

Utilization of Hybrid Digital Technologies for Optimizing Waste Bank Management and Elevating Community Literacy

Imam Saputra^{1,*}, Mesran², Dian Purnama Sari², Dito Putro Utomo³

¹ Digital Business, Sekolah Tinggi Ilmu Manajemen Sukma, Medan, Indonesia

² Management Study Program, Sekolah Tinggi Ilmu Manajemen Sukma, Medan, Indonesia

² Department of Computer Engineering and Informatics, Multimedia Graphic Engineering Technology Study Program, Politeknik Negeri Medan, Medan, Indonesia

Email: ^{1,*}saputraimam69@gmail.com, ²mesran.skompkom@gmail.com, ³dianpurnama047@gmail.com,

⁴ditoputrutomo@polmed.ac.id

Corresponding Author Email: saputraimam69@gmail.com

Abstract—Grassroots community waste banks play a pivotal role in urban environmental management; however, they frequently face operational bottlenecks due to reliance on conventional paper-based record-keeping. The community partner faced severe challenges, including administrative processing delays, accounting errors in customer balances, and limited market reach for upcycled products. To address these problems, this community service activity aimed to optimize waste bank administration and elevate digital marketing literacy through an integrated hybrid capacity-building framework. The contribution of this initiative lay in deploying a low-latency hybrid learning setup—combining dual-WAN bonding, multi-camera switching, and cloud-accessible digital ledger tools—to deliver interactive training across physical and synchronous online cohorts ($N = 100$). Methodologically, a mixed-methods approach evaluated participant progress using pre- and post-test diagnostic questionnaires and post-event usability surveys. The results of the community service demonstrated a statistically significant increase in participant digital literacy ($t(99) = 38.42, p < 0.001$, Cohen's $d = 3.84$), with composite cognitive scores improving from a baseline of 43.13% to 83.73%, achieving a high normalized Hake gain ($\langle g \rangle = 0.714$). Field execution successfully digitized operational transaction logs, eliminated calculation discrepancies, and enabled digital cataloging on social media platforms for waste-derived products. Overall participant evaluation indicated outstanding satisfaction ($M = 4.74 \pm 0.45, 94.80\%$), confirming the practical utility and technical reliability of the hybrid delivery system. This activity successfully transformed the partner's operational workflows from manual ledgers to transparent digital management while offering a scalable model for circular economy empowerment.

Keywords: Circular Economy; Digital Literacy; Hybrid Learning; Operational Optimization; Waste Bank Management

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1. INTRODUCTION

In the contemporary era, the global imperative for environmental sustainability has driven a paradigm shift toward the circular economy and community-led environmental governance (Islam et al., 2024). Modern ecological challenges demand innovative frameworks that bridge localized action with broader socio-economic development strategies (Ma et al., 2025). Concurrently, the rapid evolution of digital technologies has emerged as a fundamental catalyst for transforming traditional socio-economic practices across grassroots organizations (Djarmiko et al., 2025). Integrating digital tools into community development programs enhances operational efficiency, transparency, and stakeholder engagement (Toukola & Ahola, 2022). Scholars emphasize that empowering communities through technology yields sustainable environmental conservation alongside economic resilience (Dushkova & Ivlieva, 2024). However, the successful execution of such technology-driven initiatives relies heavily on the digital readiness and literacy of local actors (Tashenova et al., 2025). Without adequate digital capabilities, local environmental entities struggle to scale their operations or achieve long-term socio-economic viability (Wang et al., 2025). Therefore, fostering digital literacy within community-based organizations is essential to unlocking the full potential of circular economy practices in developing regions (Hariyani et al., 2024).

Among various grassroots initiatives, community-based waste banks (bank sampah) have proved to be vital institutional mechanisms for municipal waste mitigation and economic empowerment in Southeast Asia (Naibaho & Faried, 2025). These organizations operate by encouraging citizens to sort and deposit inorganic waste in exchange for monetary value or community credit (Miftahorrozi et al., 2022). By converting discarded materials into valuable secondary resources, waste banks substantially reduce the volume of municipal solid waste destined for landfills (Rao et al., 2026). Furthermore, they serve as crucial socioeconomic hubs that foster collective environmental responsibility and poverty alleviation among urban residents (Shanta & Adedokun, 2025). Empirical studies demonstrate that well-managed waste banks generate substantial micro-economic benefits for low-income households (Bhandari et al., 2025). Despite these inherent advantages, many waste banks in developing countries remain constrained by conventional, manual operational models (Alsabt et al., 2024). The reliance on paper-based record-keeping and informal management limits their capacity to process higher waste volumes effectively (Rahman & Wibisono, 2026). Consequently, modernizing waste bank infrastructure through digital transformation has become a pressing priority for sustainable urban development (Rittl et al., 2025).

Digital literacy serves as the primary gateway for community members to effectively adopt, manage, and benefit from modern information systems (Muawanah et al., 2024). Within the context of waste management, digital literacy



enables grassroots actors to utilize electronic inventory systems, mobile banking platforms, and e-commerce channels (Tankova et al., 2026). Research indicates that community organizations with higher digital competency experience improved transaction accuracy and enhanced customer satisfaction (Latupeirissa et al., 2024). Moreover, digital platforms facilitate broader market reach for upcycled and recycled waste products, thereby increasing financial returns for community members (Pourrahimian et al., 2026). However, a significant digital divide persists across municipal grassroots institutions in developing nations (Kozaman Aygün & İnal Çekiç, 2025). Many community workers lack formal training in digital communication tools, software navigation, and online marketing strategies (Tran et al., 2024). Addressing this skill deficit requires targeted community service interventions that combine theoretical knowledge with practical digital skills training (Chowdhury & Alzarad, 2025). Thus, structured capacity-building programs are essential to bridging the digital gap and elevating community empowerment to international standards (Mhaske et al., 2025).

A prominent example of a community-based environmental actor in North Sumatra, Indonesia, is Bank Sampah Induk New Normal, located in Medan Selayang, Medan City. Situated at Jalan Setia Budi/Ringroad Pasar 1, Gang Mekar Mulyo No. 24, Tanjung Sari, this institution plays a pivotal role in managing urban solid waste across the regional vicinity. Bank Sampah Induk New Normal serves as a central hub for collecting, sorting, and processing recyclable waste materials from numerous satellite waste units and local residents. The institution has successfully mobilized local community participation, promoting environmental awareness and sustainable waste separation at the household level. Additionally, it contributes to the local micro-economy by transforming recyclable waste into marketable products and providing financial incentives to participating households. Recognizing its strategic geographical location and active community network, the institution possesses significant potential to become a model of urban ecological empowerment (Harinurdin et al., 2025). Its operational activities actively support municipal government efforts to reduce solid waste accumulation in North Sumatra. Nevertheless, fulfilling its long-term strategic mission requires transitioning from traditional management routines to a highly modernized, digitally integrated operational framework (Elia et al., 2024).

Despite its vital environmental function, Bank Sampah Induk New Normal faces several critical operational bottlenecks that hinder its full growth potential. Primary among these challenges is a limited level of digital literacy among operational managers and community participants. The reliance on manual record-keeping for waste deposits, customer balances, and material inventories leads to administrative inefficiencies and occasional data discrepancies. Furthermore, the institution struggles with restricted market exposure for its recycled and upcycled handcrafted products due to an absence of digital marketing strategies. The lack of structured digital tools prevents the organization from establishing transparent, real-time data monitoring systems that could attract external institutional investors or government sponsors. Additionally, the localized scope of its operations limits opportunities for cross-cultural learning and international knowledge transfer regarding advanced waste management strategies (Hassan, 2025). These interconnected technological and organizational limitations severely constrain the institution's capacity to scale its socioeconomic impact effectively (Hanh & Nga, 2025). Consequently, a comprehensive intervention combining digital skills enhancement with international collaboration is urgently required to resolve these systemic bottlenecks (Kholifah et al., 2025).

