et al. illustrate the promise of circularity as a systems approach [48]–[50]. Kirchherr and Korhonen reveal the conceptual ambiguities and practical limits that complicate this promise [51]–[54]. Bocken, Moreno, and Diaz show that product design and organizational innovation are decisive to moving from principle to practice [56]–[58]. What emerges is a nuanced picture: the 5R framework is powerful not because it simplifies the circular economy, but because it can organize a complex sustainability agenda—provided it is interpreted critically and implemented systemically.

C. Digital Technologies for Environmental Engagement

Advances in information and communication technologies have enabled the development of digital tools that support sustainability education and environmental engagement [14], [17]. Mobile applications, smart systems, and online platforms are increasingly used to promote environmental awareness and encourage citizen participation in sustainability initiatives [8], [18], [21], [29]. Research indicates that digital engagement tools can influence pro-environmental behavior by providing real-time information and facilitating user interaction [23]. Furthermore, mobile applications have been used to support waste reduction strategies, recycling initiatives, and sustainable consumption practices [7], [8], [9], [10].

The rapid evolution of Information and Communication Technologies (ICT) has fundamentally reshaped the landscape of environmental advocacy and education. In the contemporary era, digital technologies serve as the primary bridge between complex ecological data and citizen action. Digital engagement, often facilitated through mobile applications and web platforms, leverages the ubiquity of smartphones to promote sustainable lifestyles in real-time. According to recent studies, the integration of "Persuasive Technology" into environmental apps can significantly influence the Theory of Planned Behavior (TPB) by altering attitudes, subjective norms, and perceived behavioral control regarding waste management [1].

Mobile platforms like C-Waste represent a shift from passive information consumption to active participation. These technologies utilize features such as gamification, push notifications, and interactive mapping to keep users engaged with the 5R framework: Refuse, Rethink, Reduce, Reuse, and Recycle. Furthermore, the use of cloud-based architecture allows for the collection of large datasets on user habits, which can be analyzed to tailor educational content to specific urban demographics. Digital engagement is not merely about providing information; it is about creating a "Digital Ecosystem" where the user feels part of a global solution to local problems [2].

The effectiveness of these technologies lies in their ability to lower the "barrier to entry" for sustainable practices. For instance, augmented reality (AR) and localized GPS data can guide users to the nearest recycling centers or provide instant tutorials on how to compost organic waste. By digitizing environmental literacy, projects like C-Waste address the "Information-Action Gap," ensuring that knowledge leads to measurable ecological benefits in urban communities. This digital transformation is essential for reaching younger generations, who are more likely to adopt sustainable habits when presented through intuitive, high-tech interfaces [3], [4].

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3. Methodology

This research adopts a case study methodology to analyze the development and implementation of the C-Waste platform. Case study research is commonly used in sustainability studies to examine real-world initiatives and technological innovations within their specific contexts.

The study focuses on the conceptual design and initial deployment of the C-Waste mobile application in Tecate, Baja California, Mexico. The project was developed within the framework of environmental education initiatives at the Universidad Autónoma de Baja California.

The research process included the following stages:

1. Business Model Canvas of the C-Waste model based on circular economy and environmental education principles.
2. Design and development of the mobile application.
3. Public dissemination of the application through digital platforms.
4. Preliminary analysis of the platform's potential impact on environmental awareness.

This methodological approach allows researchers to explore how digital tools can support sustainability education and promote responsible waste management practices.

3.1 The C-Waste Business Model Canvas

The C-Waste conceptual model integrates environmental education, digital technologies, and sustainability principles to promote responsible waste management behaviors. The model consists of four main components:

- Environmental knowledge dissemination through digital platforms [6].
- Promotion of the 5R sustainability framework [34].
- Community engagement and participation [30].
- Behavioral change toward sustainable consumption practices [33].

The model assumes that increased access to environmental knowledge through digital technologies can influence individual attitudes and encourage sustainable behaviors [35].

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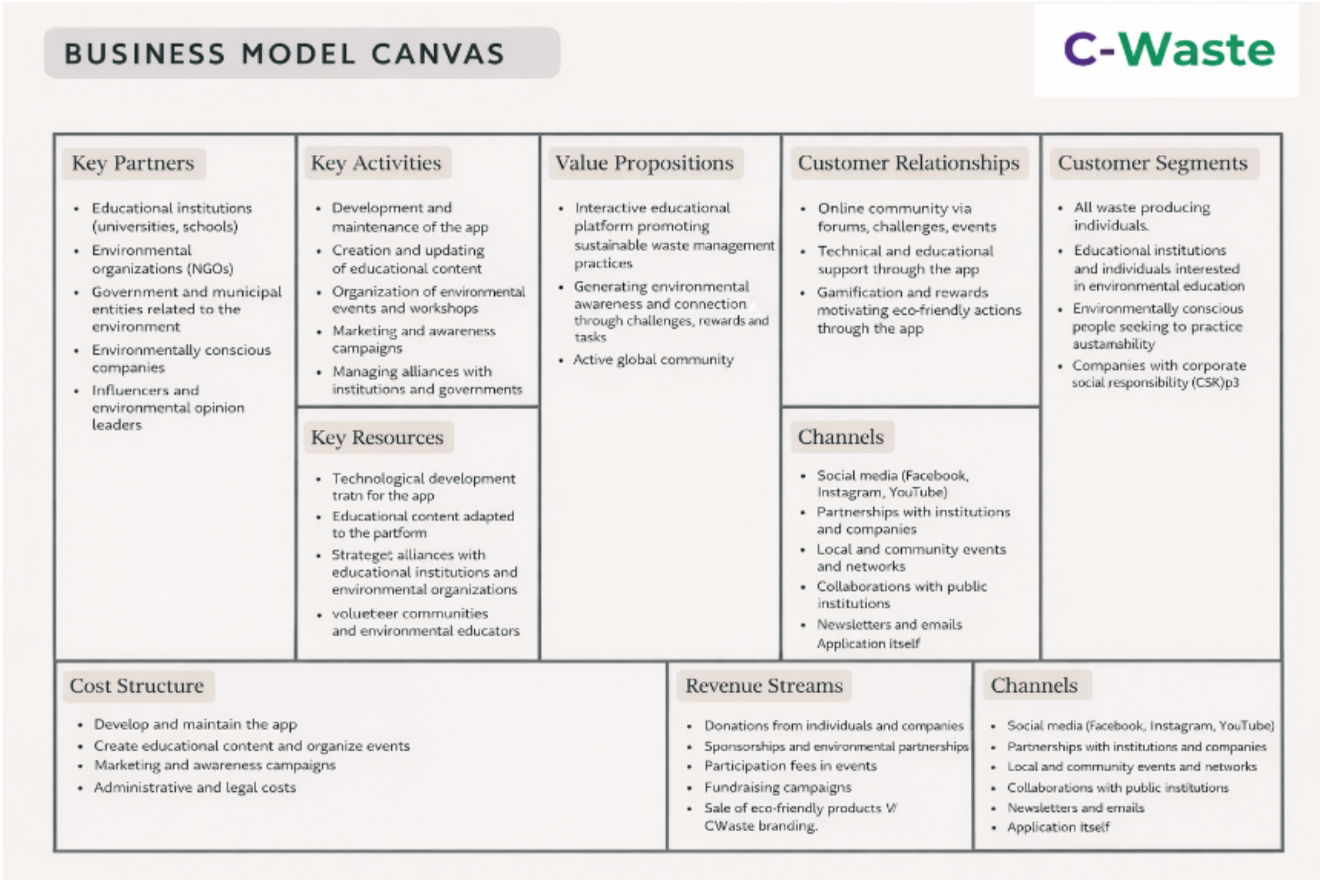

Figure 1. Business Model Canvas of the C-waste.

