Least-cost Control Optimization to Produce Concrete Prepared with Recycled Concrete Aggregate and Fly Ash

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ABSTRACT

This research illustrates how to optimize non-traditional and traditional mixes from different perspectives, particularly ecological life cycle (such as energy consumption and global warming), economic (cost), and technical performances (such as durability and mechanical characteristics). The weights to be firstly considered for each performance dimension (perspectives) depend on the users' requirements and concrete applications. Concrete mixes with different quantities of fly ashes and reclaimed concrete aggregates (RCAs) are optimized for various construction industry applications, namely residential housing far or close from the sea, economical residential housing, sustainable residential housing, and high-rise buildings. Multi-criteria decision approaches, or methodology for concrete optimizations, were used to the concrete mixes for that purpose by considering the international need scenarios such as business, as usual, service life, green, strength, and cost are often required by the consumers. The findings indicate that for all scenarios and applications that consumers can demand in terms of concrete properties, ecological and cost impacts are the optimum concrete mixes generated with both incorporations of recycled concrete aggregates and fly ashes, instead of their incorporations. This research indicates that in its applications, multi-criteria decision method or methodology for concrete optimization is straightforward. It is concentrated on the ultimate output. The optimum concrete mix selections can be directly utilized by the users and do not require excessive resources and time. Therefore, multi-criteria decision method or methodology for concrete optimization avoids the lengthy modifications and inventory analyses.

Keywords

Ecological impacts; Costs; Life cycle assessments; Quality performance; Multi-criteria analyses; Concretes

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Introduction

Essentially, this paper treatise on the need to optimize the production of concrete prepared with recycled concrete aggregates (RCAs) and fly ashes (FAs) at minimal cost through optimal selection of control strategies on numerous pollutants [1]. Empirical evidence on concrete production has focused on performance concrete developed to optimize the concrete mix designs to produce concrete that meets all structural and performance requirements in a project using recycled concrete materials. To a large extent, this approach has supported sustainability measures in concrete materials.

Many studies have reported that concretes have substantial influences on ecological effects since concretes are some of the most widely applied materials in the whole world [2]. Scholars have recommended multiple alternative approaches for that purpose to reduce the environmental impacts of mortars and also concretes, for example by integrating cementitious materials in concretes and recycled aggregate concretes and fly ashes (construction demolition waste) [3]. There are still massive gaps between ecological impacts and life cycle costs and quality performance (hardened and fresh states) because of the indirect relationships among them even though the effects of alternative concrete materials have been comprehensively researched from various perspectives. Most of the studies only considered a single view, for example, life cycle assessments or quality performance. Specific investigations are concentrating on multiple aspects [4]. However, it is hard to optimize and make relationships among the concrete mix. Various perspectives and properties due to (i) the best performing concrete mix can be recognized, but they still may not be viewed as the optimum concrete mix (OCM), for example, high strength concretes may not be the best characteristic for residential houses because of their high cost; (ii) different conditioning units for each aspect and (iii) changing weights of each element based on the applications of concretes.

Considering a single perspective, the optimal concrete mix cannot be defined [1]. In other words, the optimum concrete mixes are not nearly the ones with the lowest costs, or high service life (highest quality performance), or the low Life Cycle assessments (LCAs) (the lowest environmental impacts). Illustrating, by incorporating non-traditional materials such as reclaimed concrete aggregates, makes it possible to generate low ecological impact concretes than conventional concretes. However, if the service life of concrete mixes with non-traditional materials is far lesser than traditional concretes, the concrete mixtures with non-conventional materials may be an unsustainable solution [2]. When the concrete quality performance compares with its costs, similar reasoning can be established. For example, one can generate concretes with lesser costs than conventional concretes by utilizing non-conventional materials such as fly ashes [5]. However, the concretes with non-conventional materials are not nearly an economical alternative because extra materials can be used to attain equal load capacities to those traditional concretes and the cross-sections of the structural components made with these concretes may need to be increased. Therefore, it is vital to consider all the aspects to optimize the concrete mixes for needed scenarios and applications [4]. Also, non-traditional materials such as recycled concrete aggregates and fly ashes can only be viewed as ecologically-friendly if they threaten the concrete service life or quality.

