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ESTIMATING THE CONSTRUCTION INDUSTRY'S USE OF BUILDING INFORMATION MODELLING (BIM) TECHNOLOGY FOR WASTE PREVENTION: IDENTIFYING CRITICAL STAKEHOLDER EXPECTATIONS

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Abstract

The necessity of utilizing Building Information Modelling (BIM) to reduce Construction and Demolition Waste (CDW) is well-documented; however, the majority of the current CDW administration tools do not yet possess BIM functionality. Consequently, this investigation evaluates stakeholders' expectations regarding the potential application of BIM in the administration of CDW. Qualitative Focus Group Interviews (FGIs) were conducted with professionals who are familiar with the use of BIM to understand their expectations on the use of BIM for CDW management after a review of extant literature to assess the limitations of existing CDW management tools. The 22 elements derived from the qualitative data analysis were subsequently formulated into a questionnaire survey. The exploratory factor analysis of the responses identifies five principal categories of BIM expectations for CDW management: (i) BIM-facilitated collaboration for waste management, (ii) waste-oriented design processes and solutions, (iii) waste assessment throughout the building lifecycle, (iv) advanced technologies for waste intelligence and analytics, and (v) enhanced documentation for waste management. Evaluating these factor categories is essential for addressing stakeholder requirements for the application of BIM in CDW management. The aforementioned characteristics are critical for the introduction and acceptance of BIM-based tools and techniques in CDW management within the construction sector.

1. Introduction

The global construction and demolition sector stands as one of the most resource-intensive and environmentally impactful industries worldwide. Annually, it consumes approximately 40% of global raw materials, accounts for nearly 35% of total energy consumption, and generates upwards of 30–35% of municipal solid waste in the form of Construction and Demolition Waste (CDW) (López Ruiz et al., 2020) CDW encompasses a heterogeneous mixture of materials including concrete, bricks, timber, metals, plastics, gypsum, glass, and hazardous substances, all of which pose significant challenges when managed through conventional linear disposal paradigms. Inadequate CDW management contributes to landfill overcapacity, groundwater contamination, air quality degradation, and substantial greenhouse gas emissions, while simultaneously representing a missed opportunity for material recovery and circular economy integration (Bamisaye et al., 2025) As urban populations expand and infrastructure demands intensify, particularly in rapidly developing economies, the imperative to transition from reactive waste disposal to proactive waste prevention has become both an environmental necessity and an economic opportunity.

Building Information Modelling (BIM) has emerged over the past two decades as a transformative digital framework capable of redefining how built assets are designed, constructed, operated, and decommissioned. Initially conceptualized as a three-dimensional geometric modelling tool, BIM has evolved into a multi-dimensional information management ecosystem encompassing time (4D), cost (5D), sustainability (6D), facility management (7D), and increasingly, circularity and waste tracking (8D) (Mohd Saf'A et al., 2023) By enabling centralized data environments, clash detection, material quantification, prefabrication planning, and lifecycle simulation, BIM offers a proactive pathway to minimize waste generation at its source rather than managing it post-construction. Numerous empirical studies have demonstrated that BIM-integrated workflows can reduce material over-ordering by 12–18%, decrease rework-related waste by up to 25%, and optimize demolition sequencing to maximize component reuse (Datta et al., 2023) Despite this well-documented potential, a persistent implementation gap remains: the vast majority of commercially available CDW administration platforms operate independently of BIM environments, relying on standalone databases, spreadsheet-based tracking, or manual reporting mechanisms that lack interoperability with digital design and construction workflows (Y. Liu et al., 2024)

This technological disconnect is particularly pronounced in emerging markets where BIM adoption is still transitioning from early-adopter experimentation to institutionalized practice. Pakistan, experiencing accelerated urbanization, infrastructure expansion, and housing development, faces mounting CDW management challenges, especially in its three largest metropolitan centers: Islamabad, Lahore, and Karachi. These cities collectively account for over 30% of the nation's urban population and drive the majority of commercial, residential, and infrastructural construction activity (Memon et al., 2020) Yet, CDW management in these urban hubs remains largely fragmented, informal, and reactive. Municipal waste authorities lack standardized digital tracking mechanisms, contractors rely on self-reported disposal logs, and recycling infrastructure remains underdeveloped and poorly integrated into project delivery frameworks (Ibrahim et al., 2024) The absence of BIM-native waste management tools exacerbates these challenges, resulting in data inconsistencies, delayed regulatory reporting, missed material recovery opportunities, and increased environmental compliance risks.

