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Reverse Logistics Performance Indicators for the Construction Sector: A Building Project Case

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Abstract: While the performance evaluation of reverse logistics (RL) practices in the construction sector is crucial, it is seemingly limited compared to that in the manufacturing sector. As the project life cycle in the construction sector is typically long, effective coordination among the stakeholders is needed to integrate RL into each phase of the project life cycle. This paper proposes a new model of RL for the construction industry, incorporating the dimensions, elements, and, most importantly, indicators needed for the evaluation of RL performance. The model was initially derived from the extant literature. It was then refined through (1) focus group discussion, by which suggestions pertinent to the proposed model were collated from academics and practitioners, and (2) judgments by academics and practitioners to validate the model. The validated model includes 21 indicators to measure RL performance, spanned throughout the green initiation, green design, green material management, green construction, and green operation and maintenance phases. The paper offers a new method for how RL can be adopted in the construction industry by proposing an innovative model that will benefit stakeholders in the construction industry.

Keywords: performance evaluation; project life cycle; reverse logistics; construction; indicators

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1. Introduction

In recent years, environmental problems have become a serious issue in construction projects. The construction industry generates a significant amount of waste, which may have negative impacts on society and the environment [1,2]. Construction waste can typically be categorized as solid waste (e.g., garbage, mud, air pollution, and CO_2 emissions) and non-solid waste (e.g., delay, rework, and over costing during the construction process) [2]. According to a report by the United Nations Environment Program (UNEP), the building sector accounts for up to 40% of global annual energy consumption and 20% of global annual water usage and contributes 40% of global annual total waste as a result of building construction and demolition activities [3]. Urbanization has increased the demand for buildings and infrastructure, which in turn leads to the consumption of material resources, water, and energy and generates large quantities of material waste throughout the project's lifespan [4]. For example, Surahman et al. [4] reported that the volumes of demolition debris and waste in a major city in Indonesia (Jakarta) reached approximately 123.9 million tons between 2012 and 2020, all of which went to landfills. The production of Hebel light bricks used as constituent materials for building projects also generates 6.88% (4021.8 m^3) of waste per month [4].

Against this backdrop, the strategies proposed in the extant literature have been mostly geared toward improving construction supply chain management (SCM) by minimizing waste and adding value by conducting effective stewardship of information and refining logistics [5–7]. Green SCM (GSCM) aims to manage construction business processes in a more environmentally friendly manner [8,9]. GSCM in the construction sector typically follows a project life cycle (PLC) that includes green initiation, green design, green materials management, green construction, and green operations and maintenance (O/M) phases [10].

Reverse logistics (RL) is a subset of GSCM. Reusing, recycling, and remanufacturing are considered to be RL functions that ensure the attainment of GSCM [8]. Implementing RL is regarded as a "remedial" measure that moderates the detrimental impacts of construction projects on the environment and enables construction industries to be more efficient, gaining economic benefits and sustainable competitiveness [11,12]. RL aims to recover waste generated by construction activities, simultaneously maximizing the retained value of construction materials and reducing the costs of waste management [12,13].

However, RL appears to be implemented less frequently in the construction sector than in the manufacturing sector. One reason for this deficiency is the fact that the product life cycle in construction is generally long—much longer than in the manufacturing sector. Unlike in the manufacturing industry, where RL is typically well integrated and considered from the beginning of the product development stage, RL in the construction industry has been treated as an independent activity. Coordination between stakeholders is therefore critical to integrate RL into each phase of the PLC [14]. In this way, the design practice for deconstruction would allow a systematic demolition of buildings conducted in such a way that the demolition materials remain high in value and the amount of material damage is reduced. To maximize RL in the construction sector, construction practitioners require the awareness and know-how to incorporate RL concepts (values) from the initiation phase [12]. This step must be supported by an adequate capacity in the construction sector to evaluate the performance of RL practices [15]. Hosseini et al. [16] conducted one such study of RL practices in the construction sector, while Farida et al. [17] incorporated RL to measure the performance of green construction. Pushpamali et al. [12] attempted to incorporate RL into various decisions made by the project owners at the preconstruction stage; however, arguably their work only provided a conceptual scheme of RL decisions in construction. Finally, Hammes et al. [15] developed a measurement tool for RL performance during the construction phase carried out by the contractor, involving supplies, internal logistics, and waste management.

The study discussed in this paper focuses on the development of a performance measurement system for RL in accordance with the constructions' PLCs. The paper also proposes a new model of RL in the construction industry, along with the dimensions, elements, and indicators for the evaluation of RL performance throughout the PLC. The contributions may offer substantial benefits for stakeholders in the construction industry related to coordination and collaboration.

The remainder of the paper is structured as follows. We first review the literature on waste in the construction industry, green SCM, RL in manufacturing and construction, and performance evaluations of RL. Based on the literature review, we conceptualize the performance evaluation of RL in construction. This conceptualization provides a research framework related to the theme design and conceptual relationships. We then proceed to develop and examine the measurement of RL performance in the construction industry through focus group discussion (FGD) and expert judgments. We conclude with the results and discuss the theoretical contributions and practical implications of the research.

2. Literature Review

2.1. RL Concept and Applications

RL is traditionally triggered by the need for product returns in retail sectors [18]; manufacturers may return raw materials to their suppliers because they are of poor quality, in excess or in surplus in another way, unused, or out-of-specification. Manufacturers may also recall their products, such as car braking systems, due to manufacturing defects, commercial returns, unsold out-of-season products, or wrong deliveries. Finally, in many countries, customers have the right to return items because they are unwanted or, according to warranty, at the end of life or end of service.

Economically, companies that choose to carry out RL activities are motivated by the opportunity to recover resources cheaply and add value by transforming them into other resources with higher commercial values. Due to growing competition, many companies are forced to take back and offer refunds for unwanted products from their customers. Other companies act in strategically risk-averse ways by preventing their products or critical components from leaking to their competitors or secondary markets. With the wide spread of product-service system (PSS) business models, many companies sell products as part of their service offering (leasing) and consequently have to take the products (or assets) off the field for service/maintenance and repair [19]. Finally, the regulations and laws pertinent to environmental consciousness, such as extended producer responsibility and the "right to repair law", place extra pressure on manufacturers to adhere strictly to public environmental policy.

