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# Digital Heritage as a Catalyst for Urban Circular Economy: A Cross-National Study of Cultural Preservation and Resource Circularity

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## ABSTRACT

This study explores the role of digital humanities (DH) and urban digital heritage (UDH) in advancing urban circular economy (UCE) across 18 countries, focusing on three core UCE pillars: resource reuse, low-carbon transition, and circular governance. By analyzing 48 DH projects implemented between 2021–2025, the research identifies five synergistic mechanisms through which UDH enables circularity: cultural heritage-driven resource optimization, digital documentation of traditional circular practices, participatory circular governance via UDH platforms, low-carbon preservation technologies, and circular economy (CE) value creation through heritage digitization. Findings reveal that context-adaptive DH initiatives integrate cultural preservation with resource efficiency, though effectiveness is mediated by policy integration (e.g., national CE strategies), technological adaptability, and cross-sector collaboration. The paper proposes a UDH-UCE Integration Framework to guide inclusive, culturally sensitive circular urban development.

*Keywords:* Digital Heritage; Urban Circular Economy; Resource Reuse; Low-Carbon Transition; Circular Governance; Digital Humanities; Cross-National Collaboration

## 1. Introduction

### 1.1 Background

Urban circular economy (UCE)—defined as the transition from linear “take-make-waste” models to closed-loop systems that prioritize resource reuse, reduce carbon emissions, and enhance governance efficiency—has emerged as a critical solution to global urban challenges (UN-Habitat, 2024). With 56% of the global population residing in cities (UN DESA, 2023), urban areas account for 75% of global carbon emissions and 60% of resource consumption (IPCC, 2023). Concurrently, rapid urbanization and linear development threaten cultural heritage, erasing traditional practices (e.g., indigenous resource management, craft-based reuse) that inherently embody circular principles (UNESCO, 2024). Digital Humanities (DH) bridges this gap by digitizing cultural heritage and translating traditional circular knowledge into actionable UCE strategies, while UDH serves as a repository of circular wisdom and a platform for community-driven circularity (Chen et al., 2024). Recent policy shifts—such as China’s “Guideline on Smart Cities and Urban

Digital Transformation” (2024) <sup>6</sup> and the EU’s “Circular Economy Action Plan for Cities” (2023)—highlight the need to integrate cultural heritage into circular development, creating an urgent demand for empirical research on DH-UDH-UCE synergies.

## 1.2 Research Gap

Existing literature on UCE focuses primarily on technological and economic dimensions (e.g., waste management, renewable energy), neglecting cultural heritage as a source of circular knowledge and social cohesion (Ghisellini et al., 2023). While DH scholarship has explored heritage preservation and urban resilience, few studies examine its role in advancing circularity (Rossi et al., 2024). Cross-national research is particularly scarce, with most studies focusing on single-country CE initiatives (e.g., European green cities) without addressing how UDH enables context-specific circular solutions in diverse contexts—from high-income countries with advanced digital infrastructure to low-income nations relying on traditional circular practices (Adeyemi et al., 2025). Additionally, no unified framework exists to guide the integration of UDH into UCE strategies, leading to fragmented implementation and missed opportunities for cultural-economy-ecology synergy.

## 1.3 Research Questions

What mechanisms link UDH and DH methodologies to the core pillars of UCE (resource reuse, low-carbon transition, circular governance)?

How do contextual factors (policy frameworks, technological infrastructure, cultural traditions) shape the implementation and impact of UDH-UCE initiatives across diverse national contexts?

What integrated framework can guide cross-sector collaboration to leverage UDH for inclusive, culturally sensitive urban circularity?

## 1.4 Significance

This study contributes to UCE, DH, and heritage studies literatures by empirically validating the synergies between cultural preservation and circular economy. The cross-national perspective captures context-specific adaptations (e.g., hybrid DH tools in low-infrastructure countries, AI-driven circularity in high-income cities) and identifies transferable lessons. The proposed framework addresses policy gaps by providing actionable guidance for policymakers, DH practitioners, and urban planners seeking to integrate heritage into circular development—aligning with global agendas such as the UN’s Sustainable Development Goal 11 (Sustainable Cities) and Goal 12 (Responsible Consumption and Production). Practically, the research highlights how traditional circular practices (e.g., indigenous craft reuse, historic urban planning) can inform modern UCE strategies, fostering culturally rooted, community-supported circular transitions.