Concretes with multiple incorporation rations of both reclaimed concrete aggregates and fly ashes are optimized to show the construction sector their performance and applicability in various applications and their sustainability effects [6]. The previous scholars who made comprehensive literature review on this field showed massive studies associated with the personal effects of reclaimed concrete aggregates or fly ashes, but few investigations associated with RCA and fly ashes combined effects on concretes [7]. Moreover, most scholars researched the effects of high integration ratios of recycled concrete aggregates and fly ashes from only a single viewpoint; for example, concrete cost, quality, or ecological impacts.

The investigator of this research recommended a novel approach (multi-criteria decision method or methodology for concrete optimization) to overcome this matter and select the optimum concrete mix according to the costs, quality performance, and ecological impact [8]. Concrete mixtures containing different quantities of fly ashes and reclaimed concrete aggregates are optimized in the current research to be applied in diverse uses such as residential housing far or close from the sea, economical residential housing, sustainable residential housing, and high-rise buildings [9]. Multi-criteria decision approaches, or methodology for concrete optimizations, were used to the concrete mixes for that purpose by considering the international need scenarios such as business, as usual, service life, green, strength, and cost are often required by the consumers. This research is an example of the application of Multi-criteria decision approaches or methodology for concrete optimizations. Multi-criteria decision approaches or concrete optimizations also contribute to this study's validation [10]. The findings indicate that for all scenarios and applications that consumers can demand in terms of concrete properties, ecological and cost impacts are the optimum concrete mixes generated with both incorporations of recycled concrete aggregates and fly ashes, instead of their incorporations.

Aim and Objectives

The purpose of this study is to explore the least-cost control strategy optimization in the productions of concrete using recycled concrete aggregates and fly ashes to achieve the air quality standards at a minimal cost [1]. In this case, the pollutant concentration in the concrete mixture is addressed to optimize concrete production. Regional data sources obtained from Southeast Asian nations are relied on to offer adequate control strategies [11]. This study's outcome is expected to provide low-cost control strategies that can be used in the construction industry.

The work established frameworks of least-cost control optimization to produce concrete prepared with recycled concrete aggregates and fly ashes [2]. The basic model framework and the approaches applied the integrations can be applied in a broader global context and replicated in different industries [12]. The study introduced an integrated framework and model where a set-up of high-performance RCA and fly ash production that includes waste concrete recycling operations is suggested. The model and framework can also be applied in computing least-cost control optimization analyses of natural concrete materials. The RCA and fly ash production factories can acquire large-scale products for fiscal feasibility in the RCA and FA production [4]. Based on incremental bases, the cost impacts are analyzed, in which the operation case is viewed to have zero incremental costs. This means the model can be applied in other industries. The case of base operations considers reclaiming concrete wastes in production RCA and FA plants as infrastructural and building materials that can applied the whole construction and building industry. The model and framework designed are drawn from data acquired from different concrete reclaiming factories and manufacturing plants involved in approximating the unit incremental selling price [13]. Because data from various concrete reclaiming and manufacturing plants are used in this work, it is clear that model developed can be applied in different plants and factories in other sectors and industries. The model can also be applied in various countries to solve the current problems encountered in various parts of the world. A lot of concrete wastes are being disposed of from demolition plans [7]. Using this model, the unsustainable usage of concrete will be solved.

Literature Review

In this section, the study will present a review of existing studies related to control strategies that can optimize concrete production using recycled concrete aggregates and fly ashes at a low-cost [8]. Different sources of studies related to control strategies used in the production of concrete conducted in the Southeast Asian nations are considered. This is expected to identify measures that can be used to attain air quality standards quite easily.