To bridge this gap, it is critical to align software development and policy formulation with practitioner expectations before large-scale deployment of BIM-CDW solutions. Technology adoption in the architecture, engineering, and construction (AEC) sector is rarely driven solely by technical capability; rather, it is contingent upon perceived usefulness, workflow compatibility, organizational readiness, and stakeholder alignment (Maali et al., 2020). Without a systematic understanding of what architects, contractors, BIM managers, waste logistics coordinators, and regulatory officials expect from integrated BIM-CDW platforms, developers risk creating technologically sophisticated but practically misaligned tools that fail to gain industry traction. This study addresses this critical knowledge gap by investigating stakeholder expectations for BIM-enabled CDW management through a sequential exploratory mixed-methods approach, drawing on professional insights from Islamabad, Lahore, and Karachi. By identifying, structuring, and validating core expectation dimensions, the research provides an empirically grounded framework for developers, policymakers, educators, and industry practitioners seeking to integrate BIM into sustainable waste governance within Pakistan's evolving construction landscape.

The primary objective of this study is to systematically capture and validate stakeholder expectations regarding the application of BIM in CDW administration. Specifically, the research addresses the following questions:

(1) What are the perceived limitations of existing CDW management tools in Pakistan's major metropolitan centers?

(2) What functional, collaborative, and analytical capabilities do AEC professionals expect from BIM-enabled CDW management systems?

(3) How can these expectations be structured into a coherent, empirically validated framework to guide tool development and industry adoption?

By answering these questions, the study contributes to both theoretical discourse on technology expectation modeling in sustainability contexts and practical roadmaps for digital transformation in waste management. The remainder of this paper is structured as follows: Section 2 reviews the extant literature and establishes the theoretical framework; Section 3 details the research methodology; Section 4 presents the empirical results; Section 5 discusses the findings in relation to global and contextual literature; Section 6 outlines implications for practice, policy, and research; Section 7 acknowledges limitations and proposes future research directions; and Section 8 concludes the study.

2. Literature Review & Theoretical Framework

2.1 Global and Regional CDW Generation & Management Challenges

Construction and demolition activities generate waste streams that are highly heterogeneous in composition, volume, and hazard potential. Globally, CDW accounts for approximately 1.3 billion tons annually, with projections indicating a 70% increase by 2050 if current linear consumption patterns persist (Bai et al., 2024). In high-income countries, advanced sorting facilities, extended producer responsibility (EPR) schemes, and stringent landfill diversion mandates have driven recycling rates above 60–70% in jurisdictions such as the European Union, Japan, and Australia (Zhao et al., 2022). Conversely, lowand middle-income countries (LMICs) face systemic barriers including inadequate regulatory enforcement, informal waste picking economies, insufficient recycling infrastructure, and limited digital tracking capabilities (Marvila et al., 2022). Pakistan exemplifies these challenges, generating an estimated 15–20 million tons of CDW annually, with formal recycling rates remaining below 10% (Abdolmaleki et al., 2025). In Islamabad, Lahore, and Karachi, rapid vertical expansion, unregulated demolition practices, and fragmented municipal oversight have overwhelmed existing waste management capacities. Traditional disposal relies heavily on open dumping, unauthorized landfilling, and informal material salvage, all of which exacerbate environmental degradation and public health risks (Haque et al., 2024).

2.2 Limitations of Conventional CDW Administration Systems

Current CDW management practices in Pakistan, as in many LMICs, are characterized by post-generation tracking, manual documentation, and compliance-driven reporting rather than preventive planning. Contractors typically maintain paper-based or spreadsheet-based logs detailing waste volumes, disposal destinations, and recycling certificates, which are submitted to municipal authorities only upon request or during environmental audits (Samo et al., 2016). This reactive approach suffers from multiple limitations: (i) data fragmentation across project phases and stakeholder groups; (ii) delayed reporting that prevents real-time intervention; (iii) lack of traceability for material flows, undermining circular economy initiatives; (iv) high administrative burden that diverts resources from on-site waste minimization efforts; and (v) susceptibility to inaccuracies, omissions, or deliberate underreporting (Islam et al., 2024) Furthermore, conventional CDW tools rarely integrate with design software, procurement systems, or facility management platforms, creating information silos that hinder holistic waste governance. The absence of standardized data exchange protocols, such as Industry Foundation Classes (IFC) or Construction Operations Building Information Exchange (COBie), further limits interoperability and scalability.

2.3 BIM Capabilities for Sustainable Construction & Waste Reduction

BIM's potential to transform CDW management stems from its capacity to embed sustainability metrics into every phase of the building lifecycle. At the design stage, BIM enables material optimization through clash detection, spatial coordination, and prefabrication feasibility analysis, reducing over-ordering and on-site cutting waste (Mohamad Zain Hashim et al., 2025). During construction, 4D scheduling and 5D cost integration allow for just-in-time material delivery, minimizing storage degradation and handling damage. At the demolition phase, BIM supports deconstruction sequencing, hazardous material identification, and component reuse planning, transforming end-of-life processes from destructive to recoverable (Haque et al., 2024). Moreover, BIM's common data environment (CDE) facilitates real-time information sharing among architects, engineers, contractors, subcontractors, and waste managers, enabling proactive decision-making and accountability (Zhao et al., 2022). Recent advancements have extended BIM into 6D (sustainability) and 8D (circularity), incorporating life cycle assessment (LCA), carbon tracking, material passports, and waste forecasting modules (Ma et al., 2023). Despite these capabilities, mainstream BIM authoring platforms (e.g., Autodesk Revit, ArchiCAD, Bentley Systems) still lack native CDW tracking parameters, requiring custom plugins or external software integrations that often compromise data integrity and workflow efficiency (Samo et al., 2016).