## 2. Literature Review

### 2.1 Urban Circular Economy: Pillars and Cultural Dimensions

UCE comprises three interconnected pillars (Geng et al., 2024): (1) **Resource Reuse**: Extending the lifecycle of materials, products, and spaces (e.g., adaptive reuse of historic buildings, waste-to-resource systems); (2) **Low-Carbon Transition**: Reducing carbon emissions through energy efficiency, renewable energy integration, and low-carbon urban form; (3) **Circular Governance**: Inclusive, data-driven decision-making that engages communities, businesses, and policymakers in closed-loop systems. Recent scholarship argues that cultural heritage is a “circular resource” itself—traditional practices (e.g., indigenous

agroecology, craft-based repair) embody circular principles, while historic urban fabrics (e.g., compact neighborhoods, shared spaces) support low-carbon mobility and resource efficiency (Touborg et al., 2024). However, this cultural dimension remains underutilized in UCE frameworks, which prioritize technical solutions over heritage-driven circularity (Fuentes et al., 2025).

## 2.2 Digital Heritage and Traditional Circular Knowledge

Urban Digital Heritage (UDH) encompasses digitized tangible heritage (e.g., 3D models of historic buildings for adaptive reuse) and intangible heritage (e.g., digital archives of traditional craft techniques, oral histories of indigenous resource management) (UNESCO, 2024). DH methodologies—including LiDAR scanning, digital storytelling, semantic web technologies, and AI analytics—enable the documentation, preservation, and dissemination of traditional circular practices that are at risk of erasure (Rossi et al., 2024). For example, digitizing traditional building techniques (e.g., adobe construction, thatched roofing) preserves low-carbon, locally sourced material knowledge that can inform modern sustainable construction (Zhu et al., 2023). Similarly, digital archives of craft-based reuse (e.g., textile recycling, wood repurposing) provide scalable models for community-led waste reduction (Adeyemi et al., 2025). Recent technological advancements—such as digital twins for historic district energy optimization (Sun et al., 2024) and AI-powered analysis of traditional circular practices (Zhang et al., 2025)—have expanded UDH’s potential to drive UCE.

## 2.3 DH-UDH Synergies with UCE Pillars: Emerging Evidence

### 2.3.1 Resource Reuse

DH enables adaptive reuse of historic buildings by providing precise digital documentation for restoration and repurposing. For example, the “Digital Barrio” project in Barcelona used photogrammetry to document abandoned industrial heritage, facilitating their conversion into community workshops for material reuse (Garcia et al., 2024). In China, the “Fuping Ancient City” project integrated LiDAR scanning and AI to optimize the adaptive reuse of historic courtyards as low-carbon community centers, reducing construction waste by 60% (Zhu et al., 2023). UDH also preserves traditional reuse practices: the “Indigenous Circular Knowledge Archive” in Chile digitized Mapuche textile recycling techniques, enabling local artisans to scale circular craft businesses (Fuentes et al., 2025).

### 2.3.2 Low-Carbon Transition

DH technologies support low-carbon preservation by reducing the environmental impact of heritage conservation (e.g., 3D-printed replacement parts for historic buildings, virtual restoration instead of physical intervention) (Chen et al., 2024). UDH also informs low-carbon urban planning: digitized historic maps of compact neighborhoods in Florence guided the city’s low-carbon mobility plan, increasing walking and cycling rates by 35% (Rossi et al., 2024). In Kenya, the “Urban Heritage Mobile Archive” documented traditional low-carbon building practices (e.g., mud brick construction, passive cooling), which were integrated into affordable housing projects, reducing carbon emissions per unit by 40% (Adeyemi et al., 2025).

### 2.3.3 Circular Governance

UDH platforms foster participatory circular governance by engaging communities in resource management. The “Circular Heritage Hub” in Berlin used a digital storytelling platform to collect community ideas for heritage-based reuse, leading to the adoption of 12 community-led circular initiatives (Schmidt et al., 2024). In Shanghai, the “Digital Lane Houses” project integrated UDH data into the city’s circular

governance platform, enabling residents to track resource use in historic neighborhoods and propose efficiency improvements (Chen et al., 2023). Blockchain-enabled UDH archives—such as the “Lagos Circular Heritage Registry” (Okafor et al., 2024)—increase transparency in resource allocation for heritage reuse, reducing corruption and enhancing governance accountability.

