

Article

Construction Supply Chain Management for Circular Economy Performance: Procurement Economics and Configuration Evidence from New Zealand

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Abstract

Supply chain management (SCM) optimisation is a critical but under-examined pathway for delivering circular economy outcomes in the construction sector, particularly in geographically remote and small- and medium-sized enterprise-dominated markets such as New Zealand (NZ). This study investigates how SCM practices, such as digital tools, early contractor involvement, strategic partnerships, and reverse logistics, can be optimised to improve circular performance in NZ-built environment projects. A pragmatist, abductive mixed-methods design combined 75 case studies, a 28-case quantitative subset, 15 elite semi-structured interviews and documentary evidence. Reflexive Thematic Analysis was integrated with descriptive statistics, cross-tabulation, non-parametric testing, and configuration archetype analysis. Coordination and partnerships are the most frequently observed SCM lever, appearing in 46.7% of the 75 cases and in all four cases in the highest waste-diversion band, while digital tools are seldom deployed as the primary lever. Two operational metrics summarise these configurations: a Waste Hierarchy Index (WHI) of 77.6%, calculated across the 66 cases with an assignable waste hierarchy position, and a Digital SCM Adoption Rate (DSAR) of 15.1%, calculated across the 73 cases with a stated primary lever. Together they indicate an upstream but digitally uneven pattern of optimisation. The study contributes a configuration-based method for comparing SCM levers in circular construction, together with the first NZ evidence base of this kind, and finds that procurement reform rather than digital investment is the key constraint on circular performance. Practical implications include embedding early contractor involvement and integrated design in public procurement, funding sector-wide digital interoperability rather than firm-level tools, and extending site waste management plan reporting. Priority future research is longitudinal, scale-stratified testing of the configuration archetypes identified in this paper.



Academic Editor: Bertrand Laratte

Received: 2 September 2026

Revised: 27 September 2026

Accepted: 2 October 2026

Published: 9 October 2026

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Keywords: supply chain management optimisation; circular economy; built environment; early contractor involvement; digital integration; New Zealand

1. Introduction

The global construction sector represents one of the largest contributors to the global economy, exceeding US\$10 trillion annually and consuming over 50% of extracted raw materials [1,2]. In New Zealand (NZ), construction produces roughly 7% of gross domestic product and generates over NZ\$30 billion in annual revenue, making it the country's

fifth-largest sector [3]. Yet this economic achievement is matched by a similarly significant environmental burden: construction and demolition (C&D) waste in NZ is estimated at seven million tonnes per year and accounts for 30–40% of all material disposed of in Auckland's landfills [4,5], which is consistent with waste generation metrics observed overseas [6,7]. The persistence of this waste profile, despite two decades of policy attention, signals a systemic breakdown rather than a technical or behavioural shortfall at the project level.

A key reason for this systemic impediment is that supply chain management (SCM) in NZ construction is not optimised. The sector is dominated by small and medium-sized enterprises (SMEs), with approximately 95% of registered companies employing fewer than 20 people [8]. Procurement is typically organised within a sequential design-bid-build model that fragments accountability across designers, contractors, and material suppliers, inserting waste at the specification stage. Adversarial contracting practices, which optimise for the lowest price tender rather than whole-life value, suppress the relational trust needed for circular material flows. The result is a supply chain with design decisions, procurement choices, and waste outcomes disconnected in time and authority, which is an underlying condition that linear SCM cannot address.

Circular economy (CE) principles offer an alternative to the linear take–make–dispose model by prioritising prevention, reuse, reverse logistics and product stewardship [9,10]. However, NZ's built environment (BE) sector faces specific constraints: long supply lines, high import dependence, an SME-dominated industry structure, road-based freight, and procurement models that often prioritise lowest upfront cost over the whole-life value [11–13]. These conditions mean that international CE supply-chain solutions cannot simply be transferred into NZ without empirical testing.

Therefore, this study examines how SCM practices can be optimised to improve circular performance in NZ BE projects. It focuses on the interaction between digital tools, early contractor involvement (ECI), partnerships, reverse logistics, and procurement settings, rather than treating these levers as isolated interventions.

Four gaps motivate this study. First, institutional and policy conditions are studied at a macro level but rarely linked to project-level SCM decisions. Second, design authority and upstream procurement decisions are widely acknowledged as influential for waste outcomes, yet the SCM literature has largely been confined to downstream operations such as logistics and material handling [14]. Third, adversarial fragmentation in construction supply chains is repeatedly cited as a barrier to CE, but few studies test which specific relational SCM levers can dissolve this fragmentation. Fourth, NZ-specific empirical evidence on how SCM configurations interact with circular outcomes remains limited, with most circular construction research drawn from European or East Asian contexts whose institutional and geographic characteristics differ markedly from those of NZ [11,13,14].

The significance of this study is threefold. Empirically, it provides one of the first configuration-level accounts of circular construction SCM in NZ, a market with geographic remoteness and SME structure being under-represented in the literature. Methodologically, it demonstrates how configuration archetype analysis, combined with two transparent operational metrics, can compare SCM levers across heterogeneous cases, where effect-size estimation may not be feasible. Practically, it identifies procurement reform rather than digital investment as the binding constraint on circular performance, which redirects where public and industry effort is most likely to provide measurable diversion gains.

Therefore, the aim of this study is to investigate how SCM practices can be optimised to enhance the performance of NZ BE projects under CE constraints, with particular attention to the configurations of digital, relational, and procurement levers that sustain

high-performing circular outcomes. It does so by combining case study evidence, practitioner interviews, operational metrics and configuration archetype analysis.

The study is guided by the following research question (RQ):

- RQ: How can SCM practices be optimised to enhance the performance of BE projects in NZ?

Four supporting sub-research questions examine the empirical basis for this question:

- RQA: Which SCM levers are being used across NZ and international circular built environment cases?
- RQB: How do digital tools, early contractor involvement, partnerships and reverse logistics influence waste and cost outcomes?
- RQC: What quantitative relationships exist between SCM levers, waste hierarchy position, project scale and waste-reduction performance?
- RQD: What configuration archetypes and practical implications emerge for wider SCM optimisation in NZ?

The remainder of the paper is structured as follows. Section 2 reviews the SCM and CE literature relevant to RQ and develops the theoretical framework. Section 3 describes the mixed-methods design, data collection and analytical procedures, including two metrics: the Waste Hierarchy Index (WHI) and Digital SCM Adoption Rate (DSAR). Section 4 presents empirical findings across SCM lever distribution, ECI, digital SCM tools, partnerships and configuration archetypes. Section 5 discusses theoretical contributions and practical implications, and Section 6 concludes this article.

2. Literature Review

2.1. SCM in Construction and the Circular Economy

Construction SCM has historically been organised around a linear logic in which the project moves sequentially from design through tendering to construction and disposal [15,16]. Within this design-bid-build paradigm, designers specify materials without having to deal with the waste consequences of their choices, contractors procure supplies against contracts that reward lowest-tender price rather than whole-life performance, and waste arises as an unpriced externality at the back end of the process [17,18]. The sequential separation of design authority from procurement and waste accountability is the root cause of why marginal interventions in any single phase rarely translate into systemic waste reduction.