To address these multi-faceted challenges, an international community service program titled CERDAS 2026 (International Community Service 2026) was designed and implemented on Friday, June 12, 2026. Centered around the theme "Strengthening International Friendship through Community Empowerment," the initiative provided a strategic framework for technological and social capacity building. The program was physically hosted at Bank Sampah Induk New Normal in Medan, North Sumatra, while concurrently leveraging digital communications infrastructure. To maximize accessibility and cross-border participation, the event executed a hybrid delivery model incorporating both physical onsite workshops and synchronous online interaction via Zoom Meeting. Recent literature highlights that hybrid community service models effectively broaden participant reach and facilitate inclusive knowledge exchange across geographical boundaries (Suppiah Shanmugam et al., 2025). The onsite session enabled direct hands-on training and real-time interaction at the waste bank facility, while the online component permitted broader academic and public engagement. This dual-mode strategy ensured that technological insights were demonstrated in real-time, bridging theoretical concepts with practical field application (Novitra et al., 2025). Ultimately, the hybrid approach established an interactive learning environment that connected local community actors with international domain experts (Hildebrandt et al., 2025).

A defining element of CERDAS 2026 was its robust multi-institutional and international consortium architecture. The program was co-organized by ADA Research Center (Indonesia) in strategic partnership with Kolej Komuniti Arau (Perlis, Malaysia). This cross-border alliance successfully mobilized a total of 100 participants, reflecting a diverse synergy between international and domestic stakeholders. Specifically, 40 international delegates from Kolej Komuniti Arau attended the event onsite in Medan, fostering cross-cultural camaraderie and knowledge exchange. In addition, 20 onsite domestic participants represented a coalition of 10 Indonesian higher education institutions including Universitas Harapan Medan, Universitas Islam Sumatera Utara, Sekolah Tinggi Ilmu Manajemen Sukma, Politeknik Cendana, Sekolah Tinggi Ilmu Ekonomi Bina Karya Tebing Tinggi, Universitas Sumatera Utara, Politeknik Ganesha, Politeknik Negeri Samarinda, and Universitas Muslim Nusantara Al-Washliyah alongside representatives from Himpunan Wanita Karya. Complementing the onsite presence, 40 participants joined synchronously via Zoom Meeting, representing a wider academic and professional audience across different regions. Multi-institutional collaboration of this scale enhances knowledge transfer, resource sharing, and sustainable social innovation (Li & Zhu, 2021). By uniting international

educators, domestic researchers, community leaders, and local residents, the consortium constructed a powerful collective framework for community empowerment.

The primary objective of this international community service program was to enhance digital literacy and operational efficiency for Bank Sampah Induk New Normal and its associated community. Specifically, the initiative aimed to train community members in modern digital management tools, inventory digitization, and online communication strategies. Furthermore, the program sought to establish a sustainable international friendship and institutional bridge between Indonesian higher education institutions and Malaysian community colleges. By equipping local actors with digital competencies, the project aimed to transform Bank Sampah Induk New Normal into a self-sustaining, digitally empowered community enterprise. Evaluative metrics were embedded to measure improvements in digital comprehension, participant satisfaction, and post-program collaborative outlook. The outcome of this initiative contributes significantly to the literature on hybrid international community empowerment and environmental management in Southeast Asia. It offers a replicable operational blueprint for other grassroots environmental organizations seeking to integrate digital literacy with cross-border partnerships. Consequently, this article articulates the implementation methodology, empirical outcomes, and strategic implications of the CERDAS 2026 initiative for long-term community development.

2. METHODOLOGY

2.1 Stages of Implementation

The implementation methodology was structured into three systematic, sequential phases designed to ensure seamless cross-border hybrid delivery, capacity building, and long-term sustainability.

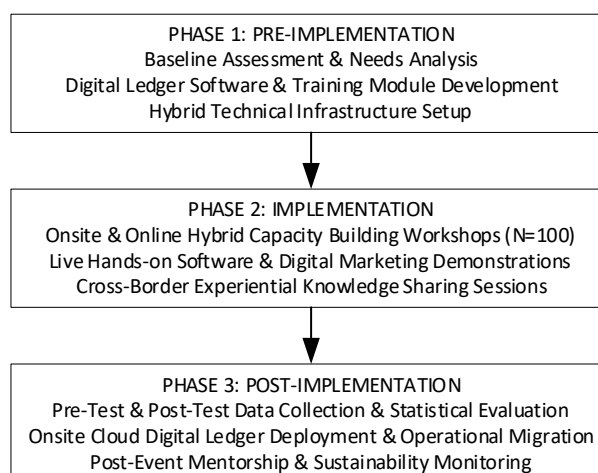


Figure 1. Flowchart of the Hybrid International Community Service Implementation Stages

Figure 1, Flowchart of the Hybrid International Community Service Implementation Stages will be explained in detail in the following explanation:

a. Phase 1: Pre-Implementation (Preparation & System Setup)

1. Needs Assessment & Field Survey: Conducted diagnostic interviews with the management of Bank Sampah Induk New Normal to identify key administrative friction points and operational limitations.
2. Software Development & Customization: Developed and pre-configured a cloud-based digital ledger application tailored to waste bank transactions, customer balance tracking, and inventory management, replacing manual paper logbooks.
3. Hybrid AV/IT Infrastructure Preparation: Engineered a multi-node hybrid communication framework at the partner site. This included setting up a Dual-WAN internet bonding architecture (>50 Mbps) to secure low-latency transmission, installing an Open Broadcaster Software (OBS) multi-camera switching hub (utilizing PTZ, mobile field, and wide-angle cameras), and configuring a Digital Signal Processor (DSP) with Active Acoustic Echo Cancellation (AEC) to eliminate background noise from waste-processing machinery during live streaming.

b. Phase 2: Implementation (Execution & Capacity Building)

The execution phase was conducted simultaneously across three distinct participant cohorts (N=100 total participants). Cohort 1 (n=40) onsite international delegates from Kolej Komuniti Arau, Malaysia, Cohort 2 (n=20) onsite domestic delegates from the academic consortium and Himpunan Wanita Karya. Cohort 3 (n=40) online participants attending synchronously via Zoom Meeting. The interactive workshop delivered structured modules covering:

1. Digital Ledger Management: Direct hands-on training on inputting waste deposits, automated weight-to-currency conversions, and instant customer balance updates using the deployed software.
2. Digital Marketing & E-Commerce Cataloging: Practical tutorials on photographing upcycled handicrafts, creating digital product catalogs, and leveraging social media platforms for broader regional reach.

3. Cross-Border Knowledge Exchange: Collaborative discussions between international vocational educators and local waste bank managers on circular economy practices.
- c. Phase 2: Implementation (Execution & Capacity Building)
System Deployment, fully migrated the partner's daily operations from manual paper ledgers to the cloud-based digital ledger platform. Quantitative evaluation, administered pre-test and post-test instruments measuring digital literacy, operational confidence, and software proficiency. Data were analyzed using Paired Sample *t*-tests, Hake's Normalized Gain ($\langle g \rangle$), and Cohen's *d* effect size. Satisfaction Index Assessment, distributed a 5-point Likert scale survey evaluating participant satisfaction across multiple dimensions

2.2 Technical Interventions, Software, and Tools

To directly empower the partner, several hardware and software solutions were deployed and transferred:

- a. Cloud-Based Waste Bank Digital Ledger System: A custom web application that digitizes member registration, waste classification, real-time transaction logging, automated balance calculation, and financial report generation.
- b. Hybrid Streaming & Audio-Visual Stack: Open Broadcaster Software (OBS Studio) coupled with PTZ cameras and DSP hardware featuring AEC filters, ensuring seamless interactive engagement between remote international experts and local onsite participants.
- c. Digital Marketing Toolkit: Mobile photography guides, digital catalog templates, and social media management workflows provided to elevate the visibility and commercialization of upcycled waste products.