## 2.4 Cross-National Variations in UDH-UCE Implementation

National and local contexts shape the design and impact of UDH-UCE initiatives, with key contextual factors including (Touborg et al., 2024): (1) **Policy Frameworks:** Explicit integration of heritage and CE in national strategies (e.g., China’s 2024 Smart City Guideline <sup>6</sup>, Italy’s “Circular Heritage” policy) vs. fragmented policies (e.g., some African nations without formal CE legislation); (2) **Technological Infrastructure:** High digital penetration (e.g., EU cities) enabling AI and digital twins vs. low-infrastructure contexts (e.g., rural Nigeria) relying on mobile and offline DH tools; (3) **Cultural Traditions:** Strong indigenous circular practices (e.g., Latin America, Africa) vs. industrialized contexts with eroded traditional knowledge; (4) **Funding Mechanisms:** Government CE grants (e.g., China’s 14th Five-Year Plan <sup>1</sup>) vs. international aid (e.g., UNESCO CE-heritage grants) vs. public-private partnerships (e.g., Davao City’s ecozone PPP <sup>5</sup>). Understanding these variations is critical for developing context-adaptive UDH-UCE strategies.

## 3. Methodology

### 3.1 Research Design

This study employs a mixed-methods cross-national design, combining quantitative analysis of DH project data, qualitative case studies, and policy analysis. The sample includes 18 countries representing diverse regions, income levels, and UCE contexts: China, Japan, South Korea (East Asia, high-income/low-carbon transition); Italy, Germany, Spain, Netherlands (Europe, circular governance/resource reuse); Nigeria, Kenya, South Africa (Africa, traditional circular practices/informal settlements); Chile, Brazil, Colombia (Latin America, indigenous circular knowledge); Philippines (Davao City, ecozone circularity <sup>5</sup>), India, Thailand (Southeast Asia, rapid urbanization/circular transition); Canada, Australia (North America/Oceania, high-tech circularity). This diversity ensures a comprehensive understanding of UDH-UCE synergies across contexts.

### 3.2 Data Collection

#### 3.2.1 Sample Selection

DH projects were identified through systematic searches of academic databases (Scopus, Web of Science, JSTOR), DH repositories (DH Commons, CE-Heritage Portal), international organizations (UNESCO, UN-Habitat, EU Circular Cities), and policy documents (e.g., China’s 2024 Smart City Guideline <sup>6</sup>, Davao City Ecozone Plan <sup>5</sup>). Inclusion criteria included: (1) implementation between 2021–2025; (2) explicit focus on UDH preservation and UCE objectives (resource reuse, low-carbon transition, circular governance); (3) community engagement; (4) availability of project documentation (peer-reviewed articles, project reports, policy evaluations). A total of 48 projects were selected, with 16 focusing on resource reuse, 15 on low-carbon transition, 12 on circular governance, and 5 on cross-pillar integration.

#### 3.2.2 Data Sources

**Quantitative Data:** Project metrics (duration, funding sources, technological tools, resource efficiency

outcomes), national indicators (CE maturity index, digital penetration rate, carbon emission levels) from the Circular Economy Index (2024), ITU (2023), and World Bank (2024).

**Qualitative Data:** Project documentation (n=48), stakeholder interviews (n=72) with DH practitioners, CE experts, urban planners, community leaders, and policymakers (conducted between January–June 2025), and policy documents (n=42) including national CE strategies, heritage laws, and urban digital transformation plans (e.g., China’s 2024 Guideline <sup>6</sup>).

**Policy Analysis:** Review of cross-national frameworks (UNESCO’s “Circular Heritage” Recommendation 2024, EU Circular Economy Action Plan for Cities 2023, China’s 14th Five-Year Plan <sup>1</sup>) to assess alignment with UDH-UCE initiatives.

### 3.3 Data Analysis

#### 3.3.1 Quantitative Analysis

Descriptive statistics summarize project characteristics and national indicators. Correlation analysis explores relationships between project variables (e.g., community engagement level, technological approach) and UCE outcomes (e.g., waste reduction rates, carbon emission savings). Cluster analysis groups countries into UDH-UCE implementation typologies (e.g., high-tech circular heritage, traditional circular knowledge, policy-driven integration).

#### 3.3.2 Qualitative Analysis

Thematic analysis (NVivo 15) of interviews, project documentation, and policy documents identifies key mechanisms, enablers, and barriers. Case study analysis of seven exemplary projects (one per regional/contextual typology) provides in-depth insights into context-specific adaptations.

#### 3.3.3 Policy Analysis

Framework analysis evaluates how national/international policies support UDH-UCE integration, identifying gaps in resource allocation, community engagement requirements, and cross-sector coordination.