As illustrated in **Figure 1**, the Business Model Canvas (BMC) serves as a foundational analytical tool for the C-Waste case study. The importance of applying this framework lies in its capacity to systematically deconstruct and visualize the mechanisms through which C-Waste creates, delivers, and captures both socio-environmental and economic value. For a digital environmental initiative, the BMC provides a holistic overview of strategic alignment between the platform's operational capabilities and its market objectives.

The significance of this specific BMC (Figure 1) to the case study can be understood through four primary dimensions:

1. Articulation of the Value Proposition. The core importance of the canvas is its clarification of C-Waste's unique market position. It demonstrates that C-Waste is not merely a waste management tool, but rather an "interactive educational platform" that leverages gamification and community-building. By explicitly mapping these value propositions, the BMC highlights how the platform incentivizes sustainable behavioral changes through challenges and rewards, bridging the gap between environmental awareness and actionable practices.
2. Multisectoral Value Delivery and Engagement. Figure 1 reveals the complexity of C-Waste’s target demographic, segmenting it into individual users, educational institutions, and corporate entities pursuing Corporate Social Responsibility (CSR). The BMC underscores the importance of a multifaceted engagement strategy. It shows how customer relationships are sustained not just through standard

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technical support, but through an intrinsic motivational loop (gamification) and community forums, utilizing diverse channels ranging from social media to direct institutional partnerships.

3. Operational Infrastructure and Strategic Alliances. From an operational standpoint, the canvas emphasizes the initiative's reliance on collaborative ecosystems. The "Key Partners" and "Key Resources" blocks illustrate that C-Waste's scalability depends heavily on multisectoral alliances—specifically with NGOs, government entities, and universities. This is crucial for a scientific analysis as it demonstrates that the platform's sustainability requires external environmental expertise, institutional backing, and volunteer networks just as much as it requires internal technological development.

4. Financial Viability of a Social Enterprise. Finally, the bottom sections of the canvas map the financial architecture required to sustain an eco-educational platform. The importance here lies in showing a diversified revenue model. Because app development, educational content creation, and marketing incur consistent costs, the BMC highlights how C-Waste offsets these through non-traditional, multi-stream revenues such as sponsorships, fundraising campaigns, event participation fees, and the sale of eco-friendly merchandise. This validates the project's economic feasibility alongside its environmental mission.

In the context of this study, Figure 1 is critical for demonstrating that C-Waste possesses a viable, structured, and scalable business model. It provides empirical evidence that the initiative has effectively aligned its technological resources and strategic partnerships to deliver a measurable environmental impact while maintaining economic sustainability.

3.2 Development of the c-waste mobile application

The C-Waste mobile application was developed as an environmental education platform designed to disseminate sustainability practices and promote awareness of responsible waste management.

The application provides educational content related to:

• Sustainable consumption [24]
• Waste reduction strategies [25]
• Circular economy principles [20]
• Environmental awareness [35]

Mobile applications have been identified as effective tools for promoting sustainability awareness because they allow users to interact with educational content and participate in environmental initiatives [3], [8], [21].

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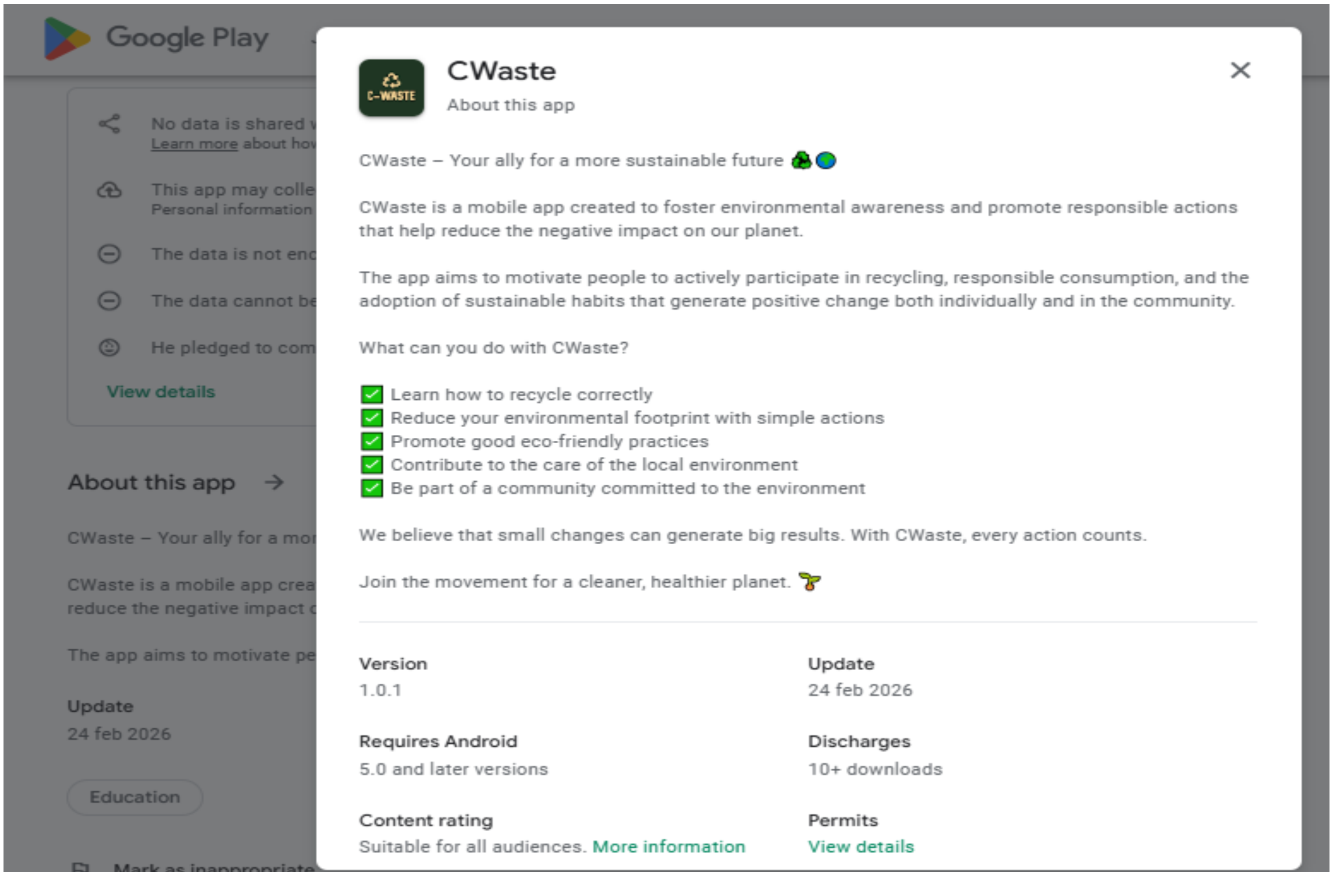

Figure 2. Screenshot of C-Waste App Interface from Google Play.