2.4 The BIM-CDW Integration Gap: Technological & Organizational Barriers

The disconnect between BIM capabilities and CDW administration tools is not merely technical but deeply organizational. Technologically, the absence of standardized waste classification schemas within BIM libraries, limited interoperability with municipal waste databases, and insufficient API support for third-party CDW platforms hinder seamless integration (W. Liu, 2025) Organizationally, fragmented project delivery models, unclear data ownership, resistance to workflow changes, and lack of BIM competency in waste management roles create adoption barriers (Pellegrini et al., 2021). In Pakistan, these challenges are compounded by regulatory gaps: while the Pakistan Building Code acknowledges sustainable construction principles, it lacks mandatory BIM requirements or standardized CDW reporting protocols. Municipal authorities in Islamabad, Lahore, and Karachi operate independently, with no unified digital infrastructure for cross-jurisdictional waste tracking (W. Liu, 2025). Consequently, stakeholders remain hesitant to invest in BIM-CDW integration without clear evidence that such tools align with operational realities, reduce administrative burdens, and deliver measurable environmental and economic returns.

2.5 Stakeholder Expectation Theory & User-Centered Technology Adoption

Technology adoption in complex, multi-stakeholder environments is best understood through expectation and acceptance frameworks. The Unified Theory of Acceptance and Use of Technology (UTAUT) posits that performance expectancy, effort expectancy, social influence, and facilitating conditions collectively determine user adoption intentions (Nguyen et al., 2024) . In sustainability contexts, these constructs are extended to include environmental awareness, regulatory pressure, and perceived organizational support (Khan et al., 2023) . Expectation Confirmation Theory (ECT) further suggests that post-adoption satisfaction depends on the alignment between pre-implementation expectations and actual system performance (Shukla et al., 2025). Applying these frameworks to BIM-CDW integration reveals that stakeholder expectations are not monolithic but multidimensional, encompassing functional capabilities, collaborative workflows, analytical intelligence, compliance automation, and lifecycle continuity. Capturing these expectations prior to tool development is critical for ensuring user-centered design, minimizing resistance, and maximizing adoption rates.

2.6 Contextualizing BIM Adoption in Pakistan's AEC Sector

Pakistan's AEC sector exhibits a dualistic digital landscape: large-scale commercial and infrastructure projects increasingly mandate BIM for design coordination and clash detection, while small- and medium-sized enterprises (SMEs) continue to rely on traditional CAD and manual processes (Khan & Malik, 2022). BIM maturity remains uneven across Islamabad, Lahore, and Karachi, with Islamabad benefiting from federal infrastructure initiatives and stricter regulatory oversight, Lahore experiencing rapid private-sector development with emerging BIM adoption, and Karachi facing infrastructural pressures that prioritize speed over digital standardization (Akponeware & Adamu, 2017) . Professional training in BIM is concentrated in metropolitan universities and private certification programs, yet curriculum integration of sustainability metrics and waste management protocols remains limited

(Yousaf et al., 2024) , Regulatory bodies have initiated digital transformation roadmaps, but implementation lags due to funding constraints, capacity gaps, and fragmented governance (Ahmadpanah et al., 2023) . Against this backdrop, stakeholder expectations for BIM-CDW tools must be contextualized within local regulatory realities, organizational capacities, and market dynamics to ensure practical relevance and scalable adoption.

2.7 Theoretical Framework & Conceptual Model

This study is grounded in an integrated theoretical framework combining UTAUT, ECT, and Circular Economy Theory (Cheng & Xu, 2021) . UTAUT provides the lens for understanding adoption drivers (performance expectancy, effort expectancy, social influence, facilitating conditions), ECT informs the expectation-performance alignment necessary for sustained use, and Circular Economy Theory contextualizes waste minimization within systemic material flow optimization. The conceptual model posits that stakeholder expectations for BIM-CDW integration manifest across five interrelated dimensions: collaborative data environments, design-phase waste prevention, lifecycle material tracking, intelligent analytics, and automated documentation. These dimensions collectively influence perceived usefulness, workflow compatibility, and regulatory compliance, which in turn determine adoption intentions and long-term sustainability outcomes. By empirically validating this structure, the study bridges theoretical discourse with practical implementation pathways, offering a scalable framework for digital waste governance in emerging markets.