While the scope and definitions of RL were initially somewhat limited to the movement of products in the opposite direction to forward logistics [20–22], focus has now shifted to activities within the reverse flow, such as component recovery, reuse, and recycling. RL is gaining the attention of industrialists and academic researchers due to the enormous quantity of waste generation in manufacturing and construction sectors, which is leading to increased environmental pressure [23]. In an expansion of its initial definition, RL now incorporates the process of planning, implementing, and controlling efficiently and effectively the reuse of disposed products [24]. This wider notion largely echoes the classic proposition of Rogers and Tibben-Lembke [25], who extended the definition of RL given by the Council of Logistics Management (now Council of Supply Chain Management Professionals (CSCMP)) to emphasize "the flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal" [25]. Depending on the various underlying motivations, the detailed structure of RL can vary to include activities such as distribution, sorting, reselling, refurbishment, remanufacturing, recycling, and disposal, among others, with the ultimate aim of recapturing the value of products after the point of sales and/or after the end of useful life [9].

Many studies consider RL from the moment the waste is generated and must be sent for recycling or environmentally correct disposal [26]. However, Guarnieri et al. [27] emphasize that RL must be considered for the entire product life cycle, including the planning and design of the productive process. The management of the product life cycle needs industrial synergies within large-scale networks to collect, recycle, reuse, and recover end-of-life products [28]. RL in the manufacturing industry would close the loop of the supply chain at different points, resulting in reusing the products as entire products, modules, or a combination of modules and materials [29].

2.2. RL in the Construction Industry

In this study, RL in the construction industry is defined as the process of planning, practicing, and managing construction items and material flows [16]. It involves information flow for effective construction waste and disposal management in the PLC [10]. The configuration and quantity of building sectors' waste are related to the waste's recycling potential, which is critical to closing material loops and reducing waste and emissions in a circular economy [30].

There is a fundamental difference between the RL concept in the manufacturing and construction sectors. This is due to the difference in the main source of returned items and the stage at which they become available. In the construction industry, major parts of materials become available after the end of life of a building, which may take a long time. This time factor may impede the implementation of RL in many ways in the construction sector and highlights the need to conceptualize RL for particular use within the construction industry due to the observed discrepancies in the associated processes between the manufacturing and construction contexts [16].

In general, RL in construction can be categorized according to the following dimensions: demolition, component recovery, reuse [12,16], deconstruction [31], and recycling [12,16]. Demolition waste is defined as a mixture of surplus materials generated from construction, renovation, and demolition activities [32]. Component recovery involves the reuse of secondary resources instead of recycling [33]. Reuse is the activity of reusing materials without the need for additional processes. Design for deconstruction (DFD) is an approach related to reusing building materials or components that have high durability [31]. Recycling is the activity of reprocessing a material to obtain material of the same quality [16].

Previous studies discussing RL in construction have been limited to individual, specific phases [12,14] due to a lack of knowledge regarding RL and initiating designs that make deconstruction impossible [14]. The deconstruction process becomes difficult to carry out at the end of life of the project if, from its beginning, the project has not been designed using the DFD concept [14]. DFD is an essential strategy when producing a modular product that aims to develop a building with a design that has high durability and easy-to-use materials in the end-of-life phase [31].

The integration of end-of-life strategies into the initiation phase is also critical for successful RL implementation in construction because the amount of material that can be recovered at the end of the building's life is determined by the type and quality of materials used in the new construction. Therefore, RL concepts should ideally be taken into consideration at an early decision (initiation) phase to allow for the collection of recovered materials to be properly managed [12]. An environmentally friendly building that is efficient throughout its life cycle (conception, design, construction, maintenance, and demolition) offers ways to reducing environmental impacts. It can provide more efficient and effective use of materials, water, and energy, thus maximizing the retained value of the construction materials while reducing the costs of waste management [12,15,34,35].

Previous research suggests that RL frameworks developed for the manufacturing industry would equally be effective in other contexts, including the construction industry [36]. For instance, the scenario analysis conducted by Surahman et al. [4] for RL material flows in the building sector would decrease final waste disposal by more than 90%. RL has also been reported to have reduced costs related to the transportation of construction materials by 25% [37]. It has been argued, therefore, that launching RL within a project environment can add value to a construction business [1]. RL, according to the construction literature, could eliminate risks and uncertainties [38], resulting in cost reduction [39] and boosting the efficiency level of the RL system through cooperation between stakeholders involved in the construction industry [12]. This would also reduce the costs of inventory, transportation, and waiting time, indirectly facilitating the minimization of waste within the system. It would also potentially improve the industry's awareness of the benefits of RL, which may result in an increased level of support from top management [40].

This research focuses on the implementation of RL in so-called "closed-loop constructions", in which the processed materials are immediately reused so that the amount of waste is minimized. In past decades, construction and demolition waste (C&DW) was mostly used for road foundations and embankments, which was considered downcycling [41]. However, in recent years, recycling C&DW as aggregates in new concrete has drawn significant attention, with similar interest shown in recycled waste glass or asphalt shingle as a raw material in the manufacture of cement [42]. Previous research has suggested that construction practitioners should give further attention to improving the management of concrete, masonry (bricks and concrete/stone blocks), mortar, and ceramic wastes because these four types of C&DW have the largest potential for recycling [43,44]. In a case study in China, Yuan et al. [45] claimed that the major obstacles in C&DW management were the lack of a well-developed waste recycling market, insufficient regulatory support, and the trend in building designs paying insufficient attention to waste reduction. A similar situation can be found in Indonesia, where stakeholders in the pre-construction phase, such as building owners and design consultants, lack knowledge about how to apply RL in the building construction process [10]. Hence, in the initiation phase, the building owner plays a vital role in creating/building environmentally friendly value by applying RL to the planned construction. Furthermore, the RL concept should be realized in the detailed engineering design (DED) made by the design consultants to facilitate DFD. When these early phases are skipped, the deconstruction process becomes hard to achieve, making the RL implementation in building projects unproductive [14].

2.3. Performance Measures of RL in the Construction Industry

According to Badenhorst [46], it is essential that companies manage all the processes involved in RL efficiently and effectively so that they understand all its aspects. The purpose of performance evaluation in RL is to measure the efficiency and effectiveness of the activities involved in the materials' reverse flow to assess whether these activities can be improved and where it is necessary to invest more resources to increase their benefit [47].

An example of such RL performance evaluation is the ten key performance indicators (KPIs) endorsed by the New Zealand (NZ) government, which address both project and company performances in the construction sector [48]. Although the NZ government intends to endorse a broad set of practical indicators, there is no appropriate KPI to measure logistics performance in the construction industry that is especially pertinent to RL. For performance measurement to be effective, there are several criteria for selecting a KPI. First, a KPI can translate practices and measures into practical knowledge and make it possible to identify and adopt superior performance standards [49]. Performance measures are also used to measure and improve the efficiency and quality of the process and identify opportunities for progressive improvements in process performance. A KPI should be able to measure and monitor the practice, as well as address the characteristics of construction projects that involve many tiers of practitioners on site [50].