This part of the research outlines the literature review on least-cost control optimization to produce concrete prepared with RCAs and FA. There are different studies associated with cost-efficient impacts of the RCA and FA production. Wijayasundara et al. [14] conducted financial analyses, and the researchers established monetary gains of recycling concrete wastes. The investigators also concluded that many limitations originate because of the present landfilling waste activities. The drawback includes the waste material emission into the atmosphere, therefore, establishing an unsustainable ecology. Wijayasundara et al. [14] researched the prospects of creating recycling plants and developing the aspects that influence this practice feasibility. These elements included the revenue charged, the recycling costs in every unit, and the profits. To examine the economic and ecological effects of reutilizing compared with C&D waste disposals, Wijayasundara et al. [14] launched system dynamics techniques. Wijayasundara et al. [14] also used the same approach to carry out the economic viabilities of creating alternatives to the markets and cost-benefit analyses of the options associated with the management of C&D wastes. Wijayasundara et al. [14] conducted economic mix design using artificial neural and technique networks as a forecasting approach and RCA mix design optimization considering less carbon (IV) Oxide disposal.

Various researches have studied RCA features [15]. Recycled concrete aggregates (RCA) are an effective way to reduce constructions and demolition wastes. However, the properties of concrete with RCA and FA have to be investigated. Nguyen et al., 2014 indicated that the concrete strength could be reduced up to 40% when RCA and FA were used. However, various elements such as replacement level, moisture content, type of RCA and water to cement ratio affect the RCA concrete strength. Unlike natural aggregate, RCA has typically higher water absorption, which could significantly affect concrete properties, especially the workability. Bartolacci et al. [15] demonstrated that concrete with drier RCA had a more considerable slump and faster slump loss than that of saturated RCA. It is clear that the strengths for the entire fine aggregate replacement increase with time with the blends having higher percentages of the combination gaining at a higher rate. This depicted the characteristics of the presence of lateritic material which from the literature review available, it stated that the strength for the material increase with the structure's life.

Recycled concrete aggregates (RCAs) and fly ashes (FAs) are utilized as recycled concrete wastes in green concretes' present structures. Concrete wastes are collected and grounded using recycling procedures to generate ground concretes that are then utilized in structural concretes. They substitute natural aggregates that are rough in this process [16]. The RCAs and FAs are sustainable concrete wastes that in the long-run can substitute the demands for natural aggregates, processes that would, in turn, result in their preservations. Nevertheless, most concrete plants have been observed to reluctant in the RCA and FA production and usage in its optimum potentials. Plants are yet to embrace the production of RCAs and FAs not only because of their unclear substance performances but also because of its unexplored operations of production plants that are yet to be determined.

Inadequate information on the cost-effective perspective to the RCA and FA production is a thoughtful issue that needs complete attention because of its impacts on the sector's changing aspects [1] It is currently unknown whether manufacturing, control of quality and production costs in standard RCA and FA production industries outweigh the advantages of recycled concrete aggregates acquired as lower price constituent materials in concretes than natural concrete aggregates. According to Bartolacci et al. [15], one explanation behind the slow manufacturing acceptances for RCA and FA production is the already existing massive ready-mixed concretes (RMCs) production plants. Nevertheless, the present patterns in which RCA and FA are increasingly substituting NCA in multiple structural developments have gradually obtained importance because of specific reasons. For example, RCA and FA production allows sustainability for concrete wastes and encourages recycling as opposed to disposals of landfills. It has also notably addressed scarcity of natural aggregates, minimized the natural aggregate demands, and ultimately, it has allowed the quarried natural aggregate conservation [16]. Despite the costs, these and many other benefits have increased manufacturing concerns and recycled concrete aggregates in structural development.

As the aggregate may be retrieved from concrete residuals after placing is finished, waste generation needs not be a challenge within the construction [17]. Usually, this represents the concrete sludge and 2.00% of the fresh aggregate material remaining after the aggregates' reclamation. The remaining concrete sludge can be mixed with the liquid from the washing of the truck. The slurry of cement pastes can be dehydrated, desiccated, grounded, and utilized to substitute NCAs with fine RCAs [16]. The only sure way of minimizing construction costs is the utilization of the available local resources and adoption of innovative construction materials. applying RCA and blended laterites as fine aggregates on all these accounts in concretes appear to the best, particularly in the place in which the mixed substances are freely available other than the natural concrete aggregates such as river sand.