CE advocates a fundamental reorientation of SCM from this linear architecture to a circular one. Theeraworawit et al. (2022) consolidate the relevant scholarship into four schools of circular SCM theory: Sustainable SCM, Environmental Management, CE SCM, and Reverse Supply Chain [19]. For this study, the CE SCM and Reverse Supply Chain perspectives are most relevant because they treat circularity as a property of the supply chain architecture, not simply as downstream recycling. In NZ, this architecture must also respond to import dependence, road-based freight, SME capacity limits, and fragmented procurement [11]. These conditions justify an empirical focus on SCM configurations rather than generic CE prescriptions.

Within the four-school taxonomy, the most theoretically productive position for the present study is the CE SCM school, which treats circular flows as a property of the supply chain architecture rather than a downstream remediation of linear waste. This school converges with the Lean Construction emphasis on designing out waste at source, and it provides the conceptual rationale for organising the empirical analysis around configuration archetypes (Section 4.5) rather than around the success or failure of individual tools. The

Reverse Supply Chain school, in turn, supplies the analytical vocabulary for the case-level study of partnerships, stewardship schemes and material exchanges (Sections 4.4 and 5.2).

2.2. Digital SCM Levers: BIM and the Golden Thread

Building Information Modelling (BIM) is the most widely cited digital SCM integration tool in circular construction. By embedding material, geometric, and life cycle information into a shared model, BIM connects design decisions to procurement, waste estimation, and material tracking [20]. Berglund-Brown et al. (2022) characterise the resulting Circular Information Flow (CIF) along four dimensions: completeness (the model contains all relevant material attributes), availability (information is generated when needed), accessibility (information is shareable across actors), and incorporation into business strategy (information shapes decisions rather than merely documenting them) [21].

Empirical evidence supports the SCM value of BIM-enabled analytics. Akinade and Oyedele (2019) report that an Adaptive Neuro-Fuzzy Inference System (ANFIS)-based waste analytics platform integrated with BIM achieved 89–94% accuracy in automated material classification and reduced over-ordering by 17–24% [17]. Fereydooni Eftekhari et al. (2024) demonstrate that a BIM-based materials passport, generated through Industry Foundation Classes (IFC) data extraction, can produce a building-level recyclability index that supports both procurement and end-of-life planning [22]. Such findings underpin the theoretical case for RQA, namely that digital SCM tools enhance transparency, efficiency and collaboration.

Yet the digital SCM literature is also clear about the conditions under which these benefits are realised. Gaps in SME adoption, siloed proprietary platforms, and digital literacy deficits frequently prevent digital tools from delivering systemic value [18,21]. These constraints are particularly significant in NZ, where 95% of construction firms are SMEs.

Materials passports present a complementary digital lever. Fereydooni Eftekhari et al. (2024) describe an IFC-based extraction process that aggregates material identities, quantities, and recoverability scores into a project-level recyclability index [22]. Such passports operate as the digital foundation for Design-for-Disassembly (DfD) strategies and for downstream material-bank infrastructure, because they enable recovered materials to be specified for reintroduction into new projects [23]. They also create the data backbone for the circular procurement contracts that increasingly accompany large public projects in Europe.

International benchmarks help calibrate the NZ digital SCM gap [24]. The Netherlands records above 90% C&D waste recovery, supported by annual waste-data collection, demolition licensing, registered waste operators, selective sorting, and landfill restrictions [25]. England and the wider UK have consistently exceeded the 70% C&D recovery target, with recovery rates above 90% since 2010 [26]. Singapore's Zero Waste Masterplan and mandatory waste reporting system require affected premises, including workplaces and construction sites, to report waste and recycling quantities and submit waste-reduction plans [27,28]. For Europe, Bain & Company (2022) estimates that recycled material use in construction could double to 28% by 2040 [29].

2.3. Relational SCM: ECI, Partnerships and Reverse Logistics

Relational SCM levers shift attention upstream from logistics towards the relational and contractual structures that determine what flows through the supply chain in the first place. ECI brings fabricators, main contractors and waste specialists into the design phase before key decisions are locked in, integrating procurement strategy selection in earlier stages [30].

Strategic partnerships extend ECI from a single project into longer-term, trust-based relationships that can sustain circular material flows [31]. Product stewardship schemes leverage existing logistics infrastructure rather than requiring new networks. Sonar et al. [32] identify the infrastructure conditions for viable reverse logistics in construction, such as recyclable material specifications, reliable collection networks, novel packaging, and accessible secondary markets. Their analysis shows that knowledge and awareness barriers and regulatory deficiencies act as underlying barriers leading to operational failures.

Ma and Zhang [33] demonstrate that government, constructor, and recycler interactions reach circular equilibrium only when both subsidy and penalty mechanisms are implemented. The relational structure of the supply chain, in their model, is not autonomous; instead, it requires an institutional framework to remain stable. The implication for RQB is that strategic partnerships should be expected to deliver resilient, responsive SCM, but their longevity depends on the institutional context in which they operate.

Reverse logistics is the operational counterpart to relational SCM [31]. Where forward logistics moves new materials from manufacturer to construction site, reverse logistics moves used and surplus materials from buildings to subsequent projects, processors or remanufacturers. The infrastructure conditions identified by Sonar et al. [32], such as specifications, collection networks, quality assurance and secondary markets, are precisely the conditions that long-term partnerships are well placed to satisfy. The Good Wrap scheme, the IKEA Auckland concrete crushing case [34], and the Auckland industrial symbiosis network reported in Section 4.4 each illustrate how reverse logistics can be assembled from existing freight back-haul, processing and procurement capacity when partnership networks coordinate around shared specifications.

2.4. Configuration Archetypes in Circular Construction SCM

A recurring conclusion across the SCM literature is that no single “magic bullet” lever explains high-performance circular outcomes. Configuration-level analyses, i.e., examining combinations of levers rather than individual tools, are increasingly seen as more explanatory. This position has an established precedent in operations management. Shah and Ward [35] show that lean manufacturing performance is attributable to mutually reinforcing bundles of practices rather than to any individual technique, and that plants adopting complementary bundles outperform those adopting isolated tools. Frohlich and Westbrook [36] demonstrate a comparable pattern in supply chain integration, where performance rises with the breadth of the integration “arc” spanning both suppliers and customers rather than with integration on either side alone. Both studies establish the analytical move this paper applies to circular construction: treating the combination of levers as the unit of analysis, and identifying which combinations recur among high performers. Circular SCM appears to involve analogous complementarity, although the empirical literature has yet to discover the specific configurations that operate in geographically remote, SME-dominated economies. Thus, the literature exhibits a clear gap with respect to NZ circular construction, which this study addresses through configuration archetype analysis (Section 4.5).

Three additional considerations support the configuration argument. First, configurations are not static; rather, they evolve over the project life cycle as design freezes, supplier relationships mature, and waste streams emerge in measurable forms. Empirical analysis must therefore distinguish between configuration components that are deployable at the design stages, those that are deployable during construction, and those that operate post-completion. Second, configurations are not equivalent in their resilience, i.e., configurations distributed across multiple actors with overlapping capabilities tend to be more durable than those depending on a single intermediary. Third, configurations interact with project scale in non-trivial ways. Larger projects can absorb the transaction costs of multi-lever

configurations, whereas smaller projects benefit disproportionately from configurations that exploit shared infrastructure rather than developing project-specific capability.