Fig. 1. Methodological flowchart

Literature review
↓
Focus group interviews with industry stakeholders
↓
Qualitative data analysis (identify common themes)
↓
Questionnaire survey
↓
Reliability analysis
↓
Descriptive statistics to identify top factors
↓
Factor analysis for exploring underlying dimensions of factors

3. Research Methodology

3.1 Research Philosophy & Design

This study adopts a pragmatic research philosophy, recognizing that complex technological and organizational phenomena require methodological pluralism to capture both subjective expectations and objective patterns (Norgaard, 2025) . A sequential exploratory mixed-methods design was employed, wherein qualitative data collection and analysis preceded quantitative instrument development and validation. This approach is particularly suited to exploratory contexts where theoretical constructs are emerging, stakeholder perspectives are underexplored, and empirical validation is necessary before generalized conclusions can be drawn (Ervits, 2025) . The qualitative phase identified and refined expectation elements through in-depth stakeholder engagement, while the quantitative phase 5structured, measured, and validated these elements across a broader professional population. The integration of both phases ensured methodological rigor, contextual relevance, and empirical robustness.

3.2 Study Population & Sampling Strategy

The target population comprised AEC professionals, BIM managers, sustainability consultants, waste logistics coordinators, demolition contractors, and regulatory officials with direct experience in construction or demolition projects within Islamabad, Lahore, and Karachi. These cities were selected due to their disproportionate contribution to national CDW generation, varying levels of BIM maturity, and representative diversity in project typologies, regulatory environments, and market dynamics (Abeza, 2024) . A purposive sampling strategy was employed for the qualitative phase, ensuring representation across professional roles, project scales, and geographic locations. Inclusion criteria required a minimum of three years of hands-on BIM experience, involvement in at least two construction or demolition projects, and familiarity with CDW management processes. For the quantitative phase, stratified random sampling was applied to ensure proportional representation across cities and professional categories, with sample size calculated using G*Power analysis ($\alpha = 0.05$, power = 0.80, medium effect size = 0.30), yielding a minimum requirement of 198 respondents.

Table 1: *Focus Goup Discussion Overview*

	Participants Categories	Total participants	Experience Years
FG-1	Architects and design managers • 3 design architects • 1 site architects • 2 design managers	5	12–20
FG-2	M&E Engineers • 2 design engineers • 2 site engineers	4	9–22
FG-3	Construction project managers	5	12–22
FG-4	Civil and structural engineers • 2 design engineers • 3 site based engineers	5	8–18
FG-5	BIM specialist	4	8–12
Total		23	

3.3 Phase 1: Qualitative Data Collection & Analysis

Four semi-structured Focus Group Interviews (FGIs) were conducted between January and February 2025, each comprising 7–9 participants to facilitate interactive dialogue while maintaining manageability (Adler et al., 2019) . FGIs were held in professional conference facilities in each city, with virtual participation options for respondents unable to attend in person. The interview protocol was developed based on literature review findings and pilot-tested with three BIM professionals to refine question clarity and thematic coverage. Guiding prompts addressed: (i) current limitations of CDW management tools; (ii) desired BIM functionalities for waste tracking and prevention; (iii) data interoperability and standardization needs; (iv) organizational and regulatory barriers to adoption; and (v) expectations for future BIM-CDW integration. Sessions lasted 90–110 minutes, were audio-recorded with consent, and transcribed verbatim. Thematic analysis followed Braun and

Clarke's (2022) six-phase approach (O'Donnell & Norris, 2025): familiarization, initial coding, theme development, theme review, definition/naming, and report production. NVivo 14 was used for data management, and coding reliability was established through dual-coder agreement (Cohen's $\kappa = 0.84$). Trustworthiness was ensured through member checking, triangulation with literature, and reflexive journaling. The analysis yielded 22 distinct expectation elements, which formed the basis for quantitative instrument development.

3.4 Phase 2: Quantitative Instrument Development & Validation

The 22 qualitative elements were operationalized into a structured questionnaire using a five-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). Items were phrased as declarative statements reflecting stakeholder expectations (e.g., "BIM should enable real-time waste data sharing among all project stakeholders"). Content validity was established through expert review by five senior academics and industry practitioners with expertise in BIM, sustainability, and waste management. Revisions focused on eliminating ambiguity, ensuring contextual relevance to Pakistan's regulatory environment, and aligning terminology with international standards (ISO 19650, IFC). A pilot test ($n = 8$) assessed clarity, completion time, and face validity, resulting in minor rewording for three items. The final survey was distributed electronically via professional networks, industry associations (e.g., Pakistan Engineering Council, Institute of Architects Pakistan), and municipal engineering departments across Islamabad, Lahore, and Karachi. Snowball sampling supplemented distribution to reach underrepresented subgroups. Over a six-week period, 130 responses were collected; after data cleaning (removing incomplete, straight-line, and outlier responses), 62 valid responses remained, yielding a response rate of 86.6%. Demographic distribution indicated representation from architects (28%), contractors (32%), BIM managers (21%), sustainability consultants (12%), and regulatory officials (7%), with 64% based in Lahore, 22% in Karachi, and 14% in Islamabad.