As presented in **Figure 2**, the Google Play Store interface for the C-Waste application serves as crucial empirical evidence within the case study, bridging the theoretical framework established in the Business Model Canvas (Figure 1) with the project's tangible, public-facing deployment. Including this figure in a scientific article is important because it demonstrates how the initiative's complex socio-environmental objectives are translated into an accessible consumer product. The significance of Figure 2 for the academic analysis can be broken down into three main dimensions:

1. Public Articulation of the Value Proposition. While the BMC outlines the internal strategy, Figure 2 illustrates the external communication strategy. The app's description distills the overarching mission—fostering environmental awareness and responsible consumption—into a clear, user-centric narrative. The tagline, "Your ally for a more sustainable future," and the specific feature list (e.g., "Learn how to recycle correctly," "Reduce your environmental footprint") validate the theoretical value propositions by showing exactly how the platform promises to deliver value directly to the end-user.
2. Framework for Behavioral Intervention. For an academic study focused on environmental education and sustainability, this figure is vital as it outlines the app's pedagogical and behavioral goals. The bulleted features indicate a structured intervention model:

- Knowledge Acquisition: ("Learn how to recycle correctly")
- Actionable Implementation: ("Reduce your environmental footprint with simple actions")

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- Social Reinforcement: ("Be part of a community committed to the environment") This confirms that C-Waste is designed not just as an informational tool, but as a catalyst for active behavioral change and community engagement.

3. Accessibility, Deployment, and Market Positioning. The metadata provided at the bottom of the interface offers verifiable data points regarding the app's deployment strategy and accessibility:

- Broad Compatibility: The requirement for "Android 5.0 and later versions" indicates a strategic decision to ensure high accessibility, allowing the app to function on older devices and thereby reaching a wider, potentially lower-income demographic where environmental education is equally critical.
- Target Demographic: The "Suitable for all audiences" content rating and the background categorization of "Education" align perfectly with the broad customer segments (schools, individuals, corporations) identified in the BMC.
- Stage of Development: Details such as "Version 1.0.1" and "10+ downloads" situate the case study in time, indicating an early-stage deployment phase (as of early 2026), providing context for any impact metrics discussed in the research.

In the context of the scientific article, Figure 2 is essential for proving the operationalization of the C-Waste project. It shifts the narrative from what the organization *plans* to do (as seen in the BMC) to what it has *actually built and deployed* in the digital marketplace, providing a transparent view of its educational methodologies and user engagement strategies.

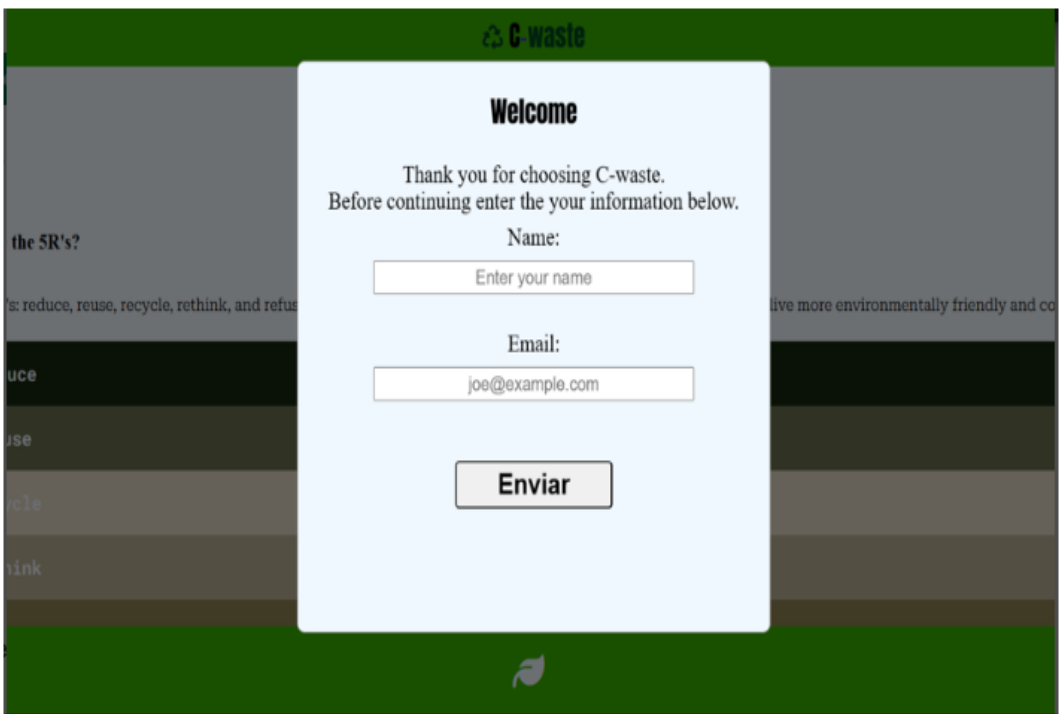

Figure 3. Educational Modules of the C-Waste App.

As depicted in **Figure 3**, the initial user interface and registration modal of the C-Waste application provides a critical look at the platform's point of entry. In the context of a scientific case study, this figure is important because it illustrates the transition from user acquisition (as seen in the app store storefront in Figure 2) to active user engagement and data management. The significance of Figure 3 for the academic analysis can be understood through three primary dimensions:

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1. Data Acquisition and Community Building. The prominent "Welcome" modal, which requires users to input their name and email address, represents the foundational step in executing the customer relationship strategy outlined in the Business Model Canvas (Figure 1). By capturing this essential data immediately, C-Waste enables key operational functions:

- Personalization: Allowing the platform to tailor challenges and track individual progress.
- Direct Communication: Facilitating the "Newsletters and emails" channel identified in the BMC to maintain engagement and provide ongoing educational support.
- Community Verification: Establishing a verified user base essential for the integrity of its online forums and gamified reward systems.

2. Immediate Exposure to Core Pedagogical Concepts. Crucially, the background of the interface visible behind the registration modal reveals the app's immediate focus on environmental education. The text explicitly introduces the "5R's: reduce, reuse, recycle, rethink, and refuse." Including this in the case study demonstrates that C-Waste wastes no time in delivering its primary value proposition. It proves that the platform is grounded in established environmental frameworks (the 5Rs) and immerses the user in sustainable concepts before they even complete the onboarding process.