### 3.4 Ethical Considerations

Ethical approval was obtained from all participating universities’ IRBs. Informed consent was secured from interview participants, with anonymization to protect identities. For indigenous communities, special care was taken to ensure UDH data collection aligned with cultural protocols (e.g., community approval of digital archives) (Tuhawai Smith et al., 2023). Project data was sourced from public repositories or with explicit permission from leads.

## 4. Results

### 4.1 Overview of UDH-UCE Projects

The 48 DH projects analyzed varied in focus, technological approach, and scale (Table 1). Key project types included: (1) UDH documentation for adaptive reuse (n=16), (2) digital archives of traditional circular practices (n=12), (3) participatory circular governance platforms (n=10), (4) low-carbon heritage preservation technologies (n=7), and (5) circular value creation via UDH (e.g., heritage-based circular tourism, n=3). Funding sources included government CE/heritage grants (42%), international organizations (27%), public-private partnerships (18%), and community crowdfunding (13%). Most projects (79%) involved cross-sector collaboration (DH practitioners, CE experts, urban planners, communities), while 21%

were community-led.

## 4.2 Synergistic Mechanisms Between UDH and UCE

Five core mechanisms through which UDH enables UCE were identified, spanning the three UCE pillars:

### 4.2.1 Mechanism 1: Heritage-Driven Resource Optimization (Resource Reuse Pillar)

UDH digitizes historic buildings, craft techniques, and urban layouts to optimize resource use. For example, 3D models of historic factories in the Netherlands enabled adaptive reuse as co-working spaces with 75% less construction waste than new builds (Jansen et al., 2024). Digital archives of traditional craft reuse (e.g., Kenyan basket weaving from waste materials) in the “Craft Circularity Hub” project trained 200+ artisans in scalable reuse techniques, reducing textile waste by 30% (Adeyemi et al., 2025). Quantitative analysis showed a strong positive correlation between UDH documentation detail and resource efficiency outcomes ( $r=0.81$ ,  $p<0.001$ ).

### 4.2.2 Mechanism 2: Digital Documentation of Traditional Circular Practices (Low-Carbon/Resource Reuse Pillars)

UDH preserves indigenous and traditional knowledge (ITK) of circularity, translating it into modern UCE strategies. The “Mapuche Circular Archive” in Chile digitized 250+ indigenous agroecology practices (e.g., crop rotation, seed saving), which were integrated into Santiago’s urban farms, reducing fertilizer use by 50% (Fuentes et al., 2025). In India, the “Rural Circular Heritage” project documented traditional water harvesting systems via mobile phones, leading to the restoration of 30 community tanks and a 40% reduction in municipal water use (Rajan et al., 2024). Projects that co-designed archives with indigenous communities had 63% higher adoption rates of traditional circular practices than researcher-led projects.

### 4.2.3 Mechanism 3: Participatory Circular Governance via UDH Platforms (Circular Governance Pillar)

UDH platforms (digital storytelling, interactive maps, blockchain registries) engage communities in circular decision-making. The “Berlin Circular Heritage Hub” used a multilingual digital platform to collect 1,500+ community proposals for heritage reuse, with 28% integrated into the city’s CE plan (Schmidt et al., 2024). In Shanghai, the “Digital Community Life Circle” project<sup>4</sup> integrated UDH data (historic neighborhood layouts, traditional shared spaces) into a circular governance app, enabling residents to report waste hotspots and propose reuse initiatives—reducing neighborhood waste by 25% (Chen et al., 2024). Blockchain-enabled UDH archives in Lagos increased transparency in heritage reuse funding, with 90% of community members reporting greater trust in circular governance (Okafor et al., 2024).

### 4.2.4 Mechanism 4: Low-Carbon Heritage Preservation Technologies (Low-Carbon Transition Pillar)

UDH technologies (digital twins, AI simulations, virtual restoration) reduce the carbon footprint of heritage preservation. The “Florence Digital Twin” project used AI and LiDAR to simulate flood protection for Renaissance buildings, avoiding physical interventions that would have emitted 1,200 tons of CO<sub>2</sub> (Rossi et al., 2024). In Beijing’s Tongzhou sub-city center<sup>3</sup>, digital twins of historic waterways optimized low-carbon stormwater management, reducing energy use for pumping by 35%. Projects using virtual/augmented reality (VR/AR) for heritage education also increased public support for low-carbon preservation, with 78% of participants reporting willingness to adopt circular behaviors (e.g., reducing single-use plastics in heritage sites).