Several studies have examined the measurement of RL performance in constructions [15]. Hammes et al. [15] stated several aspects to compare in building RL performance models in the construction industry. However, they focused only on RL performance assessment in the construction phase, which concerns supplies (green purchasing), internal logistics (use of materials, reuse of material, return of investment, and customer satisfaction), and waste management (storage, transportation, and awareness of workers in waste management). Furthermore, the study did not consider the involvement of stakeholders in measuring RL performance; to achieve success in a project, it is important to unify the understanding and perceptions of stakeholders when carrying out the project. For example, Pushpamali et al. [12] found that the role of stakeholders is vital in RL implementation. Pushpamali et al. [12] also stated that in the construction industry, the impact of upstream activities is more substantial than that of their end-of-life counterparts, and the initiation phase is particularly important for successful RL implementation. Therefore, the model used to measure RL performance, which should be integrated into the PLC throughout the initiation, design, material management, construction, commissioning and handover, and O/M phases, needs to be more efficient than that when the measurement is done separately [11,12].

The RL development model in this study was adapted from the scheme of Pushpamali et al. [12] and the GSCM concept in the construction sector developed by Wibowo et al. [10]. This model was also evolved in relation to the concept, dimensions, elements, and indicators of each phase of the PLC through an interview process and FGD with respondents (academic researchers and practitioners) as well as through the literature review. The development framework used to measure RL performance can be seen in Figure 1.

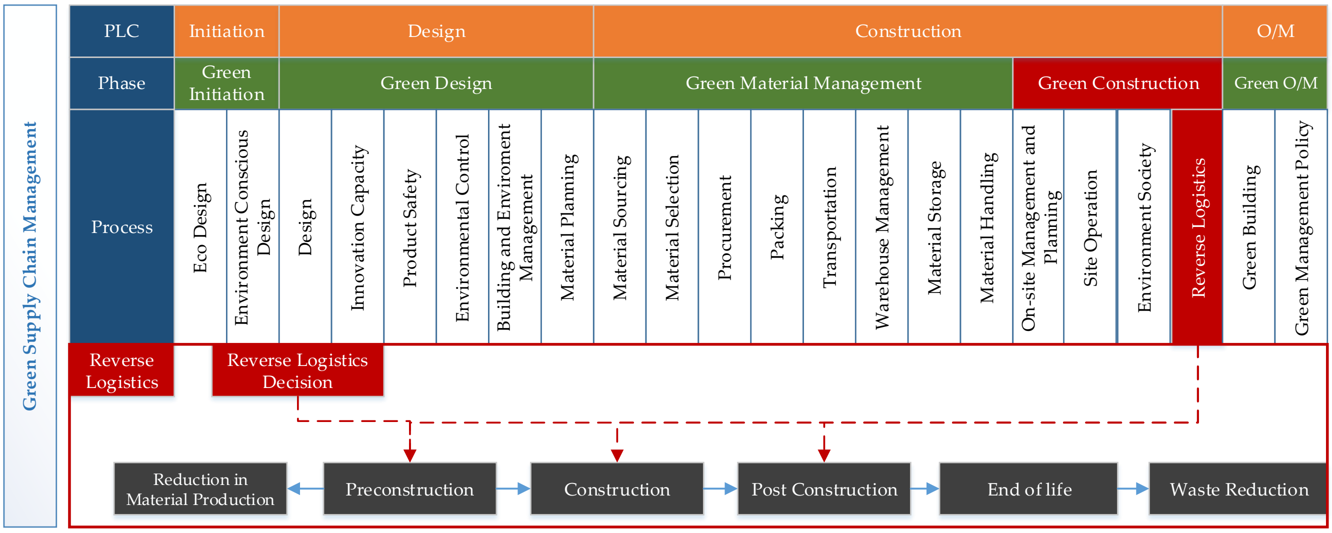

Figure 1. Framework for measuring RL performance (adapted from Wibowo et al. and Pushpamali et al.).

In the construction sector, the implementation of RL starts from the upstream supply chain, which represents all activities before the development process or preconstruction [12]. This development framework also integrates with the GSCM-PLC system, including the green initiation, green design, and green material management phases. The downstream represents all activities carried out after the construction process (postconstruction), such as the green O/M phase and end of life, including waste management and demolition activities [12].

RL should be integrated into the PLC system. However, RL is currently carried out only during the construction phase, or material is recycled after the construction phase. For instance, recycled material, such as the remainder of a cast, will be reused as material for lighter structural work, such as curbs or parking stoppers, in the construction phase. Based on these observations, improvements are needed. Such improvement needs to begin with the measurement of RL performance based on the PLC from the initiation, design, construction, commissioning and handover, and O/M phases to determine the improvement starting point precisely.

Performance measurement tools related to RL have been created in the manufacturing industry. Shaik and Abdul-Kader [51] developed a measurement tool called the overall comprehensive performance index (OCPI), which relates to aspects of financial, process, stakeholder, and innovative perspectives in manufacturing. Bansia et al. [52] also measured RL performance according to financial, customer, internal business, and innovation and growth aspects. Guimarães and Salomon [53] examined the level of urgency of indicators in the implementation of RL, considering recapture value, operation cost, technological innovation, encouragement of recycling, social and environmental acts, employment creation, long-term relationship, differentiated service, and compliance with legislation. Morgan et al. [54] looked at the effect of stakeholder commitment to implementing RL on the company's operational performance through variables, commitment to implementing a sustainable supply chain, commitment to implementing RL, sustainable RL capability, and operational performance.

3. Research Method

The purpose of the study described in this paper is to offer a new perspective on how RL can be adopted in the construction industry from the initiation, design, materials management, and construction phases to the O/M phases. The paper also proposes a new model of RL for the construction industry, along with the dimensions, elements, and, more importantly, indicators for the evaluation of RL performance during the construction's PLC.

The method adopted in this study consists of three major steps: (1) desk-based research to propose the initial RL measurement indicators, (2) FGD to collate suggestions from academics and practitioners regarding the indicators proposed and (3) validation of the indicators, also by academics and practitioners.

First, the proposed performance indicators gathered from the literature were distributed to academics and practitioners from the construction industry via an open questionnaire, which allowed respondents to make recommendations or suggestions about indicators that should be added. It was hoped that this would not only improve the accuracy but also ensure the practicality and completeness of the indicators. The respondents consisted of three academics and 13 practitioners from the construction sector. The 13 practitioners involved in project appraisal were split on the basis of their roles in each phase of the research considering the criteria proposed by Etikan et al. [55], but the academics, whose research focused on green design, RL, and sustainable constructions, partook in assessments of all the phases. These phases comprised the following:

1. Green initiation phase. The respondents who assessed RL performance at this phase were typically project owners as they were able to assess commitment to implementing RL in a construction project.
2. Green design phase. In this phase, the performance assessment was carried out by designers.
3. Green material management, green construction, and green operation maintenance phases. In these phases, contractors and material suppliers were invited as the respondents.