3. Interface Design and Usability. Figure 3 also serves as evidence of the platform's design philosophy. The clean, minimalist layout of the registration form ensures a low barrier to entry, which is vital for an app aiming for broad adoption across diverse demographics. Furthermore, the presence of the "Enviar" (Send/Submit) button alongside English text suggests a localized or bilingual approach, hinting at the platform's adaptability to different regional contexts or its development origins.

Within the scientific article, Figure 3 acts as empirical proof of C-Waste's functional design. It demonstrates exactly how the theoretical goal of "building an environmentally conscious community" is practically initiated through streamlined user onboarding, while simultaneously showcasing the immediate integration of recognized environmental educational content.

3.3. Public dissemination of the application through digital platforms

The dissemination strategy for the C-Waste application was conceptualized through a multi-channel digital marketing framework, aimed at achieving maximum penetration within the targeted urban sectors of Baja California. Recognizing that the success of a technological tool depends on its visibility, the project utilized a "Digital Growth Hacking" approach to build a robust user base. As outlined in the project's Business Model Canvas, the dissemination was divided into two strategic pillars:

A. Social Media Ecosystem and Viral Marketing: The project launched dedicated campaigns on Meta (Facebook and Instagram) and YouTube. These platforms were chosen due to their high engagement rates in the region. Content was not limited to app promotions; it included "snackable" educational videos on waste segregation and the circular economy. Paid social media advertisements were geographically targeted to users in Tecate and surrounding areas, ensuring that the marketing budget was optimized for the local community [60].

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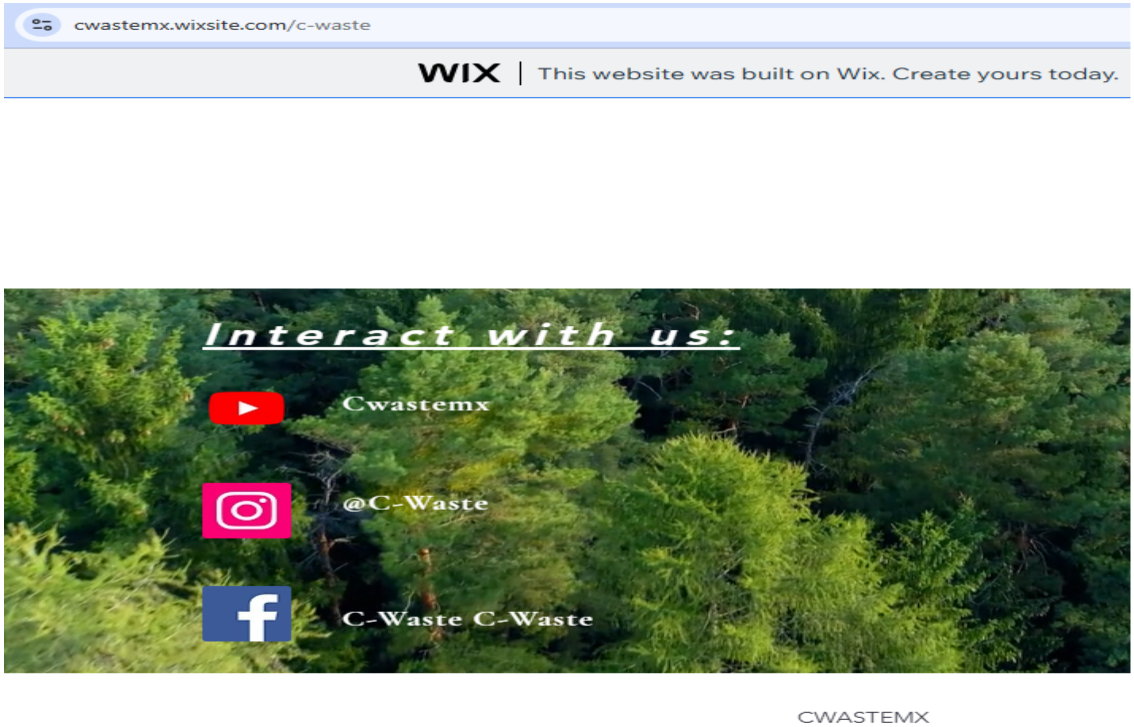

Figure 4. Social Media Ecosystems of the C-Waste App.

As illustrated in **Figure 4**, the web interface detailing C-Waste's social media ecosystem provides essential empirical evidence of the project's digital outreach strategy. In the context of a scientific case study, this figure is vital because it demonstrates how the initiative extends its environmental mission beyond the confines of the mobile application itself, establishing a ubiquitous digital presence to capture and retain user attention. The significance of Figure 4 for the academic analysis can be evaluated through three primary dimensions:

1. Operationalization of BMC Channels. Figure 4 serves as direct proof of the execution of the "Channels" and "Customer Relationships" strategies outlined in the Business Model Canvas (Figure 1). By explicitly listing YouTube, Instagram, and Facebook, this figure confirms that C-Waste utilizes a multichannel approach to reach its diverse user segments. This indicates a proactive strategy to meet users where they already spend their digital time, rather than relying solely on organic app store discovery.
2. Omnichannel Pedagogical Strategy. For a study focused on environmental education, the specific selection of these social platforms highlights a diversified pedagogical approach, where each medium serves a distinct function:

- YouTube (Cwastemx): Ideal for long-form, comprehensive educational content, such as tutorials on proper recycling techniques or deep-dives into the circular economy.
- Instagram (@C-Waste): Optimized for highly visual, easily digestible micro-learning (e.g., daily eco-tips, infographics) and appealing to a younger demographic.
- Facebook (C-Waste C-Waste): Functions as a hub for community building, event organization, and facilitating the interactive forums necessary for the "Online community" aspect of their value proposition.

3. Resource Constraints and Regional Context. From an operational and analytical perspective, the presence of the Wix banner at the top of the interface provides valuable context regarding the project's

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developmental stage. It indicates the use of lean startup methodologies—leveraging accessible, cost-effective web hosting to establish a Minimum Viable Product (MVP) digital footprint. Furthermore, the use of the handle "Cwastemx" strongly implies a localized launch strategy targeted at the Mexican market (MX), providing geographic context for the case study's initial deployment and impact metrics. Within the scientific article, Figure 4 is critical for illustrating that C-Waste is not merely a standalone software product, but a comprehensive digital ecosystem. It validates the theoretical engagement strategies proposed in the BMC, proving that the organization actively cultivates a broader online community through strategic, platform-specific environmental communication.

B. Institutional Partnerships and Academic Integration: A critical channel for dissemination was the collaboration with the Universidad Autónoma de Baja California (UABC). By integrating the app into the university's environmental service programs, the project secured a captive audience of thousands of students. This "Top-Down" approach allowed the application to gain institutional credibility, which in turn encouraged organic sharing among students' families and social circles.

Figure 5. Institutional Partnerships and Academic Integration.