This configuration framing differs in kind from the two dominant approaches to circular construction supply chains. Barrier-based studies, exemplified by the ISM-MICMAC analysis of Sonar et al. [32], rank and structure the obstacles to adoption, producing a hierarchy of what impedes circularity but not an account of which combinations of practices succeed where adoption does occur. Game-theoretic studies, exemplified by the evolutionary game modelling of Ma and Zhang [33], derive the incentive conditions under which regulators, contractors and recyclers converge on circular balance, yielding prescriptions about subsidy and penalty design rather than observations of realised supply chain arrangements. This study takes such an arrangement as its unit of analysis, asking which combinations of SCM levers recur among cases that achieved measured diversion, and what that recurrence implies for procurement design. The three approaches are complementary, addressing impediments, incentives and configurations respectively; the contribution claimed here is confined to the third approach.

2.5. Theoretical Framework

Three primary theoretical lenses inform the analysis of RQ. Together they provide complementary explanations of why coordination-centred configurations dominate the high-performance range, and they each generate testable predictions that the empirical analysis can examine.

First, Dynamic Capabilities Theory frames circular SCM as the joint deployment of three capabilities: sensing, which includes data collection, BIM, and materials information; seizing, i.e., partnership formation, ECI, and contractual reform; and reconfiguring, e.g., workflow redesign, circular procurement. The theory predicts that firms developing all three simultaneously will outperform those with only one or two [37,38]. This study's configuration archetype analysis empirically tests this prediction.

Second, Lean Construction supplies a pull-workflow logic that applies upstream of construction; for instance, designing out waste at the specification stage is more effective than sorting and recycling downstream [39]. ECI represents the construction equivalent of "design for manufacture", and the WHI introduced in Section 3.4 operationalises lean's preference for upstream interventions.

Third, the Socio-Technical Systems Theory cautions that digital tools alone cannot transform SCM. Effective digital adoption should be accompanied by social and organisational changes [40]. The theory implies that coordination may be the missing socio-technical infrastructure in NZ construction and that digital adoption rates measured in isolation could understate the conditions for high performance.

Two supporting lenses complete the framework. Reverse Logistics theory specifies the infrastructure conditions for viable circular flows, such as clear material specifications, reliable collection networks, and accessible secondary markets, and explains why partnership networks are the most efficient for assembling these conditions in fragmented markets [32,41]. Institutional Theory frames adversarial procurement as a coercive isomorphism that maintains fragmentation across the sector and identifies relational procurement as a normative-isomorphic alternative that can shift sector-wide expectations once a critical mass of public clients adopts it [42]. The two supporting lenses jointly explain why coordination-centred configurations both perform well at the project level and remain stable across projects when supported by appropriate institutional arrangements.

3. Methodology

3.1. Research Design

The study adopts a pragmatist philosophical stance with abductive reasoning, on the basis that circular SCM in NZ is an under-theorised empirical phenomenon for which neither pure deduction nor pure induction is sufficient [43,44]. A cross-sectional, mixed-methods design integrates qualitative and quantitative data to enable theoretical pattern matching across cases, interviews and documentary records.

The choice of pragmatism reflects the practical orientation of the research question with the aim to identify SCM configurations that noticeably enhance circular performance under NZ conditions, rather than to decide between competing meta-theories of SCM. Pragmatism consents to the parallel use of qualitative and quantitative evidence, treats theory as a tool for explanation rather than an end, and accommodates the abductive movement between observed patterns and probable explanations that is central to the study's analytical strategy. A cross-sectional design rather than a longitudinal time horizon was chosen on feasibility grounds, given the difficulty of tracking SCM configurations over multi-year project life cycles in a fragmented sector; the resulting limitations are addressed in Section 5.4.

3.2. Data Collection

Three data streams were assembled. First, 75 cases of circular construction projects were compiled through purposive maximum-variation sampling. These cases draw on three source types: 30 cases evidenced by the interview programme described below, 27 from NZ technical and research reports, and 18 from project and programme case studies presented in industry and conference settings. The dataset is predominantly domestic: 31 cases are from Auckland, 38 elsewhere in NZ, three overseas, and three span multiple or unspecified locations. International benchmarks from Australia, the United Kingdom, the Netherlands, other EU member states, and Singapore were included to compare the NZ findings with mature circular construction economies, rather than as coded case evidence. Within the 75-case dataset, a subset of 28 cases includes recorded waste-reduction percentages and was used for quantitative analysis.

Second, 15 elite semi-structured interviews were conducted with senior practitioners in design, contracting, policy and waste management roles (Table 1). Sampling combined purposive selection and snowball expansion. Interviews lasted 30–45 min, were recorded with consent, and were transcribed verbatim. Because several participants discussed more than one project, the 15 interviews yielded 30 case records. Case records are labelled either by participant identifier or, where a participant described a specific project in detail, by project name; the eight project-named records therefore derive from the same 15 interviews and do not represent additional sources of information. Third, documentary evidence (project reports, policy documents and industry publications) was used to triangulate case-level claims.

Table 1. Interview participant profile.

Stakeholder Group	Participants	Main Contribution to the Study
Design, engineering and built environment consultancy	4	Design-stage decisions, BIM, buildability and waste prevention
Contracting, construction materials and project delivery	3	Site operations, procurement constraints and material logistics

Table 1. *Cont.*

Stakeholder Group	Participants	Main Contribution to the Study
Waste, circular materials and reverse logistics	4	Recovery pathways, secondary materials and product stewardship
Public sector, policy and industry bodies	4	Regulation, procurement settings, professional practice and market coordination
Total	15	Cross-role evidence on SCM optimisation conditions

Across all 75 cases, a single SCM lever variable was coded according to the primary lever observed: coordination/partnerships, digital/data, procurement/contracts, other SCM practices, or not applicable. This coding decision to record the primary rather than all levers favoured analytical clarity and inter-case comparability over coverage breadth and is reflected in the DSAR metric (Section 3.4).

Where a case displayed multiple SCM levers of comparable salience, the primary lever was assigned according to the lever that the project documentation and interview evidence identified as the proximate cause of waste-reduction outcomes. Cases without sufficient information to identify a primary lever were coded as “not applicable”, rather than being forced into a category, to preserve the integrity of the lever distribution analysis.

The interview protocol was developed iteratively and covered five core areas: respondents’ experience of NZ construction SCM and its CE constraints; the SCM levers they had observed delivering circular outcomes (and the levers that had failed to deliver); the role of digital tools, partnerships in the cases they had been involved in; barriers to wider adoption of effective configurations; and policy or institutional changes the respondent considered necessary. Probes followed Braun and Clarke’s (2019) reflexive principles [45], allowing the conversation to surface implicit knowledge that structured questionnaires would have missed.

3.3. Analytical Approach

Qualitative data were analysed using NVivo Version 15.0.0 (12) through a six-phase Reflexive Thematic Analysis (RTA) following Braun and Clarke [45,46]. An initial semantic coding cycle identifying surface-level patterns was followed by a subsequent latent cycle interpreting underlying meanings, contradictions and theoretical implications. Quantitative data were analysed in SPSS Version 31.0.1.0 (49) through descriptive statistics, cross-tabulations and Kruskal–Wallis H-tests. Configuration archetype analysis combined the coded variables, such as intervention themes, SCM lever, waste hierarchy position, scale, geographic context, to identify recurrent high-performing patterns. Triangulation across cases, interviews, and documentary sources was applied at each analytical stage.

3.4. Quantitative Metrics

To make cross-case comparisons tractable, two simple operational metrics were used (Table 2). The Waste Hierarchy Index (WHI) adapts the waste hierarchy index proposed by Pires and Martinho (2019) to capture how far SCM effort is distributed towards higher-value options in the waste hierarchy [47], while the Digital SCM Adoption Rate (DSAR) is introduced in this study to quantify the extent to which digital and data tools operate as the primary SCM lever. Together, these indices translate qualitative case descriptions into comparable numerical signals that can be used in the subsequent inferential and configuration analysis.