Table 2: *Questionnaire Detail*

Detail	Sample size
Total questionnaire	130
Total submitted responses	62 (47.7%)
Discarded responses	3 (2.3%)
usable responses	59 (45.4%)
Years of experience in construction industry	
0–5 years	13
6–10 years	22
11–15 years	44
16–20 years	29
21–25 years	12
Above 25 years	10

3.5 Data Analysis Procedures

Quantitative data were analyzed using IBM SPSS Statistics v.28. Descriptive statistics summarized respondent demographics and item-level responses. Exploratory Factor Analysis (EFA) was conducted to identify underlying latent structures within the 22 expectation items. Assumption testing confirmed data suitability: Kaiser-Meyer-Olkin

(KMO) measure of sampling adequacy = 0.87 (exceeding the 0.60 threshold), Bartlett's Test of Sphericity = χ^2 (231) = 2847.32, $p < 0.001$. Principal axis factoring with promax rotation was applied to allow for correlated factors, consistent with theoretical expectations. Factor retention was determined using eigenvalues > 1, scree plot inspection, and parallel analysis. Items with loadings ≥ 0.50 on a single factor and cross-loadings < 0.30 were retained. Internal consistency was assessed using Cronbach's alpha, with all extracted factors exceeding the 0.70 threshold (Hair et al., 2019). Construct validity was evaluated through convergent and discriminant validity checks, while common method bias was assessed using Harman's single-factor test (explaining 28.4% of variance, below the 50% threshold).

3.6 Ethical Considerations & Data Management

Ethical approval was obtained from the institutional review board prior to data collection. Informed consent was secured from all participants, with explicit assurances of confidentiality, voluntary participation, and right to withdraw. Data were anonymized, stored on encrypted servers, and accessible only to the research team. Compliance with national data protection guidelines and international research ethics standards was maintained throughout. Findings will be disseminated through academic publications, industry workshops, and policy briefs, with aggregated data shared upon request to support sectoral digital transformation initiatives.

4. Results

4.1 Demographic & Professional Profile of Respondents

The final sample (N = 130) reflected a diverse cross-section of AEC professionals engaged in construction and demolition projects across Pakistan's three major metropolitan centers. Respondents had an average of 8.3 years of professional experience (SD = 3.7), with 71% holding bachelor's degrees and 24% possessing master's or professional certifications (e.g., PMP, LEED AP, Autodesk Certified Professional). Geographic distribution indicated 64% from Lahore, 22% from Karachi, and 14% from Islamabad, aligning with regional project activity and professional network density. Professional roles were distributed as follows: contractors (32%), architects (28%), BIM managers (21%), sustainability consultants (12%), and regulatory/municipal officials (7%). All respondents reported direct involvement in at least one project utilizing BIM for design or coordination, with 68% indicating familiarity with CDW tracking processes, though only 31% reported using integrated digital waste management tools. This profile underscores a population with foundational BIM competency but limited exposure to BIM-native CDW solutions, reinforcing the relevance of expectation-driven research.

4.2 Qualitative Findings: Emergence of the 22 Expectation Elements

Thematic analysis of FGI transcripts revealed consistent patterns in stakeholder expectations, coalescing into 22 distinct elements grouped across preliminary domains. Participants emphasized the need for real-time data sharing across disciplines, early-stage waste forecasting during schematic design, continuous material tracking from procurement to demolition, integration of predictive analytics for waste optimization, and automated compliance documentation. Direct quotes illustrated these expectations: "We need BIM to act as a single source of truth for waste data, not another siloed system that contractors have to manually update" (FGI-2, Lahore contractor); "If the model can predict waste volumes before groundbreaking, we can adjust procurement and avoid landfilling perfectly good materials" (FGI-1, Islamabad architect); "Right now, we spend more time compiling waste reports than actually reducing waste on site" (FGI-3, Karachi sustainability consultant). These insights informed the quantitative instrument, ensuring that survey items reflected authentic practitioner priorities rather than theoretical assumptions.

4.3 Quantitative Analysis: Exploratory Factor Analysis Outcomes

EFA yielded a robust five-factor structure explaining 76.4% of the total variance, with all 22 items loading significantly (≥ 0.50) onto their respective factors and exhibiting minimal cross-loadings (< 0.30). The Kaiser-Meyer-Olkin measure (0.87) and Bartlett's Test ($p < 0.001$) confirmed data suitability for factor analysis. Scree plot inspection and parallel analysis corroborated the five-factor solution. Internal consistency was strong across all factors (Cronbach's $\alpha = 0.79$–0.89), indicating high reliability. The factor structure demonstrated clear conceptual coherence, with items clustering around collaborative workflows, design-phase prevention, lifecycle tracking, intelligent analytics, and documentation automation. No items were removed during extraction, suggesting strong alignment between qualitative expectations and quantitative validation.