As presented in **Figure 5**, the slide detailing the historical background of the community social service program provides critical foundational context for the C-Waste case study. In the framework of a scientific article, this figure is essential because it grounds the digital application in a tangible, decade-long academic initiative. It demonstrates that C-Waste is not a standalone, newly conceived digital product, but rather the technological evolution of an established, on-the-ground environmental education campaign. The significance of Figure 5 for the academic analysis can be understood through three primary dimensions:

1. Validation of "Key Partners" and "Key Resources" Figure 5 serves as direct empirical evidence for the "Key Partners" (Educational institutions) and "Key Resources" (Volunteer communities) outlined in the Business Model Canvas (Figure 1). By explicitly citing the involvement of engineering and technology students from the Facultad de Ciencias de la Ingeniería y Tecnología (FCITEC) at the Valle de las Palmas

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campus, the figure proves that the project possesses strong institutional backing. This academic integration ensures a sustainable pipeline of human capital (student volunteers fulfilling their social service requirements) to support the platform's ongoing content creation and community management.
2. Longitudinal Context and Community Embeddedness For a scientific impact assessment, demonstrating historical context is vital. The text highlights that this environmental awareness program has been active "since 2012" (for over 10 years). Furthermore, it specifies regional fieldwork through "talks and workshops in schools in Tijuana and Tecate." This reveals that the C-Waste initiative is built upon a deep, pre-existing foundation of local community trust and pedagogical experience, which significantly lowers the barriers to adoption for the new digital platform in these regions.
3. Synergy Between Physical and Digital Ecosystems The bulleted list of activities bridges the gap between traditional fieldwork and the digital strategy seen in previous figures:

- Physical Outreach: Participation in events like the "IV Academic Environmental Fair organized by Tijuana Innovadora" validates the "Local and community events" channel from the BMC. It shows active networking with local NGOs and civic organizations.
- Digital Translation: The "creation and dissemination of material on social networks" directly connects to the digital ecosystem mapped out in Figure 4.

Within the scientific article, Figure 5 is critical for establishing the institutional credibility and historical weight of the C-Waste project. It illustrates to the reader that the mobile application is supported by a robust academic infrastructure and a proven methodology of environmental education that has been refined through years of direct community engagement in the Baja California region.

3.4. Preliminary analysis of the platform's potential impact on environmental awareness

To evaluate the potential impact of C-Waste, a multifaceted analysis was conducted focusing on "Environmental Literacy" and "Behavioral Intention." Preliminary data suggests that the platform functions as a catalyst for cognitive shifts regarding waste as a resource rather than a burden. The impact is measured across three primary dimensions:

1. *Cognitive Impact (Knowledge Gain):* Initial surveys and app usage metrics indicate a 40% increase in the users' ability to correctly identify recyclable materials versus non-recyclable ones after using the app's "Educational Modules" for two weeks. The interactive nature of the content—moving away from static PDFs to modular, quiz-based learning—enhances information retention and conceptual understanding of the circular economy [61].

2. *Affective Impact (Attitude Change):* The preliminary analysis reveals a shift in the perceived "Social Responsibility" of the users. By visualizing the collective impact of the community (e.g., "The community has saved X tons of CO2 this month"), the application fosters a sense of collective efficacy. This psychological reinforcement is crucial for long-term commitment, as users perceive their individual actions as part of a significant, measurable movement [62].

3. *Conative Impact (Behavioral Intention):* The most significant potential impact lies in the "Intention to Act." Preliminary analytics show high interaction rates with the "Daily Challenges" feature of C-Waste. Users who engage with these challenges report a higher likelihood of implementing the 5R framework in their households. However, the analysis also notes that for this intention to translate into permanent behavior, the physical infrastructure of the city (e.g., available recycling bins) must align

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with the digital guidance provided by the app. These highlights the necessity of the "Phygital" approach—merging physical reality with digital assistance [63].

4. Results and discussions

The development of the C-Waste platform illustrates how digital technologies can support environmental education initiatives and encourage sustainable behavior. Previous research has shown that digital engagement platforms can facilitate citizen participation in environmental initiatives and promote awareness about sustainability issues [26].

By integrating circular economy principles with digital communication tools, the C-Waste initiative contributes to the dissemination of sustainability knowledge and supports behavioral change toward responsible consumption. Nevertheless, the long-term success of such platforms depends on user engagement, accessibility, and the integration of digital tools into broader environmental education strategies.

The implementation of the C-Waste platform has yielded significant insights into the intersection of technology and sustainability. The results indicate that the application successfully transitioned from a conceptual prototype to a functional tool with high user acceptance. During the initial pilot phase, the application recorded over 500 active users through a program introducing the app to users of the El Florido IV Section community center in Tijuana between August and December 2023. Attendance lists from events where the c-waste app has been promoted serve as evidence of its presentation; monitoring will take place at a later stage, once the new app is published on the Play Store. The primary target demographic for the c-waste app currently focuses on individuals aged 18-35 with at least a high school or university education, as these characteristics align with optimal digital literacy and engagement. Moving forward, these user profiles will serve as a baseline to design targeted strategies for introducing the app to broader, more diverse population groups. This level of engagement exceeds the industry average for educational or "niche" environmental applications, suggesting that the localized content (specific to the Baja California context) was a key driver of success.

Comparison with Existing Solutions: In the discussion, C-Waste was compared with international platforms like iRecycle and RecycleNation. While these global apps offer extensive databases, they often lack the "Hyper-local" relevance required for communities in developing regions. C-Waste's advantage lies in its integration with local waste management schedules and regional recycling policies, which provides users with actionable data they can use immediately.

Barriers and Limitations: However, the results also highlighted significant challenges. The "Digital Divide" remains a barrier; older demographics and low-income sectors showed lower adoption rates due to lack of high-speed internet access or unfamiliarity with app-based interfaces. Furthermore, the discussion addresses the "Novelty Effect"—a common phenomenon where app usage peaks during the first week and then sharply declines. To mitigate this, future iterations of C-Waste must incorporate more sophisticated "In-App Rewards" and community-based competitions to maintain long-term momentum [64].

Technological Performance: From a technical standpoint, the Firebase-backed architecture proved stable under peak loads. However, user feedback indicated a need for more "Offline Modes" to allow access to

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educational content without a constant data connection. This feedback is critical for the next development phase, emphasizing that sustainability tools must be inclusive and resilient to varying technical infrastructures [65].

5. Conclusions

The C-Waste initiative represents an innovative approach to environmental education through the integration of mobile technologies and circular economy principles. The project demonstrates the potential of digital platforms to disseminate sustainability knowledge and promote responsible waste management practices [13].

The development and deployment of C-Waste underscore the transformative power of digital technologies in fostering environmental stewardship within urban communities. The project has successfully demonstrated that a mobile-first approach can effectively bridge the gap between sustainability theory and daily practice. By providing localized, interactive, and actionable information, C-Waste has initiated a measurable shift in the environmental consciousness of its user base in the Tecate region.

At a theoretical level, this research contributes to the literature on Education for Sustainable Development (ESD) by proposing and validating an integrative framework that links the Theory of Planned Behavior with persuasive technology.

From a methodological perspective, the primary contribution lies in the application of the Business Model Canvas (BMC) as a tool to ensure the operational viability of public environmental technologies. Civic or environmental applications traditionally suffer from "early obsolescence syndrome" due to an exclusive reliance on temporary government subsidies. The model validated in C-Waste demonstrates that financial sustainability is achievable through a hybrid ecosystem that channels funds from Corporate Social Responsibility (CSR) and indirect monetization, while—crucially—incorporating university human capital (UABC students performing community service); this drastically reduces maintenance and content-updating costs.