Methodology

This quantitative study section will present the methods and procedures used to collect and analyse regional data sources obtained from Southeast Asian nations [1]. An experimental research design is adopted. The mixture of recycled concrete aggregate and fly ash will be compared to the cement and natural aggregates in terms of air quality and different emission sources of gaseous pollutants such as SO2, NOx, and volatile organic compounds. Additionally, the study will review existing studies on the best control strategies that can be adopted for optimizing the production of concrete prepared using recycled concrete aggregate and fly ash at a minimal cost from various pollutants.

Based on American Concrete Institute (ACI) standards, mix designs were made for two alternative concretes (reclaimed concrete aggregates and fly ash concretes) after evaluating the properties of materials [2]. Percentage computations were designed founded on the weights of the materials. Containers of 3 × 6 inches were utilized. For one week and one month, the cylinders were cured in lab standard room conditions. A minimum home project strength was assumed to be a concrete compressive strength of 17 MPa (2500 psi) [7]. For each trial, five samples were cast, and there were four tests of each mix design of substitute concretes. To make a mean value in the trial, each test involved five samples two for one-week, two for one-month testing and one for additional testing. As a reference concrete, five samples for regular concretes were also tested and cast. For both fine and rough concretes, moisture contents, sieve analyses, and unit weight measurements were completed before mixing, as indicated in Table 1. In the water contents in the fine, concretes was higher than the water contents in the coarse concretes [4]. For both coarse and fine concretes, the unit weight was ranging between 105lb/ft^3 to 95lb/ft^3.

Table 1. Test Carried Out on Materials Before Mixing [8]

Material	Moisture content (%)	Unit Weight (lm/ft^3)	Fitness moduli
Recycled concrete aggregates	4.00	95.00	5.32
Fine aggregates	5.81	95.10	3.01
Normal aggregates	0.02	100.02	5.13

With a size of 3 × 6 inches, concrete samples were prepared in plastic moulds. The moulds met the ASTM C470/C470M requirements. As per the ASTM Standard Practices for preparing and curing concrete trial samples, moulds were prepared in the field. For all tests meeting ASTM C143 requirements, the slump tests were completed. As per the ASTM C231 requirements, the air content tests were carried out [8]. The mixtures of alternative concrete prepared for research purposes had a good slump from 82.550 to 95.250 mm (3.250 to 3.750 inches) within 76.20 mm to 101.60 mm (3.0 to 4.0 inches) requirements. The content of air varied from 1.80% to 2.00%. The concrete water/cement ratio utilized was 0.750 for alternative concrete types.

For the tests, all the apparatus utilized met the standard dimension outlined in the applicable ASTM standards. For tests of air content, air meters utilized was a model 2786C. Standard practices were adhered to for the curing of concrete test samples [2]. The test samples were tested at periods of one week and one month after being kept in normal room temperatures. As per ASTM standards, Table 2 describes tests carried out on concretes and materials. As per ASTM standards, Fig. 1 illustrates the concrete mixing, forming, curing, and testing.

Table 2. Tests Carried Out on Concrete and Materials as Per the American Society for Testing and Materials (ASTM) Standard [8]

Materials	**Test Method**	**Descriptions**
Unit Weights	ASTM C138	Standard test methods for densities
Slumps	ASTM C143	Standard test methods for workability
Air contents	ASTM C231	Standard test methods for freshly mixed concrete air content by pressure methods
Compressive strength	ASTM C39	Standard test methods for compressive strengths