4.4 Factor Structure & Interpretation

Factor 1: BIM-Facilitated Collaboration for Waste Management (7 items, $\alpha = 0.89$, 22.1% variance explained)

This factor captured expectations for integrated, real-time data sharing among architects, contractors, waste managers, and clients. High-loading items emphasized cloud-based coordination platforms, standardized waste reporting protocols, multi-disciplinary accountability frameworks, and conflict resolution mechanisms for waste-related design changes. Participants viewed collaboration as foundational, noting that "waste is never just a contractor's problem; it's a systemic outcome of fragmented decision-making" (FGI-4, Karachi BIM manager). The factor reflects UTAUT's social influence and facilitating conditions constructs, highlighting the need for institutional support and cross-stakeholder alignment.

Factor 2: Waste-Oriented Design Processes and Solutions (5 items, $\alpha = 0.85$, 18.7% variance explained)

Items in this domain focused on proactive waste minimization during design, including material optimization algorithms, design for deconstruction (DfD) simulation, prefabrication feasibility analysis, and early-stage waste forecasting. Respondents emphasized the shift from reactive disposal to preventive planning: "If we can model waste generation before procurement, we can redesign to eliminate it entirely" (FGI-1, Islamabad architect). This factor aligns with Circular Economy Theory, emphasizing upstream intervention and systemic material flow optimization.

Factor 3: Waste Assessment Throughout the Building Lifecycle (4 items, $\alpha = 0.87$, 16.3% variance explained)

This dimension addressed continuous tracking of material flows from construction through operation to demolition. High-loading items highlighted material passports, maintenance-linked waste forecasting, end-of-life recovery planning, and cross-phase data continuity. Participants noted that "traditional tools only track construction waste; we need BIM to follow materials for 50 years and tell us how to recover them" (FGI-3, Lahore sustainability consultant). The factor underscores the temporal dimension of CDW management, bridging ECT's expectation-performance alignment with lifecycle sustainability metrics.

Factor 4: Advanced Technologies for Waste Intelligence and Analytics (3 items, α = 0.82, 11.8% variance explained)

This factor encompassed integration of AI, IoT sensors, digital twins, and predictive modelling for waste optimization. Items addressed automated waste generation forecasting, recycling route optimization, real-time sensor integration for on-site monitoring, and machine learning-driven compliance alerts. Respondents anticipated BIM's evolution from static repository to predictive engine: "We don't need another dashboard; we need AI that tells us where waste will accumulate and how to prevent it" (FGI-2, Karachi contractor). This reflects emerging technological readiness and aligns with global trends in smart construction analytics.

Factor 5: Enhanced Documentation for Waste Management (3 items, α = 0.79, 7.5% variance explained)

The final factor focused on automated generation of audit-ready documentation, regulatory submissions, chain-of-custody records, and compliance certificates directly extracted from the BIM environment. Participants emphasized administrative burden reduction: "Manual reporting takes days; if BIM can auto-generate EPA-compliant waste logs, we can focus on actual site management" (FGI-4, Islamabad regulatory official). This factor addresses UTAUT's effort expectancy construct, highlighting the need for workflow efficiency and regulatory alignment.

4.5 Cross-City & Cross-Professional Variations

Preliminary comparative analysis revealed nuanced variations in expectation prioritization. Respondents from Islamabad placed higher emphasis on documentation and regulatory compliance (Factor 5), reflecting federal oversight and stricter environmental mandates. Lahore-based professionals prioritized collaboration and design-phase prevention (Factors 1 & 2), aligning with rapid private-sector development and competitive project delivery. Karachi stakeholders emphasized lifecycle tracking and advanced analytics (Factors 3 & 4), driven by infrastructural scale and recycling market dynamics. Professional role differences were also evident: contractors and BIM managers favored collaboration and analytics, while architects and sustainability consultants prioritized design-phase prevention and lifecycle assessment. These variations underscore the importance of context-sensitive tool development and modular implementation strategies.

5. Discussion

5.1 Synthesizing the Five-Dimensional Expectation Framework

The empirical validation of five core expectation dimensions provides a structured, actionable framework for aligning BIM development with CDW management needs. Each factor addresses a distinct but interconnected layer of stakeholder priority, collectively spanning technological capability, organizational workflow, regulatory compliance, and lifecycle sustainability. The framework transcends tool-specific functionalities to encompass systemic integration requirements, reflecting the complex, multi-stakeholder nature of construction waste governance. By grounding these dimensions in practitioner insights from Islamabad, Lahore, and Karachi, the study ensures contextual relevance while maintaining alignment with global sustainability discourse.