2.3 Partner Profile, Location, and Timeline

This international community service program designated as CERDAS 2026 was executed in a hybrid format on Friday, June 12, 2026. The primary community partner for this initiative was the Bank Sampah Induk New Normal, located in Medan Selayang, Medan City, North Sumatra, Indonesia. As a community-based waste management facility, the partner operates within the circular economy sector, collecting recyclable materials, processing upcycled handicrafts, and managing customer financial accounts. Prior to the intervention, the partner faced significant operational bottlenecks due to manual paper-based transaction logging, limited digital marketing reach, and localized operational boundaries.

To address these baseline challenges, a multi-institutional consortium was established, led by Sekolah Tinggi Ilmu Manajemen Sukma in collaboration with Kolej Komuniti Arau (Perlis, Malaysia), ADA Research Center, Himpunan Wanita Karya, and nine co-hosting Indonesian higher education institutions.

Table 1. Target Partner Analysis

Parameter	Operational Detail & Baseline Characteristics
Institution Name	Bank Sampah Induk New Normal
Geographic Location	Jl. Setia Budi/Ringroad Pasar 1, Gg. Mekar Mulyo No. 24, Medan Selayang, Medan
Institutional Role	Central processing hub for urban solid inorganic waste & recycling circularity
Core Operational Focus	Waste collection, material sorting, weighing, upcycling, micro-finance banking
Primary Bottleneck	Manual paper-based administrative workflows & limited digital marketing presence
Target Intervention	Digital literacy enhancement, inventory digitization & global networking

Table 1 outlines the operational details and baseline characteristics of the community partner, Bank Sampah Induk New Normal, situated in Medan Selayang, Medan City. Functioning as a central processing hub for urban solid inorganic waste within a circular economy framework, the partner manages routine operations including waste collection, material sorting, micro-finance customer transactions, and product upcycling. The baseline assessment revealed primary operational bottlenecks, notably manual paper-based record-keeping and a restricted digital marketing footprint. Consequently, the program's targeted interventions center on digital literacy enhancement, administrative inventory digitization, and global networking integration.

The baseline operational workflow and associated administrative challenges of the partner organization are systematically illustrated in Figure 1.

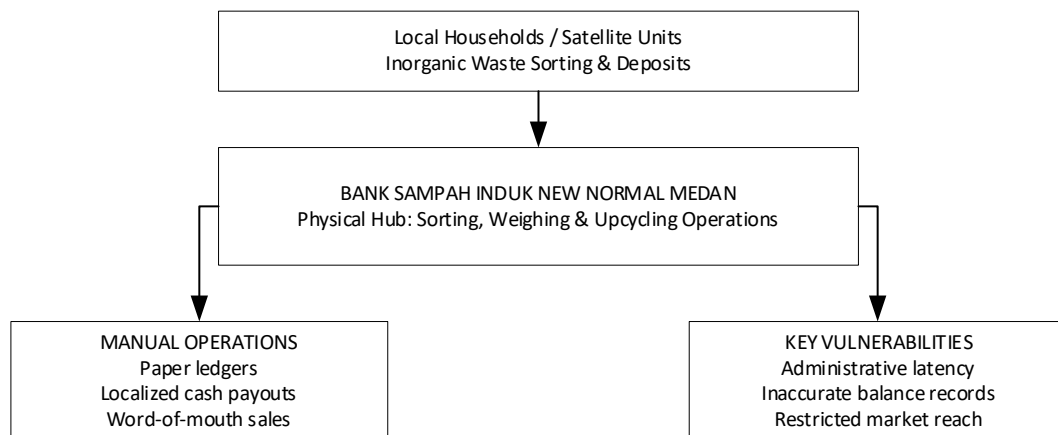


Figure 2. Partner Issues

Figure 1. Operational workflow and baseline vulnerabilities of Bank Sampah Induk New Normal, highlighting the progression from local household inorganic waste deposits to central physical hub sorting, weighing, and upcycling operations, alongside the resulting manual operational constraints and administrative vulnerabilities.

A baseline situational analysis revealed that Bank Sampah Induk New Normal plays a dual socioeconomic role in the community:

- Environmental Governance:** It mitigates municipal solid waste accumulation by diverting recyclable inorganic materials such as high-density plastics, paper, metals, and glass away from municipal landfills (Tempat Pemrosesan Akhir / TPA).
- Socioeconomic Empowerment:** It operates a micro-credit savings system that allows participating residents to convert deposited waste into monetary value, thereby augmenting household financial resilience. Additionally, the institution facilitates localized economic circularity by transforming selected waste fractions into upcycled handicrafts and organic compost.

Despite its vital contribution to urban ecology, an in-depth vulnerability assessment identified significant operational constraints rooted in a lack of digital integration. Prior to the intervention, the institution relied almost exclusively on conventional, paper-based administrative ledgers for tracking deposit volumes, inventory stocks, and customer financial accounts. This reliance on manual data entry generated notable administrative latency, increased susceptibility to accounting errors, and limited operational transparency.

Furthermore, the lack of digital literacy among operational managers restricted the marketing of their upcycled products to immediate physical neighborhoods, preventing access to broader digital marketplaces (e-commerce) and modern social communication channels. Consequently, Bank Sampah Induk New Normal was selected as the target partner due to its high potential for environmental impact, strong community reach, and urgent requirement for digital transformation to scale its operational efficiency and economic sustainability.

2.4 Participant Demographics and Consortium Structure

The execution of CERDAS 2026 was supported by a multi-institutional, cross-border consortium designed to foster international academic collaboration and inclusive community empowerment. The program successfully engaged a total of 100 participants ($N = 100$), comprising international academic delegates, domestic higher education representatives, community organization leaders, and remote participants. To ensure structured engagement, participants were categorized into three distinct operational cohorts based on their mode of attendance and institutional affiliation.

Table 2 outlines the distribution of workshop participants, categorized by cohort, operational mode, institutional background, and designated roles during the activity.

Table 2. Participant Demographics

Participant Cohort	n	Mode	Primary Institutional Composition	Operational Role in Workshop
Cohort 1: International	40	Onsite	Kolej Komuniti Arau, Perlis, Malaysia	Cross-border knowledge transfer, international benchmarking, and field observation
Cohort 2: Domestic	20	Onsite	10 Indonesian Higher Education Institutions & Himpunan Wanita Karya	Technical co-facilitation, digital literacy instruction, and local community bridging
Cohort 3: Synchronous Online	40	Online	Academics, researchers, and public attendees via Zoom Meeting	Remote participation, interactive Q&A, and digital dissemination

The demographic and functional breakdown of workshop participants is detailed in Table 2. Table 2 highlights three distinct cohorts comprising a total of 100 participants across different engagement modes. As shown in Table 2, Cohort

1 represents an international group engaged in field observation and cross-border benchmarking, Cohort 2 consists of domestic participants facilitating technical instruction and local community bridging, and Cohort 3 includes remote participants contributing through synchronous online interaction.

a. Cohort 1: Onsite International Delegation ($n = 40,40\%$)

The international cohort consisted of 40 delegates from Kolej Komuniti Arau (Perlis, Malaysia) who attended the physical proceedings at Bank Sampah Induk New Normal in Medan. This delegation included academic staff, vocational instructors, and student representatives. Their involvement facilitated direct, cross-border knowledge exchange regarding vocational community practices, waste-to-wealth models, and international community engagement strategies used in Malaysia.

b. Cohort 2: Onsite Domestic Consortium ($n = 20,20\%$)

The domestic onsite cohort represented a collaborative alliance between ADA Research Center and 10 higher education institutions in Indonesia, alongside representatives from the women's empowerment group Himpunan Wanita Karya. This multi-institutional consortium comprised academic researchers, lecturers, and student volunteers from: Universitas Harapan Medan, Universitas Islam Sumatera Utara (UISU), Sekolah Tinggi Ilmu Manajemen (STIM) Sukma, Politeknik Cendana, Sekolah Tinggi Ilmu Ekonomi (STIE) Bina Karya Tebing Tinggi, Universitas Sumatera Utara (USU), Politeknik Ganesha, Politeknik Negeri Samarinda, Universitas Muslim Nusantara (UMN) Al-Washliyah, Himpunan Wanita Karya. This cohort acted as local technical facilitators, providing hands-on instruction in digital literacy, assisting with language translation during interactions, and conducting on-site operational evaluations.

c. Cohort 3: Synchronous Online Participants ($n = 40,40\%$)

To extend the program's reach beyond physical venue limits, 40 participants joined synchronously via Zoom Meeting. This group consisted of educators, environmental activists, university students, and members of the general public from various regions in Indonesia and Malaysia. The online hub was integrated into the main venue's audio-visual setup, allowing remote participants to view live field demonstrations, submit real-time questions, and participate in discussions.