The details of the respondents involved in the indicator suggestion process are listed in Table 1. This sample seemed to satisfy the minimum number of respondents, according to Okoli and Pawlowski [56].

Table 1. Details of the respondents.

Respondent	Role	Job Title/Field of Expertise	Experience (Years)
1.	Academic	Civil engineering	>25
2.	Academic	Environmental engineering	>25
3.	Practitioner	Civil engineer	>25
4.	Practitioner	General manager	>25
5.	Practitioner	Engineer	>25
6.	Practitioner	Head of operation division	20
7.	Academic	Architectural engineering	>25
8.	Practitioner	Assistant manager of engineering and quality	>25
9.	Practitioner	Procurement engineer	5
10.	Practitioner	Supervisor project	>25
11.	Practitioner	Production officer	>25
12.	Practitioner	Project manager	>25
13.	Practitioner	Engineering and standardization officer	4
14.	Practitioner	Building information modeling (BIM) expert	>25
15.	Practitioner	Knowledge management officer	>25
16.	Practitioner	Director of human capital management and system development	>25

Second, the final evaluation model for RL performance was redistributed to the academics and practitioners in the form of questionnaire to allow them to assess the indicators. This questionnaire used a Likert scale to measure the relevance of certain indicators to measuring RL performance. Purposive sampling was also used in this research.

Finally, after all the data from respondents were collected, content validity analysis was carried out by calculating the content validity ratio (*CVR*). *CVR* is a numeric value that indicates the instrument's degree of validity determined by the experts' ratings of content validity. The sequence of steps to validate constructs and indicators using the content validity index is as follows [57]:

- Step 1: Determine the rating scale to be used to validate the constructs, concepts, elements, and indicators. The rating is 1 if the indicator is not relevant, 2 if the indicator is quite relevant, and 3 if the indicator is highly relevant.
- Step 2: Send the questionnaire to the respondents. The minimum number of respondents used to validate the results of the performance measurement indicators is at least ten [56].
- Step 3: Based on the returned responses, calculate the value of the *CVR*, which is a calculation method that linearly transforms the proportion of respondents who agree to the construct, concept, element, and indicator being tested. The formula for calculating the *CVR* can be seen in Equation (1) [58].

$$CVR = \frac{n_e - \left(\frac{N}{2}\right)}{\frac{N}{2}} \tag{1}$$

where

CVR: content validity ratio
n_e: the number of experts who gave a rating of 3 or relevant
N: the number of all experts

- Step 4: Eliminate irrelevant constructs, concepts, elements, and indicators.

3.1. Desk-Based Research

The desk-based research was conducted to collate the indicators used to measure RL performance in the construction sector. The research was performed by searching for previous studies on Scopus and the Web of Science using a combination of keywords such as "reverse logistics", "reverse logistics performance assessment", "reverse supply chain", "reverse logistics construction sector" and "waste management construction sector". Figure 2 shows the collation of RL practices and the generation of the RL performance via RL practices that are influenced by the initiation phase in the PLC, in terms of drivers and barriers.

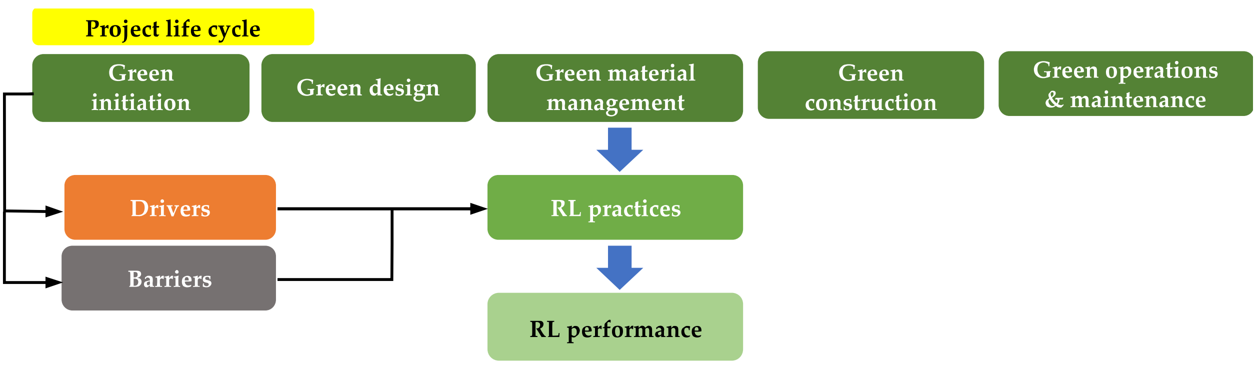

Figure 2. The relationship between PLC, RL practice, and RL performance.

Previous studies in building projects that have used the proposed framework include Wibowo et. al., Pushpamali et al., Hammes et al., Farida et al. [10,12,15,17]. Hammes et al. [15] suggested an assessment of RL performance in terms of the activities carried out in the construction phase. Wibowo et al. [10] focused on developing the concept of GSCM based on a PLC. Their study resulted in the five following basic concepts of GSCM application in the construction sector: (1) green initiation, (2) green design, (3) green material management, (4) green construction, and (5) green O/M.

Farida et al. [17] developed a GSCM assessment model for the construction sector. Pushpamali et al. [12] demonstrated that RL is strongly influenced by the decision to implement RL in the preconstruction phase or during project initiation, so the measuring tool developed should assess RL implementation from the initial phase, specifically from green initiation to the final phase of the project. Furthermore, regarding the proposed framework, a literature study related to indicators of RL performance measurement was carried out based on the PLC.

Table 2 lists the 66 indicators collected from the green initiation, green design, green material management, green construction, and green O/M phases.

Table 2. Initial RL measurement indicators in the construction sector collated from the desk-based research.