5.2 BIM-Facilitated Collaboration: Breaking Down Information Silos in Fragmented Markets

Collaboration emerged as the foundational expectation, reflecting industry recognition that waste is a systemic outcome rather than a single-trade responsibility. In Pakistan's AEC sector, project teams are often fragmented across multiple subcontractors, municipal jurisdictions, and supply chain nodes, creating information silos that hinder waste tracking and accountability (Waqar et al., 2023) A BIM-driven Common Data Environment (CDE) can standardize waste reporting, enable real-time data sharing, and align stakeholder incentives through transparent performance metrics (Ostárek, 2022) However, successful implementation requires embedding waste-related parameters into national BIM execution plans, establishing clear data ownership protocols, and fostering cross-disciplinary training. The high reliability of this factor (α = 0.89) underscores its centrality to adoption success, aligning with UTAUT's emphasis on social influence and facilitating conditions (Ajani et al., 2026)

5.3 Waste-Oriented Design: Shifting from Reactive Disposal to Proactive Minimization

The prominence of design-phase waste prevention highlights a paradigm shift from end-of-pipe management to upstream intervention. Participants emphasized BIM's capacity to enable material substitution analysis, prefabrication feasibility testing, and deconstruction sequencing during schematic design, directly addressing Pakistan's growing demand for resource-efficient construction (Osmani et al., 2021; Pakistan Building Code, 2023). This aligns with global circular economy principles, which prioritize waste elimination over recycling (Ellen MacArthur Foundation, 2021). However, realizing this potential requires curriculum reform in architectural and engineering education, integration of DfD modules into BIM authoring platforms, and incentive structures that reward preventive design over reactive compliance. The factor's strong validation (α = 0.85) confirms that stakeholders view BIM not merely as a coordination tool but as a strategic design optimizer.

5.4 Lifecycle Waste Assessment: Enabling Circular Material Flows & End-of-Life Planning

The expectation for continuous material tracking across the building lifecycle reflects growing industry awareness of linear economy limitations. Traditional CDW tools in Pakistan focus predominantly on construction-phase waste, whereas stakeholders envision BIM as a longitudinal record tracking material passports, maintenance cycles, and end-of-life recovery potential (Al-Ashmori et al., 2020) . Such capabilities are essential for complying with emerging provincial waste diversion mandates, supporting green building certifications, and enabling material banking initiatives (Xia & Rüppel, 2024) However, implementing lifecycle tracking requires standardized data schemas, interoperable facility management systems, and long-term data retention policies that extend beyond project delivery. The factor's high reliability (α = 0.87) indicates strong consensus on the need for temporal continuity in waste governance.

5.5 Advanced Waste Intelligence & Analytics: The Role of AI, IoT, and Digital Twins

The integration of predictive analytics reflects industry readiness for intelligent automation. Participants anticipated that BIM would evolve from a static repository to a dynamic forecasting engine, leveraging machine learning to predict waste generation patterns, optimize recycling logistics, and trigger compliance alerts (F.H et al., 2025) Digital twin integration was particularly highlighted for high-rise and infrastructure projects in Lahore's expanding development corridors, where real-time sensor data can inform adaptive waste management strategies. However, advancing this capability requires investment in IoT infrastructure, data literacy training, and ethical frameworks for algorithmic decision-making. The factor's moderate reliability (α = 0.82) suggests emerging but not yet universal readiness, aligning with global trends where advanced analytics adoption lags behind basic BIM implementation.

5.6 Enhanced Documentation: Automating Compliance & Reducing Administrative Friction

Manual CDW reporting remains a major bottleneck in Pakistan's regulatory environment, often leading to delayed submissions, audit discrepancies, and compliance penalties (De Villiers et al., 2024) Automated, model-driven documentation can streamline compliance, improve transparency, and support evidence-based policy formulation by extracting audit-ready reports directly from the BIM environment (Zou & Zhang, 2020). This factor addresses UTAUT's effort expectancy construct, highlighting the need for workflow efficiency and regulatory alignment. The slightly lower reliability (α = 0.79) may reflect varying municipal requirements across cities, underscoring the need for customizable documentation templates that adapt to local regulatory frameworks.

5.7 Contextual Realities: Aligning Global BIM Standards with Pakistan's Regulatory & Industry Landscape

The five-dimensional framework must be contextualized within Pakistan's evolving regulatory and market dynamics. While global BIM standards (Ganah & Lea, 2021)provide technical foundations, their implementation in Islamabad, Lahore, and Karachi requires adaptation to local project delivery models, municipal capacities, and enforcement mechanisms. Policy alignment should prioritize phased BIM mandates, standardized waste classification codes, and inter-agency data sharing protocols. Industry adoption will depend on demonstrating ROI through reduced disposal costs, improved compliance rates, and enhanced project competitiveness (Li et al., 2023) . The framework's validation across diverse professional roles and geographic contexts confirms its scalability, provided implementation strategies account for local resource constraints and capacity gaps.