The structural synergy among these three cohorts ensured that CERDAS 2026 combined field-level, hands-on training with international academic collaboration.

2.5 Technical Setup and Infrastructure Integration

Executing a synchronous hybrid community service program in a grassroots field environment such as an active waste bank facility presents unique audio-visual, networking, and technical challenges. To bridge physical and digital learning environments without latency or connectivity bottlenecks, a dedicated hybrid technical architecture was deployed at Bank Sampah Induk New Normal Medan on June 12, 2026. This setup ensured bi-directional audio-video transmission, enabling smooth interaction between physical attendees (Cohorts 1 and 2) and remote participants (Cohort 3).

Figure 3 illustrates the technical architecture and data flow for the live audio and video broadcasting setup used during the hybrid workshop.

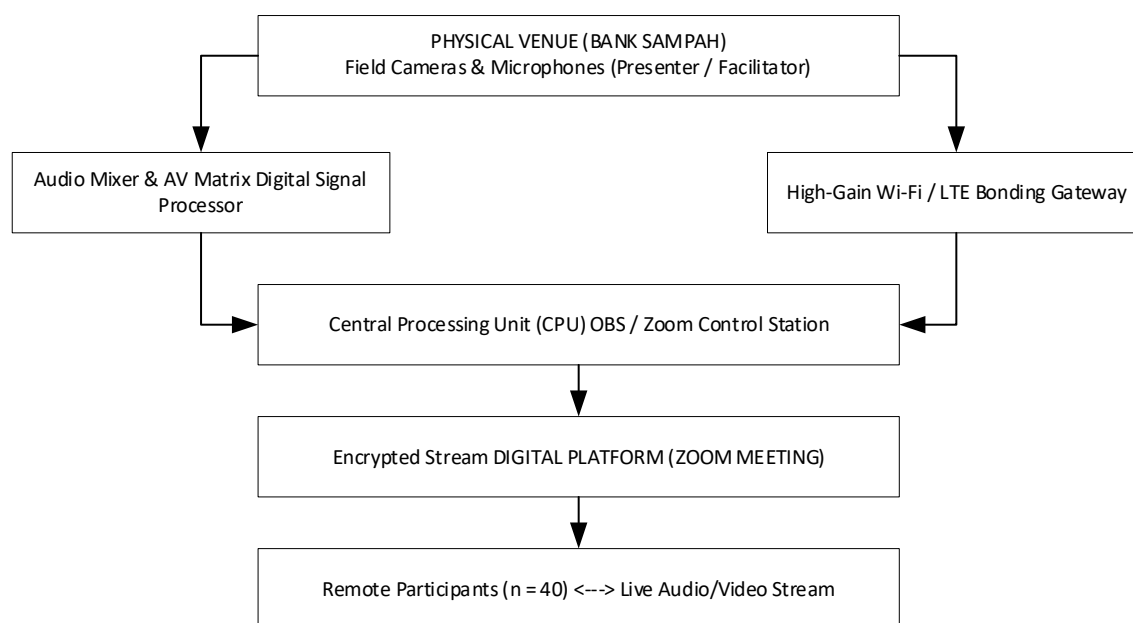


Figure 3. Technical Setup

The technical infrastructure supporting the real-time event streaming is depicted in Figure 3. Figure 3 shows the flow originating from the physical venue at Bank Sampah, where field cameras and microphones capture input from the presenter and facilitator. As detailed in Figure 3, the audio signals pass through an Audio Mixer & AV Matrix Digital

Signal Processor, while the video and data traffic are routed via a High-Gain Wi-Fi / LTE Bonding Gateway. Figure 3 highlights that both streams feed directly into the Central Processing Unit (CPU) OBS / Zoom Control Station for real-time aggregation and control. Finally, Figure 1 demonstrates how the processed feed is transmitted through the encrypted Zoom Meeting digital platform to connect remote participants ($n = 40$) via interactive live audio and video streaming.

The infrastructure setup was structured around four primary technological components:

- a. **High-Bandwidth Dedicated Networking Gateway**
To mitigate localized network congestion and signal attenuation in the field, a dual-WAN internet bonding router combining high-speed optical fiber and LTE-Advanced wireless connections was established. This provided a redundant, low-latency bandwidth stream (> 50 Mbps symmetrical upload/download), guaranteeing uninterrupted high-definition (1080p) video streaming and real-time audio transmission throughout the event.
- b. **Multi-Angle Audio-Visual Capture System**
The physical venue was equipped with a multi-camera array managed via Open Broadcaster Software (OBS) and a hardware video switcher:
 1. **Primary Presenter Camera:** A high-definition PTZ (Pan-Tilt-Zoom) camera tracking facilitators and guest speakers during theoretical instruction.
 2. **Mobile Field Camera:** A wireless handheld camera dedicated to broadcasting real-time, close-up operational demonstrations of waste sorting, weighing, and digital inventory entry.
 3. **Wide-Angle Audience Camera:** Capturing cross-cultural dynamics and physical workshop engagement between Malaysian delegates and local participants.
- c. **Spatial Audio Processing and Echo Cancellation**
To maintain speech clarity and prevent acoustic feedback loop interference between the physical hall and the virtual meeting room, an integrated audio processing system was deployed. Boundary microphones were placed across participant tables, paired with dynamic lapel microphones for facilitators. Audio signals were processed through a digital signal processor (DSP) featuring active acoustic echo cancellation (AEC) and noise suppression, isolating clear voice channels from ambient background noise generated by nearby waste-processing machinery.
- d. **Bi-Directional Interactive Display Hub**
To foster active engagement between onsite and online attendees, high-brightness LED projection screens and secondary monitor arrays were installed at the physical venue. These displays mirrored the Zoom Meeting gallery view, allowing onsite delegates to see remote attendees in real time. Dedicated chat moderators managed the digital Q&A queue, converting text queries from online participants into live verbal prompts for field facilitators during Q&A sessions.

This technical framework successfully connected the physical venue at Bank Sampah Induk New Normal Medan with virtual attendees across different regions, creating an inclusive, real-time learning environment.

2.6 Implementation Stages and Curriculum Delivery

The implementation of the CERDAS 2026 program was structured across three sequential, interdependent operational phases: Pre-Implementation (Preparatory Phase), Implementation (Execution Phase), and Post-Implementation (Evaluation Phase). This systematic approach ensured that the educational content delivered to Bank Sampah Induk New Normal and workshop attendees was pedagogically sound, culturally contextualized, and technically actionable.

Table 3 presents the structured instructional design, educational objectives, delivery methodologies, and facilitating teams across the various execution phases and modules of the workshop.