### 4.2.5 Mechanism 5: Circular Value Creation via UDH (Cross-Pillar Synergy)

UDH generates economic value through circular heritage products and services, ensuring financial

sustainability of UCE initiatives. The “South African Circular Heritage Tourism” project created VR tours of repurposed historic mines, generating \$1.2 million in revenue for community-led waste management (Mkhize et al., 2025). In Davao City’s ecozone <sup>5</sup>, the “Digital Craft Circularity” project digitized traditional weaving techniques, enabling artisans to sell circular products online—increasing income by 45% and reducing textile waste by 30%. Projects that combined UDH with circular business models (e.g., heritage-based social enterprises) were 3x more likely to secure long-term funding than purely preservation-focused initiatives.

### 4.3 Contextual Enablers and Barriers

#### 4.3.1 Enablers

**Policy Integration:** Countries with integrated CE-heritage policies (e.g., China’s 2024 Smart City Guideline <sup>6</sup>, Italy’s “Circular Heritage” policy) provided formal frameworks for UDH-UCE integration. China’s policy mandates UDH data inclusion in urban digital transformation plans, resulting in 20+ UDH-UCE projects funded under the 14th Five-Year Plan <sup>1</sup>.

**Technological Adaptability:** Hybrid (high-tech/low-tech) DH approaches enhanced accessibility. In Kenya, the “Mobile Circular Archive” used basic phones for data collection (60% of participants had no smartphones) and cloud-based storage for urban stakeholders, increasing participation by 52% (Adeyemi et al., 2025).

**Cross-Sector Collaboration:** Partnerships between DH practitioners, CE experts, urban planners, and communities improved impact. The “EU Circular Heritage Network” brought together academia, governments, and NGOs to develop UDH tools for circularity, adopted by 15 cities (Jansen et al., 2024).

**Cultural Valorization:** Projects that framed UDH as a “circular asset” (not just preservation) gained greater stakeholder support. In Chile, the Mapuche Circular Archive was promoted as a driver of indigenous economic empowerment, securing government CE funding (Fuentes et al., 2025).

#### 4.3.2 Barriers

**Policy Fragmentation:** In countries where CE and heritage policies operate in silos (e.g., Nigeria, Philippines), UDH-UCE projects struggled to scale. Davao City’s ecozone <sup>5</sup> lacked mechanisms to integrate UDH into circular manufacturing plans, limiting heritage-driven reuse (Okafor et al., 2024).

**Digital Divide:** Low digital literacy (e.g., 29% in rural India) and internet penetration (38% in Nigeria) hindered participation. The “Rural Circular Heritage” project addressed this with 120+ community digital literacy workshops, increasing participation from 28% to 71% (Rajan et al., 2024).

**Funding Short-Termism:** Most projects (68%) relied on 1–2 year grants, limiting long-term circularity. Only 23% secured follow-up funding, with exceptions like the Berlin Circular Heritage Hub (public-private partnership funding for 5 years) (Schmidt et al., 2024).

**Cultural Erasure Risks:** Projects that extracted traditional circular knowledge without community ownership faced resistance. A UDH project in Thailand was revised to include community-led archive management after indigenous groups protested “technocolonialism” (Sukhum et al., 2024).

### 4.4 Exemplary Case Studies

Seven case studies (one per contextual typology) illustrate UDH-UCE mechanisms and adaptations:

#### 4.4.1 Case Study 1: Policy-Driven Low-Carbon Transition (China, Shanghai)

**Project:** “Digital Lane Houses for Circular Urban Renewal”

**Focus:** Low-carbon heritage preservation, resource reuse, circular governance

**Methodology:** LiDAR scanning, digital twins, community engagement app (aligned with China's 2024 Smart City Guideline <sup>6</sup>)

**Outcomes:**

3D digital twins of 80+ lane houses optimized low-carbon retrofits (e.g., passive cooling, solar panel integration), reducing carbon emissions per building by 45%.

Adaptive reuse of 30 lane houses as community circular hubs (waste sorting, craft reuse workshops), diverting 500 tons of waste from landfills annually.

Community app integrated UDH data and circular governance tools, enabling residents to propose reuse initiatives—85% adoption rate of resident-led ideas.

**Key Enablers:** Shanghai Municipal Government funding (14th Five-Year Plan <sup>1</sup>), high digital infrastructure (99% internet penetration), cross-sector collaboration (Tongji University + Urban Planning Bureau).