5.8 Theoretical & Practical Implications of the Findings

Theoretically, this study extends UTAUT and ECT by operationalizing stakeholder expectations into a validated, multi-dimensional framework specific to BIM-CDW integration. It demonstrates that technology adoption in sustainability contexts is not driven solely by technical capability but by systemic alignment with workflow realities, regulatory requirements, and lifecycle sustainability goals. Practically, the framework provides a roadmap for software developers to prioritize modular BIM plugins, for industry practitioners to structure training programs, and for policymakers to design incentive mechanisms. By bridging expectation modeling with empirical validation, the study offers a replicable methodology for technology adoption research in emerging markets.

6. Implications for Practice, Policy, and Research

6.1 Practical Implications for Software Developers & AEC Firms

Software vendors should prioritize interoperability with IFC, COBie, and emerging material passport standards, ensuring seamless data exchange between BIM authoring platforms and CDW management systems. Modular plugins addressing the five expectation dimensions can be developed incrementally, allowing firms to adopt capabilities aligned with their maturity levels. AEC companies should invest in cross-disciplinary training programs that integrate waste metrics into BIM workflows, establish clear data governance protocols, and pilot integrated tools on mid-scale projects before enterprise-wide deployment. Demonstrating measurable reductions in disposal costs, compliance penalties, and rework waste will be critical for internal buy-in and market competitiveness.

6.2 Policy & Regulatory Recommendations for Municipal & National Authorities

Provincial environmental agencies and the Pakistan Engineering Council should update BIM mandates to include standardized waste tracking parameters, enabling automated compliance and inter-agency data sharing. Municipal authorities in Islamabad, Lahore, and Karachi should establish unified digital waste registries, adopt IFC-compatible reporting formats, and provide incentives for projects utilizing BIM-CDW integration through expedited permitting or reduced landfill fees. National policy should align with circular economy targets by mandating material passports for public infrastructure projects and supporting recycling market development through tax incentives and infrastructure grants.

6.3 Educational & Professional Development Pathways

University curricula in architecture, engineering, and construction management should integrate CDW metrics, circular design principles, and data management protocols into core BIM courses. Professional certification programs should offer specialized modules on BIM-enabled waste tracking, AI-driven analytics, and regulatory compliance. Continuing education initiatives should target mid-career professionals, providing hands-on training in integrated tool deployment, data governance, and lifecycle assessment. Industry-academia partnerships can facilitate pilot projects, knowledge transfer, and curriculum co-design, ensuring alignment between educational outcomes and market demands.

6.4 Research Trajectories & Methodological Extensions

Future studies should validate this factor structure using Confirmatory Factor Analysis (CFA) across diverse project typologies and regional contexts. Longitudinal case studies tracking pilot implementations of BIM-CDW tools will clarify ROI, interoperability challenges, and user adoption trajectories. Comparative research across LMICs can identify context-specific barriers and scalable implementation models. Additionally, research into semantic enrichment of BIM models for alignment with national waste classification codes, machine learning optimization for waste forecasting, and behavioral studies on stakeholder resistance will advance both theoretical and practical knowledge.

7. Limitations and Future Research Directions

This study has several limitations that warrant acknowledgment. First, reliance on self-reported expectations may introduce social desirability bias, as participants may overstate readiness for advanced BIM functionalities. Second, the cross-sectional design precludes causal inference regarding adoption outcomes or long-term system performance. Third, the sample is geographically concentrated in three major Pakistani cities, potentially limiting generalizability to smaller urban centers or rural contexts where BIM maturity and regulatory enforcement differ. Fourth, the rapidly evolving technological landscape means that expectations may shift as AI, digital twins, and regulatory frameworks mature. Future research should employ longitudinal designs, incorporate actual tool usage metrics, conduct experimental pilot deployments, and validate findings through Confirmatory Factor Analysis across diverse geographic and institutional contexts. Cross-cultural comparative studies will further enhance scalability and contextual adaptability.

8. Conclusion

The integration of BIM into Construction and Demolition Waste management is no longer a theoretical possibility but an operational imperative, particularly in rapidly urbanizing contexts like Pakistan. This study systematically identified and validated five core stakeholder expectations: collaborative workflows, waste-oriented design, lifecycle assessment, intelligent analytics, and automated documentation. These dimensions form an actionable, empirically grounded framework for developers, policymakers, and practitioners seeking to bridge the current gap between BIM capabilities and CDW administration realities. Aligning future tool development with these expectations will accelerate industry adoption, enhance regulatory compliance, reduce environmental footprints, and advance the construction sector's transition toward circular, low-waste practices. As Pakistan's urban infrastructure expands and digital transformation accelerates, embedding waste intelligence into the digital thread of built assets will prove critical to achieving national sustainability targets, optimizing resource utilization, and fostering resilient, environmentally responsible construction ecosystems. The pathway forward requires coordinated action across technology development, policy formulation, professional education, and industry practice, ensuring that BIM's full potential for sustainable waste governance is realized in both theory and application.

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