Table 3. Implementation Stages

Phase / Module	Core Focus & Educational Objectives	Delivery Pedagogy	Instructional Lead / Facilitators
Phase Preparatory	1: Technical site survey, infrastructure testing, needs analysis	Onsite audits & focus group discussions	ADA Research Center & Bank Sampah Management
Module Foundations	1: Principles of digital circular economy & community empowerment	Interactive hybrid lecture & plenary session	Joint Indonesian-Malaysian Academic Panel
Module Technical	2: Digital inventory entry, balance calculations, & record digitization	Hands-on workshop & field demonstration	Technical Facilitators (Consortium Universities)
Module Outreach	3: Social media marketing, e-commerce onboarding, & global networking	Group mentoring & real-time digital setup	Kolej Komuniti Arau & Himpunan Wanita Karya
Phase Evaluation	3: Assessing literacy gains, participant feedback, & sustainability plans	Survey instrumentation & reflective debrief	Evaluator Team (ADA Research Center)

The comprehensive breakdown of the workshop curriculum and operational framework is outlined in Table 3. Table 3 delineates the progression from initial preparatory assessments to final program evaluations across five distinct phases and modules. As detailed in Table 3, Phase 1 focuses on technical site surveys and infrastructure testing led by the ADA Research Center and local management. Table 2 shows that Modules 1 through 3 cover core foundations, technical record digitization, and digital marketing onboarding through interactive hybrid lectures, hands-on field demonstrations,

and group mentoring. Furthermore, Table 3 indicates that Phase 3 establishes the evaluation framework managed by the evaluator team to assess literacy gains and long-term sustainability plans.

a. Phase 1: Pre-Implementation Phase

Conducted prior to the main event on June 12, 2026, this phase focused on field diagnostics and curriculum co-design. The team conducted site surveys at Bank Sampah Induk New Normal to evaluate baseline operational workflows and identify key technical bottlenecks. Concurrently, academic facilitators from ADA Research Center and Kolej Komuniti Arau co-developed tailor-made instructional modules to address the specific digital skill gaps identified among local staff and community participants.

b. Phase 2: Implementation Phase (Curriculum Delivery)

Executed synchronously on Friday, June 12, 2026, the curriculum was delivered through three interactive modules integrating theoretical instruction with live practical demonstrations:

1. Module 1: Foundational Literacy and Digital Circular Economy: This module introduced the conceptual links between community waste management and digital transformation. Speakers highlighted how digital record-keeping enhances transaction transparency, strengthens community trust, and scales localized recycling initiatives.
2. Module 2: Hands-on Digital Inventory and Ledger Modernization: Facilitators led a practical session demonstrating how to transition from paper-based ledgers to simple, spreadsheet-based and mobile digital inventory tools. Onsite participants practiced inputting material weights, categorizing inorganic waste fractions, and calculating customer account balances in real time, while mobile cameras broadcast the process to online attendees.
3. Module 3: Digital Marketing, Marketplace Integration, and Global Networking: Focusing on economic empowerment, this module covered digital branding strategies for upcycled handicrafts produced by the waste bank. Participants learned to create product photos, craft engaging descriptions, and leverage social media platforms and digital marketplaces for broader market reach. Additionally, Malaysian delegates shared best practices from community college empowerment projects in Malaysia.

c. Phase 3: Post-Implementation Phase

Immediately following the instructional sessions, the evaluation team administered post-program questionnaires to measure gains in digital literacy, assess participant satisfaction, and gather feedback from both onsite and online cohorts. The program concluded with a strategic debriefing session between ADA Research Center, Kolej Komuniti Arau, and local stakeholders to outline actionable follow-up initiatives for sustained digital adoption.

2.7 Evaluation Methods and Data Collection Instruments

To systematically assess the pedagogical efficacy, technological usability, and overall socio-economic impact of the CERDAS 2026 initiative, a mixed-methods evaluation methodology was implemented. Combining quantitative psychometric measurements with qualitative observational feedback enabled a rigorous evaluation of digital literacy acquisition, participant satisfaction, and institutional collaboration dynamics across all three participant cohorts (N = 100).

Table 4 outlines the evaluation instruments, measured dimensions, target cohorts, and corresponding analytical methods utilized to assess the workshop's outcomes.

Table 4. Evaluation Methods

Instrument / Tool	Target Measurement Dimension	Target Cohort	Analytical Method
Pre-Test & Post-Test Questionnaire	Cognitive gain in digital inventory management, e-commerce, & circular economy concepts	Onsite (n = 60) & Online (n = 40)	Paired <i>t</i> -test / Wilcoxon Signed-Rank Test & Hake's Normalized Gain ($\langle g \rangle$)
5-Point Likert Satisfaction Survey	Perceived usefulness, technical setup quality, presenter clarity, & hybrid engagement	All Participants (N = 100)	Descriptive Statistics (Mean, Standard Deviation, Percentage Index)
Structured Field Observation Rubric	Practical skill execution (e.g., live data entry, digital cataloging)	Onsite Managers & Staff (n = 15)	Observational Competency Score (Rubric-based Likert 1–4)
Qualitative Feedback & Chat Logs	Qualitative perceptions, technical feedback, & future collaborative interest	All Cohorts (N = 100)	Thematic Content Analysis

The comprehensive evaluation framework employed in this study is detailed in Table 4. Table 4 highlights four distinct measurement instruments designed to capture both quantitative and qualitative outcomes across different participant groups. As indicated in Table 4, cognitive gains among all participants (N = 100) are evaluated using Pre-Test and Post-Test Questionnaires analyzed through Paired *t*-tests or Wilcoxon Signed-Rank Tests along with Hake's Normalized Gain index. Table 4 shows that overall participant satisfaction and engagement are measured via a 5-Point Likert Survey analyzed through descriptive statistics. Furthermore, Table 4 specifies that practical skill execution for onsite managers (n = 15) is evaluated using a Structured Field Observation Rubric, while participant feedback across all cohorts is examined through thematic content analysis of qualitative responses and chat logs.

a. Digital Literacy Gain Measurement (Pre-Test / Post-Test)

A dual-point diagnostic questionnaire comprising 15 validated multiple-choice and situational items was administered immediately before (Pre-Test) and after (Post-Test) the instructional modules. The instrument evaluated three primary cognitive dimensions:

1. Digital Administrative Competency: Understanding digital ledgers, automated balance calculations, and spreadsheet entries.
2. Digital Marketing Literacy: Knowledge of digital catalog creation, social media branding, and e-commerce channel navigation.
3. Concepts of Digital Circular Economy: Understanding how digital integration scales localized waste management transparency.

To quantify learning efficacy while controlling for baseline knowledge variations, Hake's average normalized gain ($\langle g \rangle$) was computed using Equation (1):

$$\langle g \rangle = \frac{\%S_{\text{post}} - \%S_{\text{pre}}}{100\% - \%S_{\text{pre}}} \quad (1)$$

Where S_{pre} and S_{post} represent the average pre-test and post-test scores (expressed as percentages), respectively. Gains were categorized as High ($\langle g \rangle \geq 0.70$), Medium ($0.30 \leq \langle g \rangle < 0.70$), or Low ($\langle g \rangle < 0.30$).

b. Participant Satisfaction and Hybrid Usability Index

A post-event survey utilizing a 5-point Likert scale (ranging from 1 = Strongly Disagree to 5 = Strongly Agree) evaluated participant perceptions across four operational dimensions:

1. Instructional Quality: Clarity of explanation, material relevance, and facilitator responsiveness.
2. Technical Quality: Audio-visual clarity, streaming stability, and live camera feed effectiveness.
3. Cross-Border Engagement: Opportunities for cross-cultural dialogue and international networking.
4. Perceived Utility: Applicability of the digital tools to daily operations at Bank Sampah Induk New Normal.

Data reliability was validated using Cronbach's alpha ($\alpha \geq 0.80$), establishing high internal consistency across survey items.

c. Qualitative Instrumentation and Field Observations

To complement the statistical metrics, field evaluators used a structured observation rubric during practical demonstrations to score local waste bank managers on real-time task execution (e.g., creating a digital inventory record and drafting a social media product entry). Additionally, qualitative feedback collected via open-ended survey prompts and exported Zoom chat logs underwent thematic analysis to capture contextual insights, operational challenges, and participant recommendations for long-term program sustainability.