Table 2. Operational metrics used in the quantitative analysis.

Metric	Formula	Result	Interpretation
Waste Hierarchy Index (WHI)	$\text{WHI (\%)} = \frac{[(\text{Prevention cases} \times 5) + (\text{Reuse cases} \times 4) + (\text{Recycling cases} \times 3) + (\text{Recovery cases} \times 2) + (\text{Disposal cases} \times 1)]}{(\text{Active cases} \times 5)} \times 100$	$\frac{[(27 \times 5) + (13 \times 4) + (19 \times 3) + (5 \times 2) + (2 \times 1)]}{(66 \times 5)} \times 100 = 77.6\%$	Measures the share of weighted SCM effort operating across the full waste hierarchy, indicating a stronger overall orientation toward higher-value options.
Digital SCM Adoption Rate (DSAR)	$\text{DSAR (\%)} = (\text{Digital/data cases as primary SCM lever} / \text{cases with a stated SCM lever}) \times 100$	Full dataset: $11/73 \times 100 = 15.1\%$; quantified subset: $2/28 \times 100 = 7.1\%$	Measures the extent to which digital/data tools operate as the primary SCM lever.

The dataset used to calculate WHI comprises the following waste-hierarchy categories across the 75 cases: prevention/design-out (36.0%, $n = 27$), reuse/relocation (17.3%, $n = 13$), recycling (25.3%, $n = 19$), recovery (6.7%, $n = 5$), disposal/landfill (2.7%, $n = 2$) and not applicable (12.0%, $n = 9$). Only cases with a coded hierarchy position ($n = 66$) are treated as “active cases” in the WHI calculation. For DSAR, 73 cases have a coded primary SCM lever, of which 11 are digital/data-led (DSAR = 15.1%), while in the 28-case quantitative subset only 2 are digital/data-led (DSAR = 7.1%).

These metrics were supplemented by descriptive statistics, cross-tabulations, and Kruskal–Wallis H-tests. Correlation was used only where both variables were ordinal or continuous. Because the SCM lever, intervention theme, geographic context and material focus variables are nominal, associations involving them are reported using chi-square and Kruskal–Wallis tests rather than correlation coefficients, which would otherwise depend on an arbitrary ordering of categories. The DSAR is deliberately restrictive: it records only the lever identified as primary in each case, so it measures the prominence of digital and data tools as a lead mechanism rather than their presence anywhere in the supply chain. Since the dataset does not code with secondary or supporting levers, a broader digital presence rate cannot be derived from it, and the DSAR should be read as a conservative lower bound on digital engagement.

4. Findings

4.1. SCM Lever Distribution and Waste Hierarchy Positioning

Table 3 summarises the distribution of primary SCM levers across the 75-case dataset. Coordination and partnerships are the dominant lever (46.7%, $n = 35$), followed by other SCM practices such as modular construction, logistics innovations and stewardship arrangements (32.0%, $n = 24$). Digital and data levers remain comparatively limited (DSAR = 15.1%), while procurement and contract levers account for only 4.0% of cases.

Table 3. Distribution of primary SCM levers across the 75-case dataset.

SCM Lever (Primary)	Cases (n)	Share of Total
Coordination/partnerships	35	46.7%
Other SCM practices (modular, logistics, stewardship)	24	32.0%
Digital/data (DSAR)	11	14.7%
Procurement/contracts	3	4.0%
Not applicable	2	2.7%
Total	75	100.0%

Figure 1 illustrates the lever distribution as a horizontal bar chart, making the scale of coordination and partnership dominance apparent and providing a visual reference for the pattern discussed throughout this section.

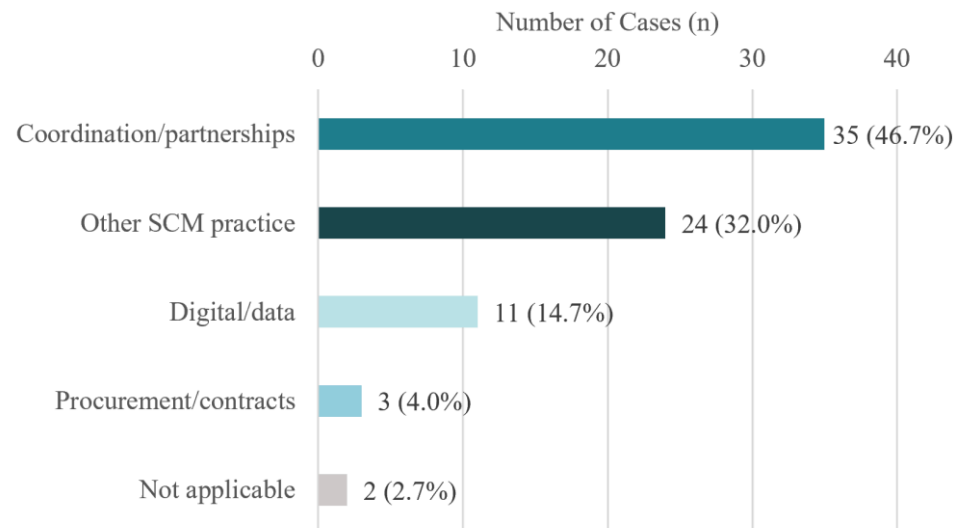


Figure 1. Primary SCM levers.

The waste hierarchy distribution also shows an upstream orientation: prevention/design-out accounts for 36.0% of cases ($n = 27$), reuse/relocation for 17.3% ($n = 13$), recycling for 25.3% ($n = 19$), recovery for 6.7% ($n = 5$), disposal/landfill for 2.7% ($n = 2$), and not applicable for 12.0% ($n = 9$). This produces a WHI of 77.6%, indicating that, on a weighted basis across the full hierarchy, SCM effort is oriented toward higher-value options, with a substantial share at the prevention and reuse levels. Table 4 summarises the main inferential results used to interpret these patterns.

Table 4. Summary of quantitative associations in the case dataset.

Analysis	Variables	Dataset	Result	Interpretation
Descriptive metric	WHI	66 active cases	77.6%	Indicates a stronger overall SCM orientation toward higher-value options.
Descriptive metric	DSAR	73 cases with stated lever	15.1%	Digital/data tools are under-used as the primary SCM lever.
Chi-square test	Intervention theme $\times$ waste hierarchy position	75 cases	$\chi^2(25) = 80.20$, $p < 0.001$	Intervention themes and hierarchy positions are systematically related. Coordination and design-led themes cluster with prevention/reuse, while site operations cluster with recycling/recovery.
Kruskal–Wallis H-test	Waste-reduction percentage $\times$ intervention theme	28 cases	$H(3) = 2.20$, $p = 0.53$	Waste reduction does not differ significantly by intervention theme alone. Configuration appears more explanatory than single-theme classification.
Kruskal–Wallis H-test	Waste-reduction percentage $\times$ SCM lever	28 cases	$H(2) = 5.39$, $p = 0.067$	Waste reduction does not differ significantly by primary SCM lever. The near-significant result reflects lower performance among other SCM practices (mean rank 6.90) rather than an advantage of coordination (16.36) over digital levers (14.00).

Figure 2 visualises the waste hierarchy distribution across the active 66-case subset.

Overall, the results indicate that SCM optimisation is not explained by one isolated tool. Instead, higher performance is associated with configurations that combine coordination, upstream decision-making and context-appropriate digital or procurement support.