No	Element	Indicator	Code	References
Green Initiation Phase				
Dimension: Commitment				
1.	General commitment	Managerial resource	RC1	[54,59]
		Selection criteria	RC2	[60]
2.	Resource efficient commitment	Recycled content	RC3	[60]
		Materials transportation	RC4	[60]
		Technical specification: low temperature asphalt	RC5	[60]
		Soil and waste management plan	RC6	[60]
Dimension: Feasibility study				
3.	Economic assessment	Saving in material cost	FS1	[61]
		Reduction in waste	FS2	[61]
		Life cycle cost	FS3	[61]
4.	Customer perceived level of service	Percentage of customer willingness	FS4	[62]
Dimension: Knowledge management process				
5.	Knowledge application process	Problem sharing	KM1	[63]
		Best practice sharing	KM2	[63]
Green Design Phase				
Dimension: Design innovation				
6.	Material efficiency	Material efficiency index	IDI1	[64]
		Reusable or recyclable material	IDI2	[64]
Dimension: Knowledge management process				
7.	Knowledge application process	Design change improvement	KM1	[64]
Dimension: Guideline for deconstruction design				
8.	Deconstruction design (DFD) for recycle material	Using recycled materials	GD1	[63]
		Avoiding use of hazardous and toxic materials	GD2	[65]
Green Material Management Phase				
Dimension: Green purchasing practices				
9.	Green supplier selection	Cost: raw material price	SSC1	[66]
		Cost: product	SSC2	[67]
		Cost: logistics	SSC3	[67,68]
		Reject rate	SSQ1	[67]
		Delivery capabilities	SSD1	[67,68]

Table 2. *Cont.*

No	Element	Indicator	Code	References
Green Material Management Phase				
Dimension: Green purchasing practices				
		Order fulfilment rate	SSD2	[67]
		Production capacity	SSD3	[67]
		Energy consumption	SSE1	[67,68]
		Wastewater treatment	SSE2	[67]
		Environmental staff training	SSE3	[67]
		Environmentally friendly material	SSE4	[68]
		Environmentally friendly planning	SSE5	[68]
		Capability of deconstruction/ disassembly design	SSI6	[67,68]
		Speed of development	SSI7	[67,68]
		Safety assurance	SSS1	[67]
10.	Supplier safety performance	Loss time accident (LTA)	SSS2	[69]
		Occupational Health and Safety (OHS)	SSS3	[69]
		Personal protective equipment (PPE)	SSS4	[68]
		Expert certification OHS	SSS5	[69]
		Safety induction	SSS6	[69]
		OHS policy	SSS7	[69]
11.	Green supplier development	Quality evaluation	SDQ1	[66]
		Delivery evaluation	SDD1	[66]
12.	Green supplier collaboration	Supplier risk assurance	SCC1	[67]
		Safety assurance	SCC2	[67]
13.	Green supplier evaluation	Quality evaluation	SEQ1	[66]
		Delivery evaluation	SED1	[66]
		Cost evaluation	SEC1	[66]
Green Construction Phase				
Dimension: Knowledge process management				
14.	Design change	Design change implementation	KM3	[63]
Dimension: RL Practices				
15.	RL supplier side	Green purchase	RLSS1	[15]
16.	RL internal side	Use of material	RLIS1	[15]
		Reuse of material	RLIS2	[15]
		Recycling material	RLIS3	[17]
		Remanufacture	RLIS4	[17]
		Residual	RLIS5	[17]
		Return on investment (ROI)	RLIS6	[15]
		Customer satisfaction	RLIS7	[15]
17.	RL waste management side	Storage 1	RLWM1	[15]
		Storage 2	RLWM2	[15]
		Transportation 1	RLWM3	[15]
		Transportation 2	RLWM4	[15]
		Transportation 3	RLWM5	[15]
		Worker awareness 1	RLWM6	[15]
		Worker awareness 2	RLWM7	[15]
Dimension: Safety				
18.	Safety	Safety performance	SF1	[60]
Green Operations and Maintenance (O/M) Phase				
Dimension: Waste management plan				
19.	Waste management plan	Technical specification: tar containing asphalt	WMP1	[60]
Dimension: Durability				
20.	Durability	Service lifetime	DR1	[60]
Dimension: Safety				
21.	Safety	Safety performance	SF1	[60]
Dimension: Knowledge sharing management				
22.	Knowledge application process	Problem sharing	KM1	[63]

3.2. FGD

In this step, the 16 respondents were given closed questionnaires asking whether or not the indicators in Table 2 are relevant in measuring RL performance in the construction sector. The respondents stated that the 66 indicators can be considered as tools for measuring RL performance in the construction sector. The respondents were then asked whether there were additional indicators for measuring RL performance in each phase of the PLC. As a result, nine additional indicators were proposed by the respondents, as shown in Table 3.

Table 3. Additional indicators proposed by academics and practitioners.

No.	Code	Indicator	Definition	Phase	Dimension
1.	ISR8	Total RL principles applied in the project	RL principles stated in the project agreement, such as requests to reuse and recycle materials	Green Initiation	Commitment
2.	MSR8	RL clause in the instruction to bidder	Existence of a clause that regulates the supplier's obligation to carry out RL	Green Material Management	Green Procurement Practices
3.	MSR9	Preparation of material priority scale plan for RL implementation	Existence of a plan to develop a material priority scale in an effort to implement RL	Green Material Management	Green Procurement Practices
4.	CSR16	Domestic content level	Percentage of the material content of domestic/local products in the whole project	Green Construction	RL Practices
5.	CSR8	Evaluation of quality, cost, and time in the results	Evaluation of quality, cost, and time on the results of construction projects that apply RL	Green Construction	RL Practices
6.	OSR6	O/M energy usage	Consumption of all the energy used to perform an action, manufacture an item, or simply inhabit a building	Green O/M	Knowledge Sharing Management
7.	OSR16	Percentage of repairs in O/M phase due to material damage	A number indicating the reliability of a system/equipment based on a review of repair costs over a period of time	Green O/M	Knowledge Sharing Management
8.	OSR61	Capacity factor	The ratio of the total actual energy produced or supplied over a definite period to the energy that would have been produced if the plant (generating unit) had operated continuously at the maximum rating	Green O/M	Knowledge Sharing Management
9.	OSR8	Corrective and preventive actions	Existence of corrective and preventive actions if there is a problem related to the implementation of RL during the maintenance process	Green O/M	Knowledge Sharing Management

3.3. Validation of the RL Measurement Indicators

To eliminate items that do not represent relevant measures to be carried out, the results of the *CVR* calculation were compared with the *CVR* minimum value guideline table based on the number of experts by Lawshe [58]. The minimum value of the *CVR* with 16 experts is 0.5.

The indicators generated from the literature study and FGD were compiled based on the PLC phases in GSCM. The reason for compiling a list of RL indicators based on the PLC is to incorporate RL from the beginning of the construction process, namely initiation and design construction. There are 75 indicators for various PLC phases in GSCM. The indicators list was distributed to respondents to provide scores related to the suitability of indicators in each phase and to add indicators based on best practices and respondents' experiences. The results of the assessment were analyzed using the *CVR*, as shown in Table 4.

Table 4. Results of the RL measurement validation.