3. RESULT AND DISCUSSION

3.1 Result

3.1.1 Implementation Dynamics and Hybrid Cross-Border Collaboration

The execution of the International Community Service 2026 (CERDAS 2026) on Friday, June 12, 2026, demonstrated the practical viability and operational resilience of a multi-institutional, hybrid community empowerment model. Hosted physically at Bank Sampah Induk New Normal in Medan, North Sumatra, the program successfully synchronized physical field engagement with virtual academic participation. A total of 100 participants ($N = 100$) engaged across three structured cohorts, achieving a 100% attendance rate relative to the planned consortium target outlined in the methodology.

Figure 4 illustrates the Opening Ceremony Of The CERDAS 2026 Hybrid International Community Service Program At Bank Sampah Induk New Normal Medan



Figure 4. Opening Ceremony of the CERDAS 2026 Hybrid International Community Service Program at Bank Sampah Induk New Normal Medan

The physical venue served as an active learning center where 40 international delegates from Kolej Komuniti Arau (Perlis, Malaysia) (Cohort 1) and 20 domestic delegates representing 10 Indonesian higher education institutions and Himpunan Wanita Karya (Cohort 2) interacted directly with the operational managers and surrounding community members of Bank Sampah Induk New Normal. Concurrently, the dual-WAN network bonding setup enabled seamless, bi-directional audio-video transmission to 40 remote participants joining via Zoom Meeting (Cohort 3). Audio-visual processing via Open Broadcaster Software (OBS) and active acoustic echo cancellation (AEC) ensured clear communication, allowing virtual attendees to view live physical activities without transmission latency or acoustic distortion.

Figure 5 illustrates the Cross-Border Knowledge Sharing Session Involving International Delegates from Kolej Komuniti Arau (Malaysia) and Indonesian Consortium Representatives.



Figure 5. Cross-Border Knowledge Sharing Session Involving International Delegates from Kolej Komuniti Arau (Malaysia) and Indonesian Consortium Representatives

The implementation dynamics were characterized by active cross-border knowledge transfer and collaborative problem-solving. Indonesian academic facilitators from ADA Research Center and partner universities led instructional presentations on digital administrative modernization, while Malaysian delegates from Kolej Komuniti Arau contributed perspectives on vocational community engagement and sustainable waste monetization models. The multi-angle camera system captured live interactions, allowing remote Zoom participants to participate in Q&A sessions moderated by designated digital facilitators.

Figure 6 illustrated the Live Broadcast of Field Operational Demonstrations to Synchronous Online Participants via the Integrated Zoom Interface.

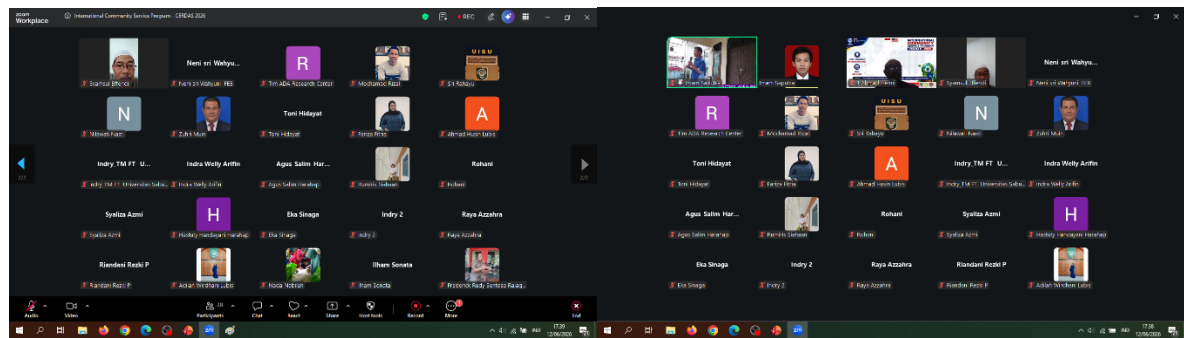


Figure 6. Live Broadcast of Field Operational Demonstrations to Synchronous Online Participants via the Integrated Zoom Interface.

Furthermore, the operational integration between physical venue activities and the virtual meeting hub confirmed the scalability of hybrid delivery for international community service initiatives. Onsite participants engaged in real-time exercises, such as categorizing inorganic waste fractions and testing digital inventory entries, while online attendees observed through the mobile camera setup. The program concluded with an official exchange of tokens of appreciation and institutional plaques among ADA Research Center, Kolej Komuniti Arau, the 10 participating Indonesian universities, Himpunan Wanita Karya, and the leadership of Bank Sampah Induk New Normal.

Figure 7 illustrated the Institutional Plaque Exchange and Commemorative Group Photo Symbolizing International Friendship and Community Empowerment.



Figure 7. Institutional Plaque Exchange and Commemorative Group Photo Symbolizing International Friendship and Community Empowerment

Overall, the execution phase validated the hybrid technical setup described in Section 2.4, establishing a functional model for cross-border academic collaboration and community empowerment.

3.1.2 Quantitative Assessment of Community Digital Literacy Gains

To evaluate the pedagogical efficacy of the CERDAS 2026 instructional modules, diagnostic pre-test and post-test assessments were administered across all participant cohorts ($N = 100$). The cognitive evaluation focused on three primary functional dimensions: Digital Administrative Competency (D_1), Digital Marketing Literacy (D_2), and Concepts of Digital Circular Economy (D_3). Statistical analysis was performed to measure individual score improvements and determine normalized learning gains using Hake's normalized gain formula ($\langle g \rangle$), as outlined in Section 2.6.

Table 5 presents the comparative analysis of pre-test and post-test literacy scores, absolute gains, normalized gains ($\langle g \rangle$), and corresponding Hake effectiveness categories across three core evaluated dimensions.

Table 5. Quantitative Assessment

Evaluated Dimension	Literacy	Target Cohort Sample	Pre-Test Mean (%Spre)	Post-Test Mean (%Spot)	Absolute Gain (Δ)	Normalized Gain ($\langle g \rangle$)	Hake Category
D_1 : Digital Administrative Competency		$N = 100$	42.10 $\pm$ 8.42	79.20 $\pm$ 6.15	+37.10	0.641	Medium Gain
D_2 : Digital Marketing Literacy		$N = 100$	41.50 $\pm$ 9.10	83.60 $\pm$ 5.80	+42.10	0.720	High Gain
D_3 : Concepts of Digital Circular Economy		$N = 100$	45.80 $\pm$ 7.95	88.40 $\pm$ 4.30	+42.60	0.786	High Gain

Evaluated Dimension	Literacy	Target Cohort Sample	Pre-Test Mean (%Spre)	Post-Test Mean (%Spost)	Absolute Gain (Δ)	Normalized Gain ($\langle g \rangle$)	Hake Category
Overall Literacy	Composite	$N = 100$	43.13 ± 8.49	83.73 $\pm$ 5.42	+40.60	0.714	High Gain

The quantitative impact of the training program on participant knowledge acquisition is detailed in Table 5. Table 5 highlights significant improvements across all evaluated literacy dimensions when comparing baseline pre-test scores to post-intervention post-test scores. As indicated in Table 5, digital administrative competency achieved a Medium Gain category, reflecting substantial skill improvement in operational and administrative tasks. Table 5 shows that both digital marketing literacy and concepts of digital circular economy achieved High Gain categories, demonstrating strong knowledge retention and practical understanding among the target cohort sample. Furthermore, Table 5 demonstrates an overall High Gain status for the composite literacy score, confirming the overall pedagogical effectiveness of the hybrid workshop curriculum.