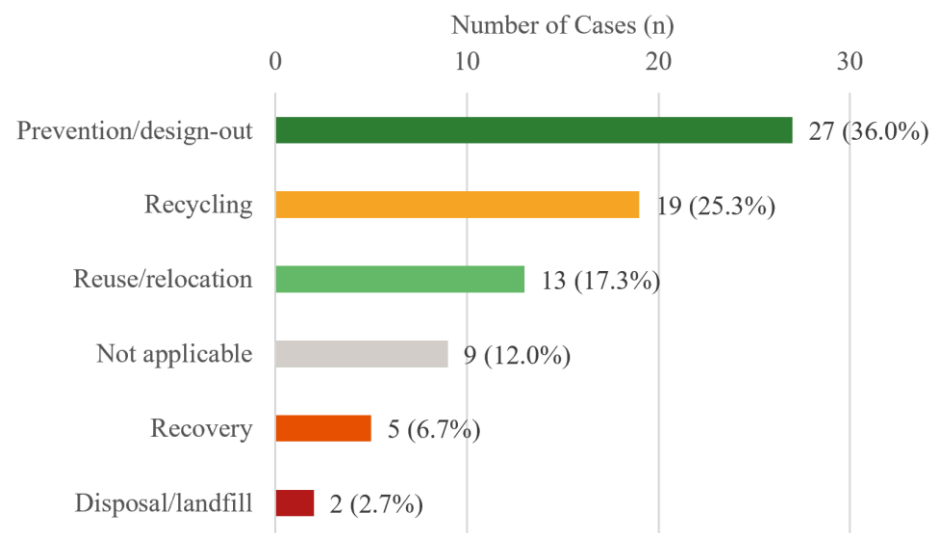


Figure 2. Waste hierarchy distribution.

4.2. Early Contractor Involvement and Design-Phase Integration

More than 80% of a project's environmental impact is determined at the design stage [48], yet most contractors are still engaged after design completion [49]. This secular mismatch between design authority and constructor expertise is the structural obstacle that ECI is designed to address.

Three NZ case examples illustrate the magnitude of the available gain. The Albany Primary School project, which combined ECI, an integrated design process (IDP), and modular coordination, achieved 88% waste diversion, an 18% cost saving and a three-week schedule advance, as reported in an interview with one construction industry practitioner. The Auckland Waste Minimisation Partnership, organised around early multi-stakeholder coordination, delivered a 41% landfill reduction over two years through coordinated material exchange. A dimensional coordination case achieved an 86.6% reduction in timber offcuts by aligning drawer and sheet-material dimensions at the design stage. As one practitioner observed, “by the time the contractor's engaged, all the decisions have been made”.

Through the Dynamic Capabilities lens, ECI operates as a seizing capability: it is the organisational routine that converts design-stage sensing (waste data, material availability, buildability assessment) into procurement action before lock-in occurs. The empirical pattern in this study is that ECI does not merely accelerate procurement but reshapes the procurement decisions themselves, lifting case performance into Bands 3 and 4 of the diversion-rate distribution.

Beyond the headline cases, the interview material adds nuance to the ECI mechanism. Practitioners consistently distinguish between formal ECI being a contracted design-stage undertaking and informal ECI comprising early conversations between client, designer and trusted contractor in the absence of a formal contract. Formal ECI is associated with the largest cost and waste improvements but requires procurement reform; informal ECI is more common but is fragile across changes in client personnel and project scope. The implication for policy is that mandating formal ECI on projects above a defined capital threshold would secure waste savings that the sector currently captures only intermittently through informal practice.

These findings reframe ECI as fundamentally a procurement instrument with direct economic returns, rather than merely a collaborative practice. Formal ECI creates a contractual allocation of design-stage responsibility that internalises the contractor's construction-phase waste and rework costs into the pre-commitment procurement cal-

culus, as evidenced by the Albany 18% cost saving. Kadefors [42] identified analogous procurement-policy tensions in Scandinavian public infrastructure, where prior marketisation policies prescribing low client involvement generated institutional resistance to relational contracting reform and project-level performance variation within the same procurement framework. The NZ evidence mirrors this dynamic: without formal procurement mandates, ECI-enabled cost savings are captured only intermittently, concentrated in projects where client governance and practitioner relationships happen to permit early engagement. The implication for construction economics is direct: informal ECI is not a substitute for procurement reform but evidence of the cost gap that reform would close.

4.3. Digital SCM Tools and the Golden Thread

The DSAR for the full dataset is 15.1%, falling to 7.1% in the 28-case quantitative subset. The DSAR records how often digital tools are the primary lever, so it measures adoption rather than efficacy, and a low rate should not be read as evidence that digital tools underperform. The proven SCM benefits of digital tools are not in dispute: BIM-integrated waste estimation achieves 89–94% material classification accuracy and reduces over-ordering by 17–24% [17]; BIM/IFC-based materials passports generate building-level recyclability metrics that support both procurement and deconstruction planning [22]; and the CIF framework provides a coherent target architecture across completeness, availability, accessibility and business-strategy integration [21]. The Good Wrap and Proclimar QR-coded collection systems also illustrate how closed-loop tracking can operate at project level in NZ. Since the SCM lever variable is nominal, the relationship between lever and waste-reduction percentage was tested with a Kruskal–Wallis H-test rather than a correlation coefficient. Across the three levers represented in the quantitative subset, the test does not reach the conventional significance level, $H(2) = 5.39$, $p = 0.067$. The mean ranks indicate that this near-significant result is driven by cases coded to other SCM practices (mean rank 6.90, $n = 5$) performing below both coordination and partnerships (16.36, $n = 21$) and digital and data (14.00, $n = 2$), rather than by any difference between coordination and digital levers. With only two digital-led cases in the subset, no inference can be drawn about the relative performance of coordination against digital tools, and none is claimed here.

Three observations support this analysis. First, the SME-dominated NZ sector lacks the BIM capability, digital literacy and integration capacity required to convert digital potential into systemic outcomes. Second, the digital landscape is fragmented; as one practitioner remarked, “everyone’s got their own system and none of them talk to each other”. Third, through the Socio-Technical Systems lens, digital tools without relational restructuring are adopted piecemeal and fail to achieve the systemic effects predicted in the literature. The low DSAR is not evidence against the potential of digital SCM. It indicates that, in the NZ cases examined, digital levers appear as components of coordination-centred arrangements rather than as standalone primary levers. Both digital-led cases in the quantitative subset achieved 80–89% diversion, which is consistent with digital tools performing well where they are deployed but seldom leading the configuration.

A complementary observation relates to the nature of digital tools that do appear in high-performing cases. They are typically narrow, task-specific applications, such as a QR-coded collection bag, a project-level material-tracking spreadsheet, a BIM clash-detection routine, etc., rather than enterprise-wide digital platforms. The pattern is consistent with the SME constraint identified above and with the Socio-Technical Systems argument that digital tools succeed where they are linked to the social and organisational structures that exist, rather than where they require those structures to be rebuilt around them.