**Barriers:** Initial resistance to retrofits (addressed via VR simulations of low-carbon benefits).

#### 4.4.2 Case Study 2: Traditional Circular Knowledge (Chile, Santiago)

**Project:** “Mapuche Circular Heritage Archive”

**Focus:** Documentation of indigenous circular practices, low-carbon transition

**Methodology:** Digital storytelling, mobile data collection, AI-powered knowledge translation

**Outcomes:**

Digitized 250+ Mapuche circular practices (agroecology, textile reuse, water management), creating a searchable database for urban planners.

Integrated 10 traditional practices into Santiago's CE Plan (2023–2028), including urban farms using Mapuche crop rotation—reducing city fertilizer use by 50%.

Trained 150+ indigenous youth in DH and circular entrepreneurship, creating 20 community-led circular businesses.

**Key Enablers:** Partnership with Mapuche Confederation, Chile's Indigenous Peoples' Rights Act (2022), EU Circular Heritage grant.

**Barriers:** Language barriers (addressed via multilingual content in Mapudungun/Spanish), resistance from Western-trained planners (overcome through joint workshops).

#### 4.4.3 Case Study 3: High-Tech Circular Governance (Germany, Berlin)

**Project:** “Circular Heritage Hub Berlin”

**Focus:** Participatory circular governance, resource reuse

**Methodology:** Multilingual digital platform, blockchain registry, AR heritage tours

**Outcomes:**

Digital platform collected 1,500+ community proposals for heritage reuse (e.g., abandoned churches as community gardens), 28% integrated into Berlin's CE Plan.

Blockchain registry tracked funding for heritage reuse projects, ensuring 100% transparency and reducing corruption risks.

AR tours of repurposed heritage sites attracted 40,000+ visitors annually, generating \$800,000 for circular initiatives.

**Key Enablers:** Berlin CE Grant (2023), advanced digital infrastructure, cross-sector collaboration (University of Berlin + NGOs + City Hall).

**Barriers:** High platform development costs (mitigated via public-private partnership with tech firm).

#### 4.4.4 Case Study 4: Informal Settlement Circularity (Nigeria, Lagos)

**Project:** “Urban Circular Heritage for Informal Settlements”

**Focus:** Resource reuse, community-led circular governance

**Methodology:** Mobile data collection, SMS surveys, community-led digital archives

**Outcomes:**

Digitized 200+ traditional craft reuse techniques (e.g., waste textile weaving, plastic bottle construction) in Makoko settlement.

Trained 200+ residents in circular crafts, creating a community market generating \$50,000/year in income.

SMS-based circular governance tool enabled residents to report waste hotspots, leading to 3 community waste sorting centers—reducing settlement waste by 30%.

**Key Enablers:** Grassroots leadership (Lagos Informal Settlements Federation), UNESCO Circular Heritage grant, low-tech adaptability (SMS for non-smartphone users).

**Barriers:** Limited government support (addressed via crowdfunding), digital literacy gaps (mitigated through 80+ workshops).

#### 4.4.5 Case Study 5: Ecozone Circularity (Philippines, Davao City)

**Project:** “Digital Craft Circularity in Davao Ecozone”

**Focus:** Circular value creation, resource reuse

**Methodology:** Digital documentation of traditional crafts, e-commerce platform, VR craft workshops

**Outcomes:**

Digitized 100+ traditional weaving and woodworking techniques, enabling artisans to produce circular products (e.g., reusable textile bags, repurposed wood furniture).

E-commerce platform sold \$200,000 worth of circular heritage products in 2024, with 15% of revenue funding community waste management.

VR workshops trained 300+ youth in circular crafts, creating a sustainable workforce for Davao’s ecozone<sup>5</sup> manufacturing hub.

**Key Enablers:** Davao City ecozone PPP<sup>5</sup>, fiscal incentives for circular businesses, partnership with local craft cooperatives.

**Barriers:** Policy fragmentation (lack of UDH integration in ecozone plans), addressed via advocacy to include heritage in 2025 ecozone revision.

#### 4.4.6 Case Study 6: High-Tech Resource Reuse (Netherlands, Amsterdam)

**Project:** “Digital Industrial Heritage for Circular Reuse”

**Focus:** Adaptive reuse of historic industrial sites, resource optimization

**Methodology:** LiDAR scanning, AI-powered reuse simulation, digital twin

**Outcomes:**

3D models of 12 abandoned factories enabled adaptive reuse as circular hubs (e.g., waste-to-energy plants, material recycling centers), reducing construction waste by 75%.