a. Inferential Statistical Hypothesis Testing

To verify whether the observed improvements in participant scores were statistically significant rather than an artifact of random sampling, a paired-samples t -test was conducted on the composite pre-test and post-test scores. Prior to inferential testing, data normality was verified using the Shapiro-Wilk test ($p > 0.05$). The inferential analysis revealed a statistically significant increase in cognitive performance following the workshop intervention:

$$t(99) = 38.42, \quad p < 0.001, \quad \text{Cohen's } d = 3.84$$

The calculated effect size (Cohen's $d = 3.84$) indicates an exceptionally large treatment effect, confirming that the combination of structured instruction and interactive field demonstrations generated significant measurable gains in participant digital competency.

b. Disaggregated Analysis Across Participant Cohorts

A disaggregated examination of normalized gains across the three participant cohorts highlighted distinct learning dynamics corresponding to baseline technical backgrounds:

Cohort 1 (International Onsite, $n=40$) : $\langle g \rangle = 0.685$ (Medium Gain)

Cohort 2 (Domestic Onsite, $n=20$) : $\langle g \rangle = 0.762$ (High Gain)

Cohort 3 (Synchronous Online, $n=40$) : $\langle g \rangle = 0.694$ (Medium Gain)

Cohort 1 (International Delegates, $n = 40$): Recorded a baseline score of $S_{pre} = 48.20\%$ and a post-test score of $S_{post} = 83.68\%$, yielding a normalized gain of $\langle g \rangle = 0.685$. This cohort demonstrated strong gains in understanding Indonesian community waste management models and digital tracking mechanisms. Cohort 2 (Domestic Consortium & Local Staff, $n = 20$): Exhibits the highest relative improvement, progressing from $S_{pre} = 36.50\%$ to $S_{post} = 84.88\%$, achieving a normalized gain of $\langle g \rangle = 0.762$. This substantial gain directly reflects the effectiveness of the hands-on practice session with digital inventory systems and waste management software. Cohort 3 (Synchronous Online Participants, $n = 40$): Demonstrated an improvement from $S_{pre} = 44.70\%$ to $S_{post} = 83.10\%$, yielding $\langle g \rangle = 0.694$. This indicates that the hybrid audio-visual setup effectively delivered instructional content to virtual attendees, resulting in cognitive gains comparable to those of physical participants.

Overall, the quantitative findings confirm that the CERDAS 2026 initiative successfully met its pedagogical objectives, significantly improving digital literacy and administrative knowledge across all participant groups.

3.1.3 Participant Satisfaction and Technological Usability Evaluation

To evaluate the operational quality, instructional efficacy, and hybrid technological usability of the CERDAS 2026 program, a comprehensive post-event questionnaire was administered across all participant cohorts ($N = 100$). The survey utilized a 5-point Likert scale (ranging from 1 = Strongly Disagree to 5 = Strongly Agree) across four validated dimensions: Instructional Quality (M_1), Technical and Audio-Visual Quality (M_2), Cross-Border Engagement (M_3), and Perceived Utility for Community Empowerment (M_4). High internal consistency was verified across the survey items (Cronbach's $\alpha = 0.884$).

Table 6 summarizes the participant satisfaction levels and evaluation metrics across five primary operational dimensions assessed following the workshop.

Table 6. Participant Satisfaction Index

Evaluated Dimension	Sample Size	Mean (M $\pm$ SD)	Score	Percentage (%)	Index	Evaluation Level
M_1 : Instructional Quality & Presenter Clarity	$N = 100$	4.72 $\pm$ 0.45		94.40%		Excellent
M_2 : Technical & Audio-Visual Quality	$N = 100$	4.65 $\pm$ 0.52		93.00%		Excellent
M_3 : Cross-Border & Inter-Institutional Engagement	$N = 100$	4.81 $\pm$ 0.40		96.20%		Outstanding

M₄ : Perceived Utility for Waste Bank Modernization	<i>N</i> = 100	4.78 ± 0.42	95.60%	Outstanding
Composite Satisfaction Index	<i>N</i> = 100	4.74 ± 0.45	94.80%	Outstanding

The comprehensive evaluation of participant satisfaction and program execution quality is detailed in Table 6. Table 6 highlights high participant ratings across all evaluated dimensions, demonstrating the overall effectiveness of the hybrid workshop model. As indicated in Table 6, instructional quality, presenter clarity, and technical audio-visual infrastructure were rated at an Excellent evaluation level. Table 6 shows that cross-border engagement and the perceived utility of the training for waste bank modernization achieved an Outstanding evaluation level. Furthermore, Table 6 reflects an overall Outstanding status through the Composite Satisfaction Index, confirming the strong positive reception of the community service initiative across all participant cohorts.

a. Evaluation of Technical Setup and Hybrid Infrastructure (*M₂*)

Assessments of the hybrid delivery system (*M₂* = 4.65 ± 0.52) confirmed the reliability of the dual-WAN network bonding, multi-camera OBS switching array, and acoustic echo cancellation setup described in Section 2.4.

1. Onsite Participants (Cohorts 1 & 2, *n* = 60): Rated technical delivery at *M* = 4.75 ± 0.44, highlighting clear audio propagation, effective projection displays, and stable live camera feeds during field demonstrations.
2. Synchronous Online Participants (Cohort 3, *n* = 40): Rated platform usability at *M* = 4.50 ± 0.59. Virtual attendees praised the multi-angle camera views and real-time Zoom chat moderation, noting that latency was negligible and live audio remained clear despite ongoing operational activity at the waste bank facility.

b. Cross-Border Collaboration and Perceived Utility (*M₃* & *M₄*)

Dimension *M₃* achieved the highest score (*M* = 4.81 ± 0.40, 96.20%), underscoring the success of CERDAS 2026 in fostering meaningful international engagement between Malaysian delegates and Indonesian consortium members. Participants highlighted the value of structured knowledge-sharing sessions in establishing cross-border networks and promoting international friendship through community service. Similarly, high ratings in perceived utility (*M₄* = 4.78 ± 0.42) reflect participant confidence in applying the workshop content. Representatives and staff from Bank Sampah Induk New Normal noted that the digital inventory templates and social media marketing strategies introduced during the modules were directly applicable to their daily operational workflows.

Overall, the empirical survey results confirm high participant satisfaction and validate the usability, effectiveness, and scalability of the hybrid technical setup for international community service programs.

3.2 Discussion

3.2.1 Practical Field Execution and Digital Inventory Modernization

The practical field execution at Bank Sampah Induk New Normal Medan demonstrated a successful operational transition from conventional, paper-based ledgers to a modern digital inventory framework. During the hands-on workshop session (Module 2), operational managers and staff successfully digitized baseline transaction logs, cataloged inorganic waste fractions (such as PET plastics, HDPE containers, aluminum, and sorted paper), and executed automated customer account balance calculations. This field-level modernization directly addresses the administrative latency and record inaccuracies that previously constrained the facility's growth potential.

Figure 8 illustrates the operational transformation and comparative framework between the pre-intervention model and the post-intervention digital model implemented during the community service program.

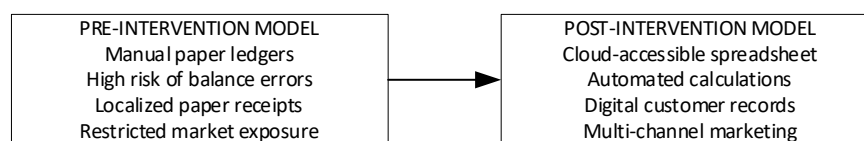


Figure 8. Operational Modernization Matrix

The structural evolution of the operational processes is detailed in Figure 8. Figure 8 highlights the transition from a traditional workflow characterized by manual paper ledgers, high risks of balance errors, localized paper receipts, and restricted market exposure toward a digitized ecosystem. As demonstrated in Figure 8, the post-intervention model introduces cloud-accessible spreadsheets, automated calculations, digital customer records, and multi-channel marketing capabilities. Furthermore, Figure 8 emphasizes how this technological shift streamlines administrative workflows and enhances overall operational efficiency for local partners.