The economics of digital adoption in the NZ context reveal a cost-to-opportunity asymmetry. The investment required to establish digital tracking infrastructure for a single

project typically exceeds waste-cost savings achievable from digital tools alone in an SME-dominated market without the relational structures that would allow that investment to be amortised across projects and supply chains. Papadonikolaki et al. [50] demonstrated in their analysis of BIM-enabled supply chain partnerships that relational, collaboratively structured arrangements diffuse BIM benefits across supply chains more effectively than transactional ones, which is the organisational form absent in the 85% of NZ cases that deploy no digital levers. Dowsett and Harty [51] reinforce this finding, showing that when organisational dimensions of BIM adoption receive limited attention, the technology yields only narrow technical productivity gains rather than the systemic SCM efficiencies reported in the wider literature. The 7.1% DSAR in the high-performing subset is, therefore, not a refutation of digital SCM's economic potential; rather, it is empirical evidence of the organisational infrastructure investment that must precede digital returns in the NZ construction sector.

4.4. Collaboration, Partnerships and Reverse Logistics

Strategic partnerships and reverse-logistics infrastructure dominate the high-performance band of the dataset. The Good Wrap scheme illustrates that through supplier–installer–recycler partnerships, the scheme achieves 95% clean-wrap rates and uses existing freight back-haul networks for reverse logistics, requiring no new physical infrastructure. The Auckland industrial symbiosis network coordinates approximately 580 tonnes of monthly diversion through inter-firm material exchanges. Material banks for structural steel reuse achieve 68% reuse rates in commercial retrofits [22].

The partnership pattern aligns with the ISM-MICMAC analysis of Sonar et al. [32]: knowledge and awareness barriers and regulatory deficiencies are the root causes that drive operational failures in reverse logistics; these barriers can be removed through shared learning and self-imposed standards by coordinated partnership networks. The evolutionary game modelling of Ma and Zhang [33] reinforces this finding by showing that coordination-based configurations require government subsidies, rather than penalties alone, to reach circular equilibrium.

Within the performance bands, the dataset reveals a noteworthy pattern: coordination/partnerships represent the SCM lever in 100% of Band 4 cases ($\geq 90\%$ diversion). As one senior practitioner reflected, “the projects where we got the best outcomes were where everyone was around the table from day one”. Through the Lean Construction lens, coordination is the construction-SCM equivalent of the pull signal: it creates the demand alignment that triggers circular material flows. Where coordination is absent or weak, even well-resourced digital and procurement levers fail to produce upper-band performance.

Figure 3 visualises the lever composition of the four performance bands. Coordination and partnerships are present at every diversion level and are the only lever in Band 4 ($\geq 90\%$ diversion, $n = 4$). Cases coded to other SCM practices are concentrated in the lower bands, accounting for four of the 11 cases below 80% diversion but only one of the 17 at or above it. Both digital-led cases appear in Band 3 (80–89%). This pattern is consistent with the Dynamic Capabilities argument that sensing, seizing, and reconfiguring capabilities operate together, but with only four cases in the highest band it should be read as indicative rather than conclusive.

A second feature of the partnership pattern is the role of intermediaries. In each high-performing partnership case, an intermediary actor, i.e., a stewardship scheme operator, a council waste team, or an industrial symbiosis facilitator, absorbs the transaction costs that would otherwise prevent SMEs from participating. Intermediation explains why partnership-based outcomes are reproducible at SME scale, despite the resource constraints that prevent the same firms from sustaining bespoke bilateral arrangements. The policy

implication is that subsidising intermediation is likely to be a higher-leverage intervention than subsidising firm-level capability uplift, particularly in a sector, 95% of which consist of SMEs.

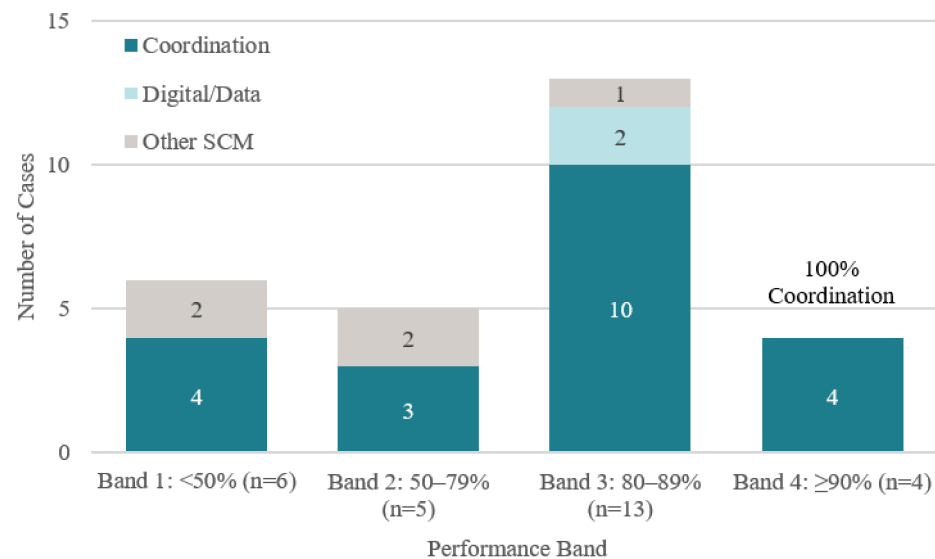


Figure 3. Primary SCM lever composition (28-case subset).

The economic benefits of the partnership pattern deserve further elaboration. High-performing arrangements generate value through three distinct economic channels: avoided disposal fees—for instance, at NZ\$65 per tonne, the Auckland symbiosis network’s 580 tonnes per month represents approximately NZ\$453,000 in annual avoided disposal costs, before accounting for recovered material value; back-haul cost-sharing through reverse logistics, as the Good Wrap zero-new-infrastructure model demonstrates at commercial scale; and relational capital that reduces procurement transaction costs across repeated project engagements.

4.5. Configuration Archetypes

Cross-tabulating SCM lever, intervention theme, waste hierarchy position and scale across the high-performance segment of the dataset yielded three dominant configuration archetypes (Table 5).

Table 5. Three dominant high-performing SCM configuration archetypes.

Archetype	Core Components	Performance Signature	Theoretical Interpretation
A1. Design-out + Coordination + Prevention	IDP/ECI; relational procurement; Design-for-Disassembly (DfD); upstream waste hierarchy positioning.	Highest diversion rates (Band 4 ≥ 90%); highest cost-saving incidence (e.g., 18% Albany).	Full triple-capability deployment in Dynamic Capabilities terms (sense + seize + reconfigure); lean “design-for-manufacture.”
A2. Site Operations + Coordination + Recovery/Recycling	On-site source separation; stewardship partnerships; coordinated recycling relationships.	Moderate-to-high diversion (Band 2–3); reliable cost-neutral performance.	Partial capability deployment: strong seizing/reconfiguring, limited sensing.
A3. Combined Multi-Lever + Prevention	Simultaneous digital + coordination + procurement reform; observed mainly in international cases.	Highest ambition configurations; performance contingent on institutional context.	Full triple-capability deployment plus institutional scaffolding (subsidy/penalty mix).

A central observation is that all three archetypes include coordination/partnerships as a core component. Digital tools appear as accelerators within coordination-focused archetypes, not as standalone configurations. Through the Dynamic Capabilities lens, Archetype 1 represents full triple-capability deployment (sensing via BIM-supported waste estimation, seizing via ECI, reconfiguring via IDP). Archetypes 2 and 3 represent partial capability deployment, which is effective but sub-optimal without the full configuration.

The configuration evidence directly addresses RQ; that is, SCM optimisation in NZ circular construction is achieved through complementary, multi-lever configurations focused on coordination and partnerships, with digital and procurement levers serving as accelerators. No single lever can achieve Band 4 performance in isolation.