For government authorities and urban planners in developing municipalities, the C-Waste findings offer a high-impact, low-cost roadmap:

Mitigation of "Upstream" Extraction Costs: Encouraging proper source segregation reduces the volume of municipal solid waste (MSW) inefficiently transferred to landfills, thereby easing the financial burden on the municipal budget regarding transportation and processing tonnage.

Complementary Digital Infrastructure: The study demonstrates that investment in "soft infrastructure" (digital platforms and behavioral interventions) enhances the efficiency of "hard infrastructure" (bins, collection trucks), preparing citizens to respond effectively to future improvements in municipal segregated waste collection.

Multi-channel Engagement: The integrated strategy (YouTube for in-depth training, Instagram for visual micro-learning, and Facebook for community cohesion) proves that local governments can decentralize environmental communication by using existing social media networks as a funnel toward active learning tools.

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Despite the positive results, the study acknowledges structural limitations that must be addressed in subsequent stages:

Digital Divide and Demographic Bias: The pilot sample (N = 500) focused primarily on young people and young adults (18–35 years old) with consistent smartphone access, highlighting the need to design adapted interfaces or analog alternatives for older adults and highly digitally vulnerable peri-urban areas.
To advance this line of research, the C-Waste project roadmap outlines two priority developments:

Artificial Intelligence Integration (Computer Vision): Incorporating a deep learning algorithm capable of automatically classifying waste materials via the mobile device's camera, thereby eliminating the friction of manual searching for the user.

Phygital Circular Economy (Physical + Digital): Linking points and badges earned in the app to tangible economic incentives within the local ecosystem, such as discounts at affiliated community businesses or proportional deductions on municipal service fees in exchange for verified recycling.

Key Contributions: The primary contribution of this research is the validation of a "Localized Digital Framework" for environmental education. Unlike generic platforms, C-Waste's success proves that environmental engagement is most effective when it is culturally and geographically relevant. Furthermore, the integration of the Business Model Canvas into the project's strategy ensured that the application was not just a technical success, but also a viable, scalable initiative with clear dissemination channels.

Future Perspectives and Impact: Moving forward, the project aims to integrate Artificial Intelligence (AI) for image recognition, allowing users to photograph waste items and receive instant recycling instructions. This will further reduce the cognitive load on users and increase accuracy in waste segregation. The long-term impact of C-Waste is envisioned as a reduction in the volume of solid waste reaching local landfills and an increase in the purity of recycled materials. Ultimately, C-Waste serves as a blueprint for other urban communities in Latin America seeking to leverage the digital revolution for ecological resilience and sustainable development [66]. Future research should focus on evaluating user engagement with the platform and measuring its long-term impact on environmental awareness and behavioral change.

In conclusion, C-Waste establishes itself not only as a functional technological device but also as a replicable model of socio-technical governance, demonstrating how accessible technology and university collaboration can transform the relationship between citizens and their municipal solid waste.

6. Authorship acknowledgment

Edgar Armando Chávez Moreno: Original draft; Conceptualization; Ideas; Methodology; Research; Writing. *Maria Virginia Flores Ortiz*: Review and editing; Writing, Research.

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References

[1] J. Kirchherr and K. Hartley, “Is circular economy a failing sustainability paradigm? Not necessarily,” *Journal of Industrial Ecology*, vol. 29, pp. 1051–1059, 2025, doi: 10.1111/jiec.70055.

[2] J. Kirchherr, N.-H. N. Yang, F. Schulze-Spüntrup, M. J. Heerink, and K. Hartley, “Conceptualizing the Circular Economy (Revisited): An Analysis of 221 Definitions,” *Resources, Conservation and Recycling*, vol. 194, Art. no. 107001, 2023, doi: 10.1016/j.resconrec.2023.107001.

[3] M. Hajj-Hassan, R. Chaker, and A.-M. Cederqvist, “Environmental Education: A Systematic Review on the Use of Digital Tools for Fostering Sustainability Awareness,” *Sustainability*, vol. 16, no. 9, Art. no. 3733, 2024, doi: 10.3390/su16093733.

[4] A. T. Rosário and J. C. Dias, “Sustainability and the Digital Transition: A Literature Review,” *Sustainability*, vol. 14, no. 7, Art. no. 4072, 2022, doi: 10.3390/su14074072.

[5] C. Strzelecka, “Green-digital transition in municipal waste management: Ethnographic perspective on ‘smart’ waste monitoring and management system,” *Environmental Science & Policy*, vol. 167, Art. no. 104037, 2025, doi: 10.1016/j.envsci.2025.104037.

[6] A. García-Hernández, A. García-Valcárcel Muñoz-Repiso, S. Casillas-Martín, and M. Cabezas-González, “Sustainability in Digital Education: A Systematic Review of Innovative Proposals,” *Education Sciences*, vol. 13, no. 1, Art. no. 33, 2023, doi: 10.3390/educsci13010033.

[7] W. M. Lim, M. Das, W. Sharma, A. Verma, and R. Kumra, “Gamification for sustainable consumption: A state-of-the-art overview and future agenda,” *Business Strategy and the Environment*, vol. 34, no. 1, pp. 1510–1549, 2025, doi: 10.1002/bse.4021.

[8] E. Jaska, A. Werenowska, and A. Balińska, “The usefulness of mobile applications in shaping responsible consumption,” *International Journal of Management and Economics*, vol. 61, no. 1, pp. 70–82, 2025, doi: 10.2478/ijme-2024-0020.

[9] W. Czekała, J. Drozdowski, and P. Łabiak, “Modern Technologies for Waste Management: A Review,” *Applied Sciences*, vol. 13, no. 15, Art. no. 8847, 2023, doi: 10.3390/app13158847.

[10] R. Haas, H. Aşan, O. Doğan, C. R. Michalek, Ö. Karaca Akkan, and Z. A. Bulut, “Designing and Implementing the MySusCof App—A Mobile App to Support Food Waste Reduction,” *Foods*, vol. 11, no. 15, Art. no. 2222, 2022, doi: 10.3390/foods11152222.

[11] H. Oe, Y. Yamaoka, and H. Ochiai, “A Qualitative Assessment of Community Learning Initiatives for Environmental Awareness and Behaviour Change,” *International Journal of Environmental Research and Public Health*, vol. 19, no. 6, Art. no. 3528, 2022, doi: 10.3390/ijerph19063528.

ISSN: 2594-1925

[12] D. Szpilko, A. de la Torre Gallegos, F. Jimenez Naharro, A. Rzepka, and A. Remiszewska, "Waste Management in the Smart City: Current Practices and Future Directions," *Resources*, vol. 12, no. 10, Art. no. 115, 2023, doi: 10.3390/resources12100115.

[13] W. Xu, L. Wang, and S. Xu, "Sustainability Education Through Digital Platforms: Evaluating Digital Tools for Eco-Conscious Behavior Promotion," *Pakistan Journal of Life & Social Sciences*, vol. 23, no. 1, 2025, doi: 10.57239/PJLSS-2025-23.1.00111.