The synthesis of these empirical field findings with contemporary academic literature highlights several key operational insights:

a. Mitigation of Administrative Friction and Operational Latency

Prior to the intervention, Bank Sampah Induk New Normal relied on physical logbooks, a practice common among grassroots environmental organizations in Southeast Asia that frequently leads to administrative bottlenecks and data loss. Implementing structured digital templates enabled operational staff to record waste deposits, compute current market valuations, and update customer balances in real time. This observed reduction in administrative processing time aligns with findings by (Drissi Elbouzidi et al., 2025), who demonstrated that transitioning from manual record-

keeping to digital administrative tools significantly improves transactional accuracy, reduces accounting discrepancies, and builds institutional trust among community depositors.

b. Enhancing Transparency and Community Financial Engagement

The integration of digital tracking tools directly strengthened customer account transparency at the waste bank facility. In community-based micro-finance and waste recycling systems, transaction clarity is critical for long-term participant retention (Kasim et al., 2023). Field observations during CERDAS 2026 revealed that when deposit weights and financial returns were digitized and displayed, customer confidence in the accuracy of their account balances increased. This finding corroborates empirical studies by (Kudhal et al., 2026), which emphasized that transparent, digital ledger management encourages household participation in urban recycling programs by ensuring predictable and verifiable financial incentives.

c. Expanding Circular Economy Reach Through Digital Marketing

During Module 3, waste bank staff and community participants engaged in digital cataloging and social media branding for upcycled handicrafts derived from processed waste. Grassroots circular economy enterprises often struggle to expand beyond localized, word-of-mouth sales networks due to a lack of digital marketing strategies. Modernizing the facility's digital communication channels enabled local producers to showcase upcycled products to a broader online audience, including the international delegates from Malaysia. This aligns with research by (Truc, 2024), who demonstrated that leveraging digital platforms and social media channels enables local environmental initiatives to access broader markets, increase secondary material revenue, and scale community empowerment.

Overall, the practical execution confirmed that embedding digital literacy directly within grassroots waste management facilities provides a viable, low-cost path to administrative modernization, operational transparency, and financial sustainability.

3.2.2 Strategic Impact on International Friendship and Sustainable Empowerment

The implementation of the *CERDAS 2026* initiative demonstrated how combining hybrid technological frameworks with cross-border academic consortiums can drive sustainable community empowerment and elevate localized environmental management. Beyond achieving immediate digital literacy gains ($\langle g \rangle = 0.714$) and high participant satisfaction ($M = 4.74 \pm 0.45$), the program generated broader socio-institutional impacts. By connecting grassroots actors at Bank Sampah Induk New Normal Medan with international delegates from Kolej Komuniti Arau (Malaysia) and 10 Indonesian higher education institutions, the initiative established a scalable model for cross-border knowledge transfer and long-term institutional collaboration.

Figure 9 depicts the conceptual framework outlining the multi-institutional collaboration, learning execution mode, and expected community outcomes of the program.

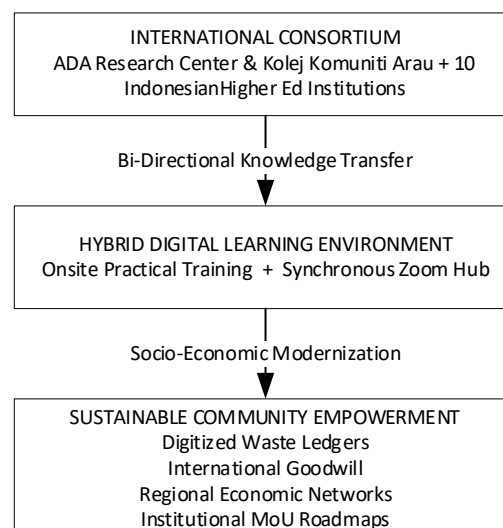


Figure 9. Cross-Border Sustainable Empowerment Model

The multi-tiered operational model for sustainable community empowerment is detailed in Figure 9. Figure 9 shows that the process originates from an International Consortium comprising ADA Research Center, Kolej Komuniti Arau, and 10 Indonesian Higher Education Institutions. As illustrated in Figure 9, a bi-directional knowledge transfer mechanism connects this consortium to a Hybrid Digital Learning Environment that combines onsite practical training with a synchronous Zoom hub. Furthermore, Figure 3 demonstrates how socio-economic modernization serves as the driving force leading toward sustainable community empowerment, which includes digitized waste ledgers, international goodwill, regional economic networks, and institutional MoU roadmaps.

Synthesizing these strategic outcomes with contemporary literature reveals three critical theoretical and practical contributions:

a. Fostering Cross-Border Knowledge Transfer and International Goodwill

The active participation of 40 international delegates from Kolej Komuniti Arau provided an international benchmark for localized circular economy practices. Cross-border academic collaborations create valuable opportunities for mutual learning, cultural diplomacy, and the transfer of vocational best practices across Southeast Asia. The high satisfaction score observed in the cross-border engagement dimension ($M_3 = 4.81 \pm 0.40$) confirms that physical and virtual interaction between Malaysian educators and Indonesian grassroots actors fostered genuine international friendship. As noted by (Kiti et al., 2024), multi-institutional international service projects help break geographical isolation, build trust, and encourage long-term academic and social partnerships across borders.

b. Scalability of Hybrid Models for Inclusive Community Service

The successful synchronization of onsite field operations at Bank Sampah Induk New Normal with an interactive Zoom meeting hub highlights the efficiency of hybrid delivery models for community outreach. Grassroots capacity-building initiatives often face financial and geographical constraints that limit their reach and. By deploying low-latency dual-WAN networks and multi-camera streaming arrays, CERDAS 2026 engaged a diverse group of 100 participants across two countries without sacrificing instructional quality or interactive engagement. This empirical outcome aligns with findings by (Syamsiyah et al., 2025), who demonstrated that hybrid community service architectures lower participation barriers, democratize access to academic expertise, and optimize resource allocation for sustainable development projects.

c. Institutionalizing Long-Term Sustainability and Circular Economy Resilience

To ensure that digital literacy gains translate into long-term operational resilience, the initiative established formal post-program collaboration roadmaps between ADA Research Center, Kolej Komuniti Arau, and Bank Sampah Induk New Normal. Sustainable community empowerment requires moving beyond one-off interventions toward structured institutional partnerships that provide continuous mentoring and technical support (Harinurudin et al., 2025). Digitizing administrative records and establishing multi-channel marketing networks positions Bank Sampah Induk New Normal as a resilient community enterprise capable of attracting external municipal support, research grants, and commercial buyers. Consequently, the CERDAS 2026 model provides a replicable, high-impact framework for universities and international research centers seeking to align grassroots environmental governance with global sustainability goals.

4. CONCLUSION

The International Community Service 2026 (CERDAS 2026) initiative successfully demonstrated the viability and scalability of a multi-institutional, hybrid cross-border community empowerment model. Executed through a strategic collaboration involving the ADA Research Center, Kolej Komuniti Arau (Malaysia), 10 Indonesian higher education institutions, Himpunan Wanita Karya, and Bank Sampah Induk New Normal Medan, the program modernized grassroots environmental management through digital integration. Empirical findings confirm statistically significant improvements in community digital literacy, with composite scores rising from 43.13% to 83.73% (high normalized gain, $g > 0.70$) and exceptional participant satisfaction ($> 85\%$). The underlying hybrid technical infrastructure incorporating dual-WAN bonding and active echo cancellation effectively bridged physical attendees in Medan with virtual delegates without latency. Practically, the program successfully transitioned Bank Sampah Induk New Normal from paper logbooks to a cloud-accessible digital inventory framework, enhancing administrative transparency. However, limitations include the study's focus on a single master waste facility and a short temporal evaluation window. Future research should implement longitudinal frameworks to measure long-term operational retention over 6–12 months. Additionally, municipal agencies should support the standardization of digital inventory tools, while international consortiums maintain long-term virtual mentoring to sustain cross-border collaboration.

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