The economic logic of archetype membership is reflected directly in contract structure. Archetype 1 employs relational procurement models (integrated design processes, alliance-type ECI arrangements) that shift risk allocation upstream and enable the designing-out of waste at the point of maximum design influence, before costs are committed. Archetype 2 achieves cost neutrality through avoided disposal rather than upstream prevention, i.e., source separation and stewardship costs are offset by avoided landfill fees with zero design-stage value creation. Archetype 3 configurations involve platform-level digital procurement economies that remain largely inaccessible at current NZ project volumes. This tiered economic structure corresponds with the relational contracting framework of Kadefors et al. [44], which postulates that the policy ambiguity and limited client resources in public procurement organisations produce precisely the project-level variation between Archetype 1 and Archetype 2 outcomes observed in this paper, with Archetype 1 performance remaining contingent on deliberate procurement design rather than embedded sector-wide practice.

Two cross-archetype patterns should be highlighted. First, the relationship between archetype membership and performance band is asymmetric: Archetype 1 cases concentrate in Bands 3 and 4, Archetype 2 cases concentrate in Bands 2 and 3, and Archetype 3 cases, which are predominantly international, populate Bands 3 and 4 in jurisdictions with supportive policy governments. Within the NZ subset, Archetype 1 is the only configuration consistently associated with Band 4 outcomes. Second, the cost performance of the archetypes diverges from the waste performance. Archetype 1 cases tend to combine the highest waste outcomes with positive cost effects, with the Albany 18% saving being a prime example, because waste prevention upstream eliminates the procurement, handling and disposal costs that would otherwise accompany downstream-oriented configurations. Archetype 2 cases tend to be cost-neutral, recovering the cost of source separation and stewardship through avoided disposal fees. Archetype 3 cases, observed mainly internationally, often involve a one-off capital outlay, for instance on a digital platform, materials passport infrastructure, etc., that is amortised across multiple subsequent projects.

Further observation concerns project scale, where the dataset does not support inference. The scale variable records the unit of analysis of each case, distinguishing project or site, programme, national, and international or comparative levels, rather than project size or capital value. A national-level case is not a larger project but a different level of aggregation, so the variable cannot be treated as an ordinal measure of scale, and no variable in the dataset records capital expenditure. What the cases do show is that Archetype 1 outcomes are not confined to large projects: the Albany Primary School case reached them on a small project where ECI and integrated design were embedded in procurement. Whether scale independently conditions configuration adoption remains an open question requiring scale-stratified sampling with recorded project values.

5. Discussion

5.1. Addressing the Research Question and Hypotheses

The findings answer the overarching RQ by showing that SCM optimisation in NZ circular built environment projects is achieved through coordination-centred configurations rather than through isolated digital, procurement or logistics tools. In response to RQA, coordination and partnerships are the most common SCM lever, appearing in 46.7% of all cases, while digital/data tools remain relatively rare as the primary lever. This pattern suggests that the sector's current optimisation capacity is relational rather than technological.

For RQB, digital tools, ECI, partnerships and reverse logistics each contribute to circular performance, but their effects differ. Digital tools improve visibility, waste estimation and material tracking, yet the DSAR of 15.1% indicates limited primary adoption. ECI and IDP shift decision-making upstream, where waste can be designed out before specification and procurement lock-in. Partnerships and reverse logistics provide the coordination infrastructure needed to convert material recovery from a project-level aspiration into a workable supply-chain practice.

For RQC, the evidence indicates that lever choice and configuration are associated with circular outcomes, but more weakly than initially anticipated. The association between intervention theme and waste hierarchy position is significant ($\chi^2(25) = 80.20, p < 0.001$), supporting the argument that configuration shapes where interventions sit on the waste hierarchy. The comparison of waste-reduction performance across SCM levers, however, is not significant ($H(2) = 5.39, p = 0.067$), and the non-significant Kruskal–Wallis result for intervention theme alone ($H(3) = 2.20, p = 0.53$) cautions against over-claiming the effect of any single intervention type. The configuration evidence in Section 4.5 is therefore distributional rather than inferential, and the proposition that lever configuration predicts measured diversion is not confirmed on this dataset.

For RQD, the configuration archetypes show that the strongest pathway combines design-out, coordination and prevention. Digital and procurement tools are therefore best understood as accelerators within coordination-led configurations, not substitutes for relational SCM. The practical implication is that NZ policy and industry should prioritise ECI, relational procurement, shared material-exchange infrastructure and open digital standards that enable SMEs to participate in circular supply chains.

5.2. Theoretical Contributions

The study makes four primary theoretical contributions, each of which connects an established theoretical lens to a quantified empirical consistency in the dataset.

First, in Dynamic Capabilities terms, the configuration archetype analysis shows that circular SCM optimisation requires simultaneous deployment of all three capabilities: sensing, seizing and reconfiguring. Partial deployment, i.e., coordination or digital alone, yields lower performance than the full triple-capability configuration represented by Archetype 1.

Second, for Lean Construction, the WHI of 77.6% provides a quantitative measure of the upstream orientation of the NZ sector. The sector already directs more SCM effort to prevention and reuse than to recycling, recovery and disposal. The remaining 22.4% gap, however, identifies an opportunity for Lean Construction to eliminate downstream-oriented SCM through pull-workflow redesign of procurement and specification processes. The WHI thus operationalises lean waste-hierarchy preference as a measurable management metric.

Third, for the Socio-Technical Systems Theory, the DSAR quantifies one dimension of the social–technical gap in the NZ context. No case in Band 4 records digital and data as its primary lever, while coordination and partnerships are present in all four, which is difficult

to reconcile with the assumption that digital tools are the primary optimisation lever. The more defensible reading is that social coordination is the recurring requirement, and digital tools operate as enablers within it. The two digital-led cases in the subset both achieved 80–89% diversion, indicating that digital levers perform well where adopted but are seldom adopted as the lead mechanism. The DSAR, like the WHI, can be re-applied to other geographies and time periods to compare the social–technical maturity of construction supply chains.

Fourth, for the reverse-logistics literature, the ISM-MICMAC barrier analysis of Sonar et al. (2024) [32] is given NZ-specific empirical validation: knowledge/awareness and regulatory deficiencies are the root-cause barriers, with the Good Wrap scheme and Auckland industrial symbiosis network indicating that viable reverse logistics can operate through existing infrastructure when coordination fills the regulatory gap. The implication for theory development is that reverse logistics in construction should be modelled as a co-ordination problem with logistics characteristics, rather than as a logistics problem with coordination characteristics; the dataset shows the latter framing systematically misallocates intervention effort.

The fifth contribution is methodological. The combination of NVivo-based RTA, SPSS inferential analysis, and configuration archetype analysis demonstrates an analytical conduit that other researchers in geographically remote, SME-dominated sectors can adapt. The conduit is replicable: cases are coded against a small set of categorical variables such as the intervention theme, SCM lever, waste hierarchy position, scale, and geographic context; a quantitative subset is used to test inferential associations; and configuration archetypes are generated by cross-tabulating high-performing cases. The use of two new metrics of WHI and DSAR anchors the analysis in measurable concepts that can be compared across studies, which addresses one of the secondary literature gaps identified in Section 2.2.

5.3. Implications for Practice

For contractors, the priority is to build coordination capability before investing in digital systems. ECI protocols, long-term supplier relationships and material exchange partnerships create conditions under which digital tools can generate value. For clients and project owners, procurement should include early circular material planning, ECI, and whole-life cost evaluation rather than lowest-tender selection alone.