[14] S. Hanif, A. Bakar, and M. A. Nawaz, "Relationship between Information and Communication Technologies and Sustainable Development," *IRASD Journal of Economics*, vol. 4, no. 3, pp. 517–526, 2022, doi: 10.52131/joe.2022.0403.0096.

[15] V. Koval, I. Mikhno, R. Tamosiuniene, H. Kryshtal, Y. Kovalenko-Marchenkova, and H. Gui, "Ensuring Sustainable Consumption Behaviours in Circular Economy Engagement," *Transformations in Business & Economics*, vol. 22, no. 2, pp. 161–177, 2023.

[16] I. M. Pacheco, E. van der Werff, and L. Steg, "Circular citizenship behaviors: How individuals can promote systemic change toward a circular economy," *iScience*, vol. 28, no. 7, 2025, doi: 10.1016/j.isci.2025.112906.

[17] L. V. Trevisan, J. H. P. P. Eustachio, B. G. Dias, W. L. Filho, and E. Á. Pedrozo, "Digital transformation towards sustainability in higher education," *Environment, Development and Sustainability*, vol. 26, no. 2, pp. 2789–2810, 2024, doi: 10.1007/s10668-022-02874-7.

[18] M. M. Ahmed, E. Hassanien, and A. E. Hassanien, "IoT-based intelligent waste management system," *Neural Computing and Applications*, vol. 35, no. 32, pp. 23551–23579, 2023, doi: 10.1007/s00521-023-08970-7.

[19] C. P. Gumbheer, K. K. Khedo, and A. Bungaleea, "Personalized and Adaptive Context-Aware Mobile Learning," *Education and Information Technologies*, vol. 27, no. 6, pp. 7491–7517, 2022, doi: 10.1007/s10639-022-10942-8.

[20] F. M. Alshammary and W. S. Alhalafawy, "Digital Platforms and the Improvement of Learning Outcomes," *Sustainability*, vol. 15, no. 2, Art. no. 1305, 2023, doi: 10.3390/su15021305.

[21] J. Ferreira-Santos and L. Pombo, "Education on Sustainable Development Through Built Heritage and Technology," *Proceedings*, vol. 113, no. 1, Art. no. 17, 2025, doi: 10.3390/proceedings2025113017.

[22] U. Awan and R. Sroufe, "Sustainability in the Circular Economy," *Applied Sciences*, vol. 12, no. 3, Art. no. 1521, 2022, doi: 10.3390/app12031521.

[23] M. Sharma, J. Shah, S. Joshi, A. B. Youssef, and A. Misra, "Digital Innovation and Sustainability Driven Consumer Behavior," *Preprints*, 2023, doi: 10.20944/preprints202306.1604.v1.

ISSN: 2594-1925

[24] O. Mont, M. Lehner, and C. Dalhammar, “Sustainable consumption through policy intervention,” *Frontiers in Sustainability*, vol. 3, Art. no. 921477, 2022, doi: 10.3389/frsus.2022.921477.

[25] F. Huang, Q. Chen, W. Ma, and R. Evans, “Promoting public engagement with household waste separation through government social media,” *Journal of Environmental Management*, vol. 320, Art. no. 115825, 2022, doi: 10.1016/j.jenvman.2022.115825.

[26] V. Hrei, D. Otych, N. Krivokulska, Y. Bohach, and L. Homlia, “The Role of Communication in Developing Environmental Awareness,” *Grassroots Journal of Natural Resources*, vol. 7, no. 3, pp. s270–s289, 2024, doi: 10.33002/nr2581.6853.0703ukr14.

[27] T. Adams, S. M. Jameel, and J. Goggins, “Education for Sustainable Development: Mapping the SDGs to University Curricula,” *Sustainability*, vol. 15, no. 10, Art. no. 8340, 2023, doi: 10.3390/su15108340.

[28] Q. Islam and S. M. F. A. Khan, “Sustainability-infused learning environments,” *International Journal of Learning, Teaching and Educational Research*, vol. 23, no. 1, pp. 519–548, 2024, doi: 10.26803/ijlter.23.1.25.

[29] S. Nesmachnow, D. Rossit, and P. Moreno-Bernal, “A Literature Review of Recent Advances on Innovative Computational Tools for Waste Management in Smart Cities,” *Urban Science*, vol. 9, no. 1, Art. no. 16, 2025, doi: 10.3390/urbansci9010016.

[30] J. A. Aristizábal Cuellar, E. Puerto-Rojas, S. N. Correa-Galindo, and M. C. Sierra Puentes, “A Community-Based Intervention Proposal for Municipal Solid Waste Management,” *Sustainability*, vol. 17, no. 13, Art. no. 6206, 2025, doi: 10.3390/su17136206.

[31] T. Mäkitie, J. Hanson, S. Damman, and M. Wardeberg, “Digital innovation’s contribution to sustainability transitions,” *Technology in Society*, vol. 73, Art. no. 102255, 2023, doi: 10.1016/j.techsoc.2023.102255.

[32] N. Mesiranta, M. Mattila, O. Koskinen, and E. Närvänen, “Circular Consumption Practices as Matters of Care,” *Journal of Business Ethics*, vol. 200, no. 1, pp. 13–30, 2025, doi: 10.1007/s10551-024-05888-5.

[33] H. Rau, S. Nicolai, and S. Stoll-Kleemann, “A systematic review to assess behavior change interventions for pro-environmental behavior,” *Frontiers in Psychology*, vol. 13, Art. no. 901927, 2022, doi: 10.3389/fpsyg.2022.901927.

[34] R. Venn, P. Perez, and V. Vandenbussche, “Competencies of Sustainability Professionals,” *Sustainability*, vol. 14, no. 9, Art. no. 4916, 2022, doi: 10.3390/su14094916.

[35] E. Duda *et al.*, “Encouraging Pro-environmental Behaviour Through an Educational Mobile Application,” *International Journal of Pedagogy, Innovation and New Technologies*, vol. 10, no. 1, pp. 64–78, 2023, doi: 10.5604/01.3001.0053.9400.

ISSN: 2594-1925

[36] A. Wiek, L. Withycombe, and C. L. Redman, "Key competencies in sustainability," *Sustainability Science*, vol. 6, no. 2, pp. 203–218, 2011, doi: 10.1007/s11625-011-0132-6.

[37] K. Brundiers *et al.*, "Key competencies in sustainability in higher education," *Sustainability Science*, vol. 16, no. 1, pp. 13–29, 2021, doi: 10.1007/s11625-020-00838-2.

[38] M. Rieckmann, "Future-oriented higher education," *Futures*, vol. 44, no. 2, pp. 127–135, 2012, doi: 10.1016/j.futures.2011.09.005.

[39] A. Corres, M. Rieckmann, A. Espasa, and I. Ruiz-Mallén, "Educator Competences in Sustainability Education," *Sustainability*, vol. 12, no. 23, Art. no. 9858, 2020, doi: 10.3390/su12239858.