No.	Element	Indicator	Code	References
Green Initiation Phase				
Dimension: Commitment				
1.	General commitment	Managerial resource	RC1	[54]
		Selection criteria	RC2	[60]
2.	Resource efficient commitment	Total RL principles applied in the project	ISR8	FGD
Dimension: Feasibility study				
3.	Economic assessment	Saving in material cost	FS1	[61]
		Reduction in waste	FS2	[61]
Dimension: Knowledge management process				
4.	Knowledge application process	Best practice sharing	KM2	[63]
Green Design Phase				
Dimension: Design innovation				
5.	Material efficiency	Material efficiency index	IDI1	[64]
		Reusable or recyclable material	IDI2	[64]
Dimension: Guideline for deconstruction design				
6.	DFD for recycled material	Using recycled materials	GD1	[63]
		Avoiding use of hazardous and toxic materials	GD2	[65]
Green Material Management Phase				
Dimension: Green purchasing practices				
7.	Green supplier selection	Cost: Raw material price	SSC1	[66]
		Cost: Product	SSC2	[67]
Dimension: Green procurement practices				
8.	Green procurement practices	RL clause in the instruction to bidder	MSR8	FGD
		Preparation of material priority scale plan for RL implementation	MSR9	FGD
Green Construction Phase				
Dimension: RL practices				
9.	RL internal side	Use of material	RLIS1	[15]
		Reuse of material	RLIS2	[15,17]
		Recycling material	RLIS3	[17]
		Residual	RLIS5	[17]
10.	RL waste management side	Evaluation of quality, cost, and time on the results of construction projects that apply RL	CSR8	FGD
11.	Knowledge application process	Problem sharing	KM1	[63]
		Percentage of repairs in O/M phase due to material damage	OSR16	FGD

4. Synthesis of the RL Performance Measurement for the Construction Industry

An RL performance evaluation indicator that integrates each phase in the PLC needs to be developed as a first step to determine the performance of the construction sector in implementing RL. In this study, the RL evaluation indicator was developed by adopting RL performance indicators from the manufacturing sector. Based on the results of the *CVR*, as shown in Table 4, 21 indicators have a *CVR* value greater than the minimum *CVR* value (>0.5). Therefore, 21 indicators are considered valid for measuring RL performance in the construction sector, as shown in Figure 3.

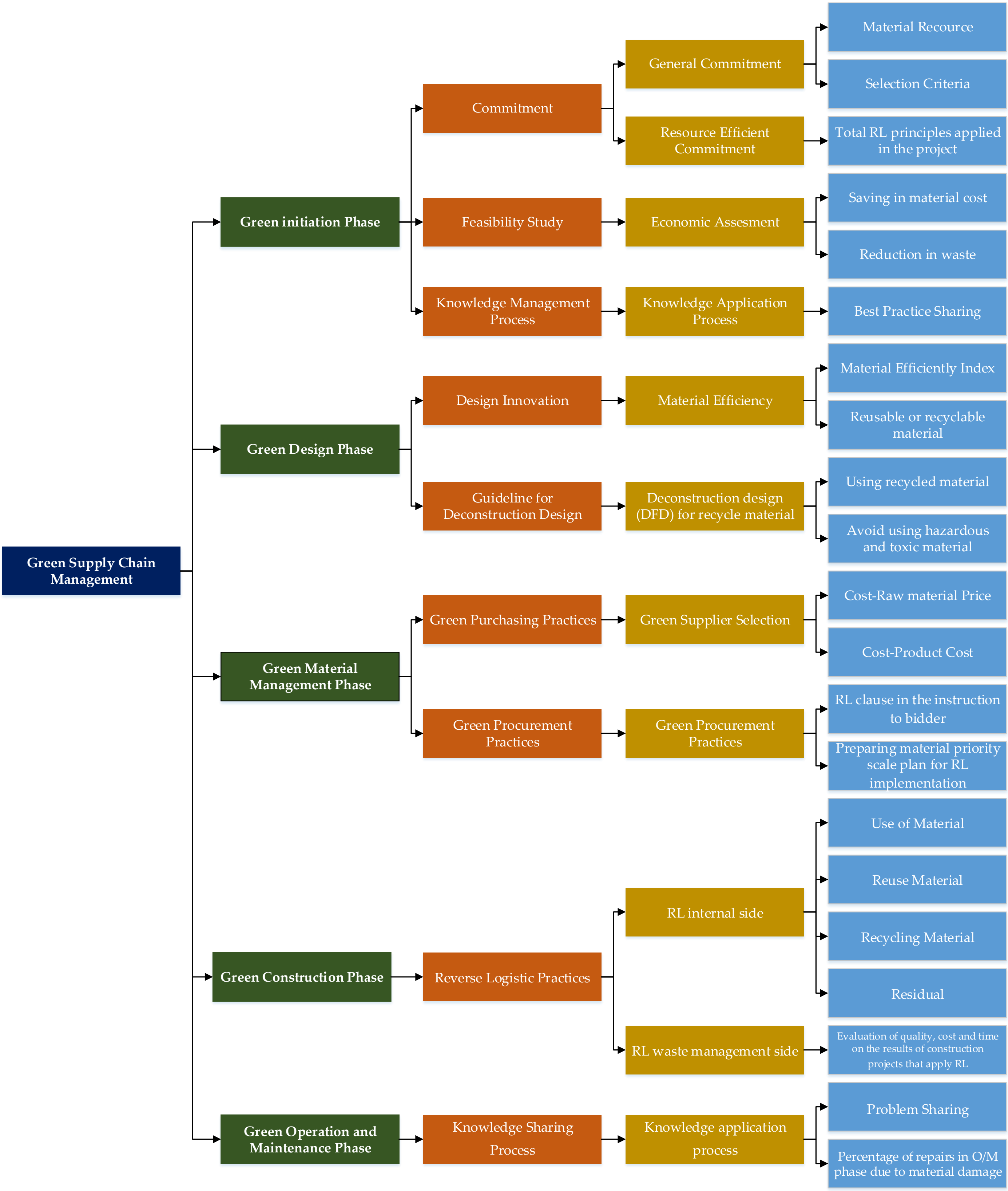

Figure 3. The final RL performance measurement for the construction industry.

In the construction industry, the duration of projects is typically long, and the phases (initiation, design, material management, construction, operation, and maintenance) are integrated. The present study differs from that of Hammes et al. [15], which measured RL performance based on supplies, internal logistics, and waste management. While their research focused only on the construction phase, using 12 RL measurement indicators, this study develops the concept of RL measurement on the basis of the PLC with 21 measurement indicators. The present research is more robust because the concept of PLC [10], as the basis for measuring RL, continues through several stages, namely the desk-based research and the validation process carried out by 16 people in the construction industry. This study also develops RL measurements based on the research of Wibowo et al. [10] and Pushpamali et al. [12], whose formation of RL indicators involves three stages, namely, desk-based research, FGD and validation involving the experts. However, the present research is also more robust than these studies because the measurements are carried out at each phase in the PLC, namely green initiation, green design, green material management, green construction, and green O/M.