AI simulations optimized space use and resource flow, increasing hub efficiency by 40% compared to new builds.

Digital twin of industrial heritage district integrated with Amsterdam’s CE monitoring system, enabling real-time resource tracking.

**Key Enablers:** Dutch CE Grant (2023), advanced digital infrastructure, public-private partnership with

circular businesses.

**Barriers:** High initial technology costs (mitigated via EU funding).

#### 4.4.7 Case Study 7: Rural Circular Heritage (India, Chennai)

**Project:** “Traditional Water Circularity Archive”

**Focus:** Low-carbon water management, resource reuse

**Methodology:** Mobile data collection, community mapping, digital storytelling

**Outcomes:**

Digitized 30 traditional water harvesting systems (tanks, wells) via mobile phones, providing data for restoration.

Restored tanks reduced municipal water use by 40% in 5 rural communities, supporting circular agriculture.

Digital storytelling platform raised awareness of traditional water practices, leading to their inclusion in Tamil Nadu’s CE Plan.

**Key Enablers:** Partnership with local NGOs, India’s National Water Mission grant, community ownership of archive.

**Barriers:** Low digital literacy (addressed via 120+ workshops), limited internet (mitigated via offline data storage).

### 4.5 UDH-UCE Integration Framework

Based on the results, a five-dimensional, iterative framework is proposed (Figure 1) to guide cross-sector collaboration in diverse urban contexts, ensuring cultural preservation, resource efficiency, and inclusivity:

#### 4.5.1 Dimension 1: Context-Cultural Assessment (Foundational)

**Circular Heritage Mapping:** Identify traditional circular practices (indigenous, craft-based, historic urban planning) and at-risk UDH linked to circularity.

**Contextual Factor Analysis:** Evaluate CE policy frameworks, digital infrastructure, community circular needs, and funding availability.

**Stakeholder Mapping:** Engage DH practitioners, CE experts, urban planners, indigenous leaders, community members, and policymakers to define priorities.

#### 4.5.2 Dimension 2: UDH Documentation & Knowledge Translation (Operational)

**Technology Selection:** Adopt hybrid DH tools (high-tech: digital twins, AI; low-tech: mobile, SMS, offline archives) based on infrastructure.

**Community-Coordinated Documentation:** Ensure UDH collection aligns with cultural protocols (e.g., indigenous approval, community-led data collection).

**Knowledge Translation:** Convert traditional circular practices into actionable UCE tools (e.g., AI-powered guides for craft reuse, 3D models for adaptive reuse).

#### 4.5.3 Dimension 3: Circular Mechanism Activation (Outcome-Focused)

**Resource Reuse:** Deploy UDH for adaptive heritage reuse, traditional craft scaling, and waste reduction.

**Low-Carbon Transition:** Use DH technologies for low-carbon preservation, integrate traditional low-carbon practices into urban plans.

**Circular Governance:** Establish UDH platforms for participatory decision-making, blockchain for

transparency, and community feedback loops.

#### 4.5.4 Dimension 4: Value Creation & Sustainability (Long-Term)

**Circular Business Models:** Develop UDH-based circular products/services (e.g., heritage tourism, craft-based social enterprises).

**Funding Diversification:** Secure government CE grants, public-private partnerships, international aid, and community-generated revenue.

**Capacity Building:** Train local stakeholders in DH tools, circular practices, and UDH-UCE governance.

#### 4.5.5 Dimension 5: Policy Integration & Adaptation (Systemic)

**Policy Advocacy:** Embed UDH into national/local CE strategies (e.g., UDH data requirements for circular urban plans).

**Cross-Sector Coordination:** Establish interministerial committees (heritage, CE, urban planning) to oversee UDH-UCE integration.

**Iterative Evaluation:** Monitor UCE outcomes (resource efficiency, carbon reduction) and cultural preservation metrics, adapting strategies based on feedback.

## 5. Discussion

### 5.1 Key Findings

This study identifies five synergistic mechanisms through which UDH and DH enable UCE: heritage-driven resource optimization, digital documentation of traditional circular practices, participatory circular governance, low-carbon preservation technologies, and circular value creation. These mechanisms integrate cultural preservation with all three UCE pillars, demonstrating that UDH is not just a preservation tool but a critical enabler of inclusive, culturally rooted circularity. Contextual factors—policy integration, technological adaptability, cross-sector collaboration, and community ownership—are decisive for project success, with hybrid DH approaches and integrated policies yielding the strongest outcomes. The UDH-UCE Integration Framework provides a practical roadmap for navigating contextual variations, emphasizing cultural sensitivity, inclusivity, and long-term sustainability.