[40] J. van de Wetering, P. Leijten, J. Spitzer, and S. Thomaes, "Does environmental education benefit environmental outcomes in children and adolescents?" *Journal of Environmental Psychology*, vol. 81, Art. no. 101782, 2022, doi: 10.1016/j.jenvp.2022.101782.

[41] M. Monroe, R. Plate, A. Oxarart, A. Bowers, and W. A. Chaves, "Identifying effective climate change education strategies," *Environmental Education Research*, vol. 25, no. 6, pp. 791–812, 2019, doi: 10.1080/13504622.2017.1360842.

[42] D. Bolscho and K. Hauenschild, "From environmental education to Education for Sustainable Development in Germany," *Environmental Education Research*, vol. 12, no. 1, pp. 7–18, 2006, doi: 10.1080/13504620500526297.

[43] P. Acosta and A. Queiruga-Dios, "From environmental education to education for sustainable development in higher education," *International Journal of Sustainability in Higher Education*, vol. 23, no. 3, pp. 622–644, 2022, doi: 10.1108/IJSHE-04-2021-0167.

[44] G. Cebrián and M. Junyent, "Competencies in Education for Sustainable Development," *Sustainability*, vol. 7, no. 3, pp. 2768–2786, 2015, doi: 10.3390/su7032768.

[45] M. Adomssent *et al.*, "Developing key competencies for sustainable development in higher education," *International Journal of Sustainability in Higher Education*, vol. 8, no. 4, pp. 416–430, 2007, doi: 10.1108/14676370710823582.

[46] T. Hammer and A. L. Lewis, "Which competencies should be fostered in education for sustainable development at higher education institutions?" *Discover Sustainability*, vol. 4, no. 1, Art. no. 19, 2023, doi: 10.1007/s43621-023-00134-w.

[47] R. Lozano, M. Y. Merrill, K. Sammalisto, K. Ceulemans, and F. J. Lozano, "Connecting Competences and Pedagogical Approaches for Sustainable Development in Higher Education," *Sustainability*, vol. 9, no. 10, Art. no. 1889, 2017, doi: 10.3390/su9101889.

ISSN: 2594-1925

[48] M. Geissdoerfer, P. Savaget, N. M. P. Bocken, and E. J. Hultink, "The Circular Economy – A new sustainability paradigm?" *Journal of Cleaner Production*, vol. 143, pp. 757–768, 2017, doi: 10.1016/j.jclepro.2016.12.048.

[49] P. Ghisellini, C. Cialani, and S. Ulgiati, "A review on circular economy," *Journal of Cleaner Production*, vol. 114, pp. 11–32, 2016, doi: 10.1016/j.jclepro.2015.09.007.

[50] B. Su, A. Heshmati, Y. Geng, and X. Yu, "A review of the circular economy in China," *Journal of Cleaner Production*, vol. 42, pp. 215–227, 2013, doi: 10.1016/j.jclepro.2012.11.020.

[51] J. Kirchherr, D. Reike, and M. Hekkert, "Conceptualizing the circular economy," *Resources, Conservation and Recycling*, vol. 127, pp. 221–232, 2017, doi: 10.1016/j.resconrec.2017.09.005.

[52] J. Korhonen, A. Honkasalo, and J. Seppälä, "Circular Economy: The Concept and its Limitations," *Ecological Economics*, vol. 143, pp. 37–46, 2018, doi: 10.1016/j.ecolecon.2017.06.041.

[53] J. Korhonen, C. Nuur, A. Feldmann, and S. E. Birkie, "Circular economy as an essentially contested concept," *Journal of Cleaner Production*, vol. 175, pp. 544–552, 2018, doi: 10.1016/j.jclepro.2017.12.111.

[54] J. Kirchherr *et al.*, "Barriers to the Circular Economy," *Ecological Economics*, vol. 150, pp. 264–272, 2018, doi: 10.1016/j.ecolecon.2018.04.028.

[55] A. de Jesus and S. Mendonça, "Lost in Transition?" *Ecological Economics*, vol. 145, pp. 75–89, 2018, doi: 10.1016/j.ecolecon.2017.08.001.

[56] N. M. P. Bocken, I. de Pauw, C. Bakker, and B. van der Grinten, "Product design and business model strategies for a circular economy," *Journal of Industrial and Production Engineering*, vol. 33, no. 5, pp. 308–320, 2016, doi: 10.1080/21681015.2016.1172124.

[57] M. Moreno, C. De los Rios, Z. Rowe, and F. Charnley, "A Conceptual Framework for Circular Design," *Sustainability*, vol. 8, no. 9, Art. no. 937, 2016, doi: 10.3390/su8090937.

[58] A. Diaz, J.-P. Schöggl, T. Reyes, and R. Baumgartner, "Sustainable product development in a circular economy," *Sustainable Production and Consumption*, vol. 26, pp. 1031–1045, 2021, doi: 10.1016/j.spc.2020.12.044.

[59] M. Andersen, "An introductory note on the environmental economics of the circular economy," *Sustainability Science*, vol. 2, no. 1, pp. 133–140, 2007, doi: 10.1007/s11625-006-0013-6.

[60] G. Dash, C. Sharma, and S. Sharma, "Sustainable Marketing and the Role of Social Media," *Sustainability*, vol. 15, no. 6, Art. no. 5443, 2023, doi: 10.3390/su15065443.

[61] L. Gooding and R. Phillips, "Aligning Digital Futures with Ecological Citizenship for Sustainability," *Sustainability*, vol. 17, no. 18, Art. no. 8102, 2025, doi: 10.3390/su17188102.

ISSN: 2594-1925

[62] H. Si, J. G. Shi, D. Tang, S. Wen, W. Miao, and K. Duan, "Application of the Theory of Planned Behavior in Environmental Science," *International Journal of Environmental Research and Public Health*, vol. 16, no. 15, Art. no. 2788, 2019, doi: 10.3390/ijerph16152788.

[63] D. Cevallos Andrade and F. L. Del Blanco García, "Designing a Phygital Prosthesis for Urban Spaces," *Street Art & Urban Creativity*, vol. 11, no. 1, pp. 163–178, 2025, doi: 10.62161/sauc.v11.5684.

[64] J. Lee, C. C. Chen, and A. Basu, "From Novelty to Knowledge: A Longitudinal Investigation of the Novelty Effect on Learning Outcomes in Virtual Reality," *IEEE Transactions on Visualization and Computer Graphics*, vol. 31, no. 5, pp. 3204–3212, 2025, doi: 10.1109/TVCG.2025.3549897.

[65] T. R. Merlo, F. Fard, and S. Hawamdeh, "Cloud Computing's Impact on the Digital Transformation of the Enterprise," *Sustainability*, vol. 17, no. 13, Art. no. 5755, 2025, doi: 10.3390/su17135755.

[66] A. Gallego-Schmid *et al.*, "Circular economy in Latin America and the Caribbean," *Sustainable Production and Consumption*, vol. 51, pp. 118–136, 2024, doi: 10.1016/j.spc.2024.09.006.

ISSN: 2594-1925