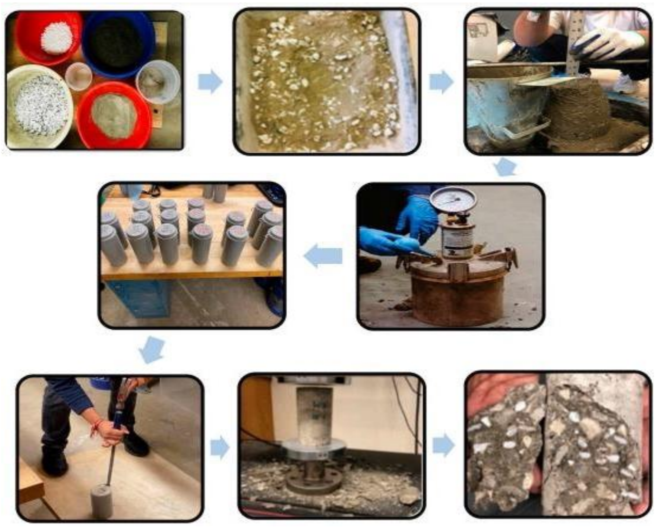

Figure 1. Procedures for preparing concrete specimens as per ASTM standards [8]

For fly ash concretes**,** with 100, 75, 50, and 30% fly ash concretes substituting cements for concretes in each mix design respectively (table three), four mix designs were made. Based on the Specification 211.1-91 of the American Concrete Institute, all the mix designs were made [2]. Also, air content measurement, slump tests, moisture content measurement, unit of aggregate measurements and sieve analyses were carried out as shown in Table 3.

Table 3. Fly ash concrete mix proportions [8]

Materials	**% replacements**	**Of fly ash**		
	1st trial (30%)	2nd trial (50%)	3rd trial (75%)	4th trial (100%)
Water (Ibs)	237.67	237.67	237.67	237.67
Fly ash classes C (Ibs)	130	216.67	238.06	433.33
Fine aggregate (Ibs)	1583.24	1583.24	1583.24	1583.24
Coarse aggregate (Ibs)	1755.76	1755.76	1755.76	1755.76
Cement (Ibs)	303.33	216.67	108.33	0
Water/cement ratio	0.75	0.75	0.75	0.75

Regarding recycled concrete aggregates, based on the material weights, percentage computations were designed [1]. 17 MPa (2500 psi) was the target of compressive strength. Different proportions of natural aggregates were substituted with reclaimed concrete aggregated from the mix design to accomplish this compressive strength. The amounts of materials such as water, fine aggregate and coarse aggregate were accomplished by mix design computation outline in Table 4. The mixes had the same water to cement (w/c) ratios of 0.750. With 100, 75, 50, and 30% recycled concrete aggregates substituting cements for concretes in each mix design respectively (Table 4), four mix designs were made [4]. Including one extra specimen, five specimens for regular concretes (normal concretes with zero proportion of RCAs) were prepared. With various recycled aggregate portions, twenty specimens were prepared.

Table 4. RCA Mix Proportions [8]

Materials	% replacements	Of fly ash		
	1st trial (30%)	2nd trial (50%)	3rd trial (75%)	4th trial (100%)
Recycled aggregate concrete (lbs)	5427.00	904.00	1446.00	1717.00
Fine aggregate (lbs)	1578.00	1578.00	1578.00	1578.00
Normal aggregate (Ibs)	1231.00	877.00	351.00	0
Cement (Ibs)	433.00	433.00	433.00	433.00
Water/cement ratio	0.750	0.750	0.750	0.750

Results and Discussion

In the construction industry, material costs are major concerns. Construction materials can regularly have adverse effects on the environment [2]. The material costs can be minimized to generate concrete products by utilizing fly ashes as an alternative for cements and reclaimed concrete aggregate as an alternative for virgin concrete aggregates in the construction industry.

During this research study, the prices and ratios of fine and coarse aggregates and waters were presumed to be constant as per mix designs [7]. The application of recycled concrete aggregates, fly ashes, and cement was the only factor affecting the concrete costs. At a local shop, a bag of 94Ib Portland cement Type I can be bought for 13.8 cents per pound. At a local shop, a bag of fly ashes can be bought for 1.75 cents per pound. State Crushing lists reclaimed concrete aggregate for sale and cost $ 16 to $ 18 per cubic yard. It relies on the buying quantity, even though the official cost of recycled aggregate concretes is unavailable [10]. When cheapest, a 12