For industry bodies and policymakers, the findings support investment in shared infrastructure: material exchanges, product stewardship schemes, industrial symbiosis networks, common material classification standards and open waste-data systems. These interventions reduce the burden on SMEs and allow circular SCM capability to be shared across projects.

For researchers, configuration-level analysis is a more productive approach for circular SCM than individual-lever studies. The three archetypes identified in this article provide a testable framework for future NZ and international research, particularly for replicating the WHI and DSAR metrics across comparable economies. Both metrics could also be incorporated into existing SWMP and sustainability-reporting frameworks at relatively low cost and would create the longitudinal evidence base that this cross-sectional study cannot provide on its own.

The implications also extend to the metrics used in the sector. WHI offers a way to quantify upstream orientation that is comparable across projects, organisations, and time periods. This indicator is agnostic to differences in project scope and material composition, since it is calculated based on the share of weighted SCM effort rather than on absolute waste volumes. Similarly, the DSAR offers a measure of digital SCM penetration. Both metrics could be incorporated into existing SWMP and sustainability-reporting frameworks

at relatively low cost and would create the longitudinal evidence base that this cross-sectional study cannot provide on its own.

5.4. Limitations

Five limitations should be acknowledged. The study is cross-sectional, so dynamic effects of SCM configuration over the project life cycle cannot be directly measured. The NZ-specific context, while a deliberate choice, limits external validity to comparable geographically remote, SME-dominated economies. The 15-interview elite sample, while purposively diverse, is weighted toward larger firms with the resources to engage in formal circular initiatives, which may understate the constraints facing smaller firms and qualify the practice recommendations in Section 5.3. Only 28 of the 75 cases include quantified waste-reduction percentages, and the DSAR records only the primary SCM lever, so multi-lever interactions within cases are partially abstracted from the analysis. Finally, the quantitative subset is small and unevenly distributed across levers, with only two digital-led and five other-practice cases, which limits the statistical power of between-lever comparisons and precludes effect-size estimation; the configuration findings should therefore be treated as hypotheses for larger-sample testing rather than as established relationships. These limitations point directly to the future research agenda outlined in the conclusion.

A further methodological caveat applies to the practitioner-perspective evidence. The corresponding author's long industry experience provides contextual fluency, but it also creates the possibility that the SCM levers most familiar to the practitioner community are over-represented relative to less visible alternatives. Triangulation across cases, interviews, and documentary evidence, together with the inclusion of international benchmarks that did not feature in the practitioner experience base, has been used to mitigate this risk; readers should nevertheless interpret the configuration archetypes as a robust account of high-performing patterns observable in the dataset rather than as an exhaustive account of all theoretically possible pathways.

6. Conclusions

This study investigated how SCM practices can be optimised to enhance the performance of NZ BE projects under CE constraints. The evidence shows that optimisation is achieved through complementary, coordination-centred configurations rather than through isolated digital, procurement, or logistics tools. Coordination and partnerships appear in 46.7% of cases and all highest-performing cases, while digital tools serve mainly as accelerators within wider relational configurations.

The quantitative results qualify this conclusion rather than confirm it. The DSAR of 15.1% shows that digital/data tools are seldom the primary SCM lever, while the WHI of 77.6% indicates an orientation toward higher-value options on the waste hierarchy. The association between intervention theme and waste hierarchy position is significant ($\chi^2(25) = 80.20, p < 0.001$), but neither the comparison of waste-reduction performance across SCM levers ($H(2) = 5.39, p = 0.067$) nor that across intervention themes ($H(3) = 2.20, p = 0.53$) reaches significance. The configuration argument therefore rests on the recurrence of coordination-centred arrangements among the highest-performing cases rather than on a demonstrated statistical effect, and testing it will require a larger measured sample.

Three archetypes summarise the empirical pattern. The strongest pathway combines design-out, coordination and prevention; the second combines site operations, coordination and recovery; and the third involves multi-lever configurations, mainly in international cases with stronger institutional support. For NZ, the practical priority is therefore to embed ECI and IDP, strengthen relational procurement, build shared digital infrastructure,

develop reverse-logistics and material-exchange networks, and require SWMP reporting that captures coordination and material-flow planning rather than compliance alone.

Five practical recommendations for industry are as follows:

1. Embed early contractor involvement and integrated design processes as default requirements in public construction procurement.
2. Adopt relational procurement and long-term partnership frameworks in place of single-project lowest-tender contracting.
3. Invest in shared digital infrastructure with open material classification standards and BIM waste plug-ins designed for SMEs.
4. Develop product stewardship and industrial symbiosis networks that capitalise on existing freight back-haul capacity.
5. Mandate site waste management plan (SWMP) reporting that includes coordination requirements rather than compliance checklists alone.

Future research should test these archetypes longitudinally, replicate WHI and DSAR in comparable economies, and examine SME digital adoption pathways in more detail. Overall, the study shows that circular SCM optimisation in NZ is fundamentally relational, with digital and contractual reforms acting as enablers of coordinated supply-chain performance rather than substitutes for it.

Two further avenues are worth exploring. Configuration analysis lends itself to qualitative comparative analysis (QCA) techniques that can identify necessary conditions for high performance across larger case samples. Case studies that track individual SMEs through the adoption of partnerships and digital arrangements over multiple projects would provide the longitudinal evidence base required to distil the practical recommendations into specific implementation playbooks. Together, these avenues would translate the system-level findings of this study into operational guidance at the level where most NZ construction work is delivered.

In conclusion, the empirical evidence presented in this paper supports a clear answer to RQ. SCM optimisation for circular built environment projects in NZ is best understood not as a question of choosing the right individual lever but as a question of compiling the right configuration of levers around a coordination-led core. Once coordination is established, digital tools, procurement reform and reverse-logistics infrastructure each amplify performance; if coordination is missing, no individual lever has been shown to deliver Band 4 outcomes. The optimisation programme for the sector is fundamentally relational, with digital and contractual reforms serving as enablers of relational performance rather than as substitutes for it.

Author Contributions: Conceptualisation: J.T. and K.S.; methodology: J.T. and K.S.; formal analysis: K.S.; investigation: K.S.; data curation: K.S.; writing—original draft preparation: K.S.; writing—review and editing: J.T., F.E.R. and K.D.; visualisation: K.S.; supervision: J.T., F.E.R. and K.D.; project administration: K.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Ethics Committee of Auckland University of Technology (Ethics Application 24/360, 7 October 2025).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The original data presented in the study are openly available in <https://doi.org/10.6084/m9.figshare.32962283>.

Conflicts of Interest: The authors declare no other conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

SCM	Supply Chain Management
NZ	New Zealand
WHI	Waste Hierarchy Index
DSAR	Digital SCM Adoption Rate
C&D	Construction and Demolition
SMEs	Small and Medium-sized Enterprises
CE	Circular Economy
BE	Built Environment
ECI	Early Contractor Involvement
RQ	Research Question
BIM	Building Information Modelling
CIF	Circular Information Flow
ANFIS	Adaptive Neuro-Fuzzy Inference System
IFC	Industry Foundation Classes
DfD	Design-for-Disassembly
UK	United Kingdom
EU	European Union
RTA	Reflexive Thematic Analysis
IDP	Integrated Design Process
ISM	Interpretive Structural Modelling
MICMAC	Cross-Impact Matrix Multiplication Applied to Classification
SWMP	Site Waste Management Plan
QCA	Qualitative Comparative Analysis

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