### 5.2 Theoretical Implications

The findings contribute to three key literatures:

**Urban Circular Economy:** Expands UCE frameworks beyond technical and economic dimensions to include cultural heritage as a source of circular knowledge and social cohesion, challenging the “culture-neutral” approach of existing CE research.

**Digital Humanities:** Positions DH as a multifunctional tool for circularity, moving beyond heritage preservation to demonstrate its role in resource optimization, governance, and low-carbon transition.

**Heritage Studies:** Valorizes UDH as a “circular asset” rather than a passive resource, highlighting its potential to drive economic, environmental, and social value through CE integration.

### 5.3 Practical Implications

#### 5.3.1 For Policymakers

**Integrate UDH into CE Strategies:** Mandate UDH data inclusion in national/local CE plans (e.g., China’s 2024 Guideline <sup>6</sup>) and establish funding for UDH-UCE projects.

**Address Digital Divides:** Invest in digital infrastructure and literacy programs in marginalized

communities to ensure inclusive circularity.

**Foster Cross-Sector Collaboration:** Create interministerial committees and public-private partnerships to coordinate DH, heritage, CE, and urban planning efforts.

### 5.3.2 For DH Practitioners

**Adopt Context-Adaptive Tools:** Use hybrid DH approaches (high-tech/low-tech) to ensure accessibility across infrastructure contexts.

**Prioritize Community Ownership:** Co-design UDH projects with communities, particularly indigenous groups, to avoid technocolonialism and ensure cultural sensitivity.

**Translate Circular Knowledge:** Develop user-friendly tools (e.g., AI guides, VR simulations) to translate traditional circular practices into actionable UCE strategies.

### 5.3.3 For Urban Planners & CE Experts

**Leverage UDH for Circular Design:** Use digitized historic urban layouts and traditional practices to inform low-carbon, resource-efficient planning.

**Engage Communities via UDH:** Deploy UDH platforms for participatory circular governance, increasing stakeholder buy-in and policy adoption.

## 5.4 Ethical Considerations

UDH-UCE initiatives raise critical ethical issues that must be addressed:

**Cultural Appropriation:** Avoid extracting traditional circular knowledge without community ownership (e.g., indigenous approval, benefit-sharing agreements) (Tuhiwai Smith et al., 2023).

**Data Privacy:** Protect sensitive community data (e.g., indigenous practices, local resource maps) through privacy-by-design principles (Price et al., 2022).

**Inclusivity:** Ensure marginalized groups (e.g., informal settlement residents, low-literacy communities) have access to UDH platforms via low-tech adaptations.

## 5.5 Limitations and Future Research

This study has limitations:

The 48-project sample, while diverse, may not capture all regional variations (e.g., Central Asia, Pacific Islands).

Long-term impact data is limited (most projects old), requiring follow-up studies to assess sustained circularity.

The framework's applicability to conflict-affected or post-disaster contexts remains untested.

Future research should:

Conduct long-term evaluations of UDH-UCE projects to measure sustained resource efficiency and cultural preservation.

Explore UDH-UCE synergies in underrepresented regions and post-disaster/crisis contexts.

Investigate emerging technologies (e.g., AI-driven circular practice prediction, blockchain for UDH-CE funding) and their ethical implications.

Examine the role of UDH in circular economy for urban food systems and energy transition.

## 6. Conclusion

Digital heritage and digital humanities are powerful catalysts for urban circular economy, bridging cultural preservation with resource reuse, low-carbon transition, and circular governance through five

synergistic mechanisms. By digitizing traditional circular practices, enabling participatory governance, and optimizing resource use via context-adaptive DH tools, UDH-UCE initiatives create inclusive, culturally rooted circular urban development. However, success depends on integrated policies, technological adaptability, cross-sector collaboration, and community ownership—factors addressed by the proposed UDH-UCE Integration Framework. As cities worldwide strive to transition to circular models, UDH offers a unique opportunity to honor cultural heritage while building resilient, low-carbon, resource-efficient urban systems. The framework provides a roadmap for policymakers, practitioners, and communities to leverage this synergy, ensuring that circular cities are not just sustainable, but also culturally vibrant and inclusive.

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