The green initiation and design phases play important roles in supporting RL performance measurement. In the initiation phase, the stakeholder (owner) must ensure that the project being built is sustainable, taking into consideration the work of the architect in the design phase. In the design phase, the DED implementation should consider the guideline for deconstruction design. The green material management phase also involves using eco-friendly materials to replace non-eco-friendly materials according to the previous phase. The green construction phase can incur an enormous amount of waste, but if the project already uses eco-friendly material, both waste and emissions will be reduced. When the reuse and recycling of material is successfully applied according to the project conditions in the field, the implementation of RL becomes easier, and so as controlling energy consumption becomes more efficient in the green O/M phase. Therefore, the RL performance measurements need to be integrated throughout the PLC system.

In manufacturing companies, where the RL process takes place in one organization, one location, or one work unit (blended), it is relatively easy to apply and control SCM related to material, information, and financial flows. In contrast, in companies operating in the construction sector, each stakeholder involved in measuring RL performance may work with different organizations (consisting of three or more organizations) or fragmented project owners, contractors, and consultant teams within a certain period. The role of stakeholders, especially in construction projects, is very important.

Previous research has emphasized that the stakeholders in the construction sector can be a decisive factor in "making or breaking" a project [70]. Therefore, the commitment of stakeholders to construction projects is important because they come from different organizations, educational backgrounds, and specializations to perform a task within certain time limits and with certain goals. Thus, it is necessary to establish a common premise of shared interest in the building project. If stakeholders in each phase do not have the same rationale, values, or spirit, RL will be difficult to implement. Therefore, the importance of the PLC approach is in its ability to unite or link the understanding and values of stakeholders on the basis of RL.

4.1. The Roles of Project Owners in the Green Initiation Phase

Green initiation is the initial stage in the implementation of a project. In this phase, the value or spirit of the project requirements is an important aspect in implementing GSCM. Establishing this value helps create collaboration between stakeholders in a project, allowing the project's goals to be achieved [71].

In the green initiation phase, there are six indicators that are considered valid in this study, comprising (1) RC1: managerial resource, (2) RC2: selection criteria, (3) FS1: saving material cost, (4) FS2: reduction in waste, (5) KM2: best practice sharing about green projects, and (6) ISR8: total RL principles applied in the project. The green initiation phase is related to the project owner's commitment to implementing green aspects in the project to be made. The project owner is a key stakeholder because they have the authority to decide project criteria and also commitment is the main determining factor in implementing environmentally friendly projects. These results are in line with the indicators proposed by Olanipekun et al. [72], who found that, from the perspective of various stakeholders, the project owner's commitment depended on their experience and capability in handling green building projects. Having workforce who are capable of applying various aspects of the project that have environmental impact is also crucial to the implementation of RL in terms of managerial resources (RC1) [54]. Furthermore, FS1 (saving material cost) and FS2 (reduction in waste) are indicators used to measure the feasibility dimension when evaluating RL performance on a green project. Saving material cost (FS1) shows the estimated profit obtained if the project uses recycled materials and the estimated waste (FS2) that can be derived from the use of recycled materials. These two indicators to measure the feasibility of RL implementation are adapted from research by Halil et al. [61], where both indicators are used to assess the feasibility of implementing green construction from an economic perspective [61]. Research by Tan et al. [73] has shown that the economic aspect is the main consideration in determining the feasibility of a green project as the results of such feasibility studies influence the owner's decisions in setting project criteria, such as RL implementation.

4.2. Material Efficiency Index in the Construction Design Phase

Design is defined as the process of developing a solution to a particular problem using the necessary experts and tools. It is a step in the planning process where a detailed description is produced that reflects the project concept. Importantly, green parameters and sustainable construction occur only when the environmental, social, and economic considerations are addressed and incorporated into the design process [74]. In sustainable design, social, environmental, and economic factors need to be taken into consideration before designing any construction project. Studies should be conducted regarding the ability to supply raw materials and whether the building users benefit from using minimum resources with less damage to the environment [75]. A well-defined design policy among stakeholders can also be crucial before starting a project with a green project concept. Some researchers believe that designers can make changes to the design mentality and process to engage in green issues.

The construction requirements for any sustainable project should be decided on prior to the construction phase, and sufficient time should be spent to come up with an appropriate plan to avoid changes during construction and to save time and cost [75]. Therefore, designers must be involved in the project process from the initial stage—the "planning stage"—to incorporate effective changes related to the green project concept [74].

The indicators in the green design phase declared valid in this study are the material efficiency index (ID1), recycling material (ID2), use of recycled materials (GD1), and the level of use of hazardous materials (GD2). By using the material efficiency indicator (ID1), the company adopts a system capable of tracking the use of all materials from the beginning of processing until the material reaches the end of its useful life. Hence, with material efficiency as an indicator, the company controls how a material is reused, recycled, and remanufactured. Controlling the use and selection of materials is a means for companies to determine ideas for improvement, one of which is through the implementation of RL as this improvement aims to increase the efficiency of the material index. Furthermore, with the ID2 (reusable or recyclable material) indicator, designers become more conscious of making designs that are environmentally friendly and easy to disassemble. Through the application of environmentally friendly design concepts, waste problems caused by the construction process can be overcome. The application of environmentally friendly design concepts also facilitates the implementation of RL [76]. The use of recycled material (GD1) is one indicator used to measure eco-design. Its aim is to reduce the use of virgin materials so that the availability of materials can be maintained in the long term [59], and the company can obtain cost savings by purchasing recycled materials in procurement activities. The use of nontoxic or nonhazardous materials (GD2) helps ensure that the deconstruction results from implementing RL do not endanger workers when used [65].

4.3. Green Procurement in the Green Material Management Phase

Material management is the system for planning and controlling to ensure that the correct quality and quantity of materials and equipment are specified in a timely manner. Materials should be obtained at a reasonable cost and be available for use when needed. The cost of materials represents a large proportion of the overall construction cost. Therefore, the role of stakeholders in controlling the management of RL in the green material management phase is essential because it provides the basis for the green construction phase related to field implementation. In the construction sector, RL performance in the green material management phase is also related to green procurement practices. Green procurement practices include green supplier selection, supplier safety performance, green supplier development, green supplier collaboration, and green supplier evaluation activities. Green procurement practice is an important criterion in creating sustainability and plays a role in maintaining environmental performance to minimize impacts throughout the construction process [77].

The green material management indicators in this study are raw material price (SSC1) and product cost (SSC2). These two indicators are used to measure the performance of RL because both measure the profits obtained by the company when implementing RL. The indicators' relevance is reinforced by research by Škapa and Klapalová [78] regarding company profits. These two indicators are also able to measure the use of material resources in procurement activities. Resource use is the main indicator in the criteria for green public procurement projects for road construction. In addition, the indicators that are declared valid within the green procurement practices dimension are the MSR8 indicator (existence of an RL clause on the employee requirement/instruction to bidder) and the MSR9 indicator (existence of a plan to develop a material priority scale for RL implementation). According to previous research, the presence of the MSR8 and MSR9 indicators will guarantee the implementation of RL [79].

4.4. Reuse and Recycle in the Green Construction Phase

Green construction, as the next concept to engage with in the construction process of environmentally friendly buildings, is developed by various stakeholders. A particularly important stakeholder in this phase is the contractor. The contractor is tasked with planning, implementing, and supervising construction activities from start to finish to ensure that all aspects are in accordance with existing regulations. In this PLC concept, contractors are not only responsible for constructing strong and efficient buildings but must also pay attention to the environment. Green construction is an important phase in minimizing the environmental impact caused. The green construction approach seeks to balance the capabilities of the environment with the needs of human life for present and future generations [17] through the efficient use of resources [80]. The three main stages in green construction are reducing the use of non-environmentally friendly resources, reducing the waste generated during the process, and reducing the emissions generated by the project. The purpose of implementing green construction is to minimize waste at the construction stage indirectly by reducing energy and resources; as a result, emissions will also be reduced during the construction process [10].

However, there are several obstacles that prevent companies from implementing green construction. These include the following: (a) contractors being constrained by the limited availability of environmentally friendly equipment; (b) the unavailability of workers trained in the principles of green construction; (c) a lack of certainty about the type of environmentally friendly material declared by a legitimized institution; (d) technology limitations in implementing green construction; (e) no effective internal collaboration between large contractors and specialist contractors and (f) limited regulations governing green construction.

In the green construction phase, the relevant indicators are the use of material (RLIS1), reuse of material (RLIS2), recycling of material (RLIS3), residual of material (RLIS 5), and evaluation of quality, cost, and time. Some construction project results have applied RL (CSR8) as an indicator used to measure the performance of RL in the green construction phase. This indicator relates to operational activities during the construction process. Reuse and recycling are values that are measured in the application of RL, making these two indicators very important in measuring RL performance. Reuse and recycling in RL are also supported by Ripanti and Tjahjono [13].

4.5. Problem Sharing in Green O/M Phase

The green O/M phase is related to energy consumption as the largest energy consumption occurs in this phase from the perspective of life cycle costs [81]; thus, the implementation of RL performance measurement is critical. The green O/M phase involves project residents or users. Therefore, every stakeholder, especially the owner and building manager, needs a coordinated understanding of the importance of focusing on the occupants of the building. The indicators used to measure the performance of RL in the green O/M phase are problem sharing (KM1) and the percentage of repairs in the O/M phase due to material damage (OSR16). KM1 indicator is used to measure the RL application constraints that arise at the end of the phase so that the obstacles that arise can be anticipated from the beginning of the project. The percentage of repairs in the O/M phase due to material damage (OSR16) aims to determine the performance of the RL material used in the project. This indicator is in line with Abraham et al. [81], who state that an enterprise's preference in the O/M phase no longer requires significant investment. Creating a noticeably effective product from recycled aggregates makes the construction material substantially greener and more sustainable. These results can be assisted by the coordination of project managers and governing bodies in lowering the cost of the life cycle of materials that can be used in the homes. Through life cycle cost analysis, building owners can obtain detailed information about material costs, and the environmental impacts due to C&DW can be reduced by using the waste from other products.

5. Conclusions

RL is considered a remedial measure that moderates the detrimental impacts of construction projects on the natural environment and enables organizations to be more efficient and effective by attaining economic benefits and sustainable competitiveness. In this case, RL aims to increase the value of waste generated by construction activities and reduce costs for waste management. To gain a better perception of the RL of companies, RL performance measurement should be implemented throughout the whole PLC.

5.1. Theoretical Contributions

Performance evaluation of RL practices in construction sectors is crucial, but only few studies have focused on measuring the RL performance. Most research on RL in the construction sector, e.g., Pushpamali et al. [12], has not specifically provided an evaluation of the RL performance and, in this respect, they seemed to focus only on the construction phase, e.g., Hammes et al. [15] and Farida et al. [17].

This paper contributes to the construction sector's literature by presenting a new, PLC-based perspective on how RL can be adopted, from the initiation, design, materials management, and construction phases to the O/M phases. It also enhances the research area of Green Supply Chain Management (GSCM) in construction, where the RL performance has become an important factor for the construction sector in order to be more environmentally conscious.

Finally, the paper proposes a new model that integrates the work of Wibowo et al. [10], Pushpamali et al. [12], Hammes et al. [15], and Farida et al. [17]. The model consists of dimensions, elements, and indicators for the evaluation of RL performance throughout the construction's PLC.

5.2. Implications for Practice

This paper identifies the Green Supply Chain Management (GSCM) as an important platform that enables the stakeholders to get involved in each phase of the PLC. The scope of PLC includes the initiation and design phases, two critical phases that determine the success of RL. The development of the RL measurement model starts with the construction of each phase in the PLC. In the initiation phase, the building owners play a vital role in creating/building environmentally friendly value by applying RL to the constructions. The RL concept should also be realized in the DED made by the design consultant, creating the DFD.

The environmentally friendly results of the construction project are then handed back to the owners, who continue applying environmentally friendly values during the O/M phase. The role of each stakeholder during the construction process of a building or infrastructure is critical. The environmentally friendly value based on the PLC and in accordance with GSCM and RL applications must be implemented by all stakeholders.

5.3. Limitations and Future Work

This paper has some limitations. First, the selection of the participants of FGD, though involving a wide range of stakeholders who were truly independent experts at every phase of the PLC, was based on a purposive sampling. This, arguably, relied on the personal opinion of the participants. Second, the use of questionnaire to validate the measurements by a relatively small number of respondents might lead to bias though this has been mitigated by closely liaising with them and, at the same time, ensuring their responses were kept anonymous and confidential.

With respect to the abovementioned limitations, the performance measures of RL practices in the construction sector proposed in this paper are thus considerably conceptual in nature. Future research should therefore look into applying the measures to real building projects, in order to ascertain their practical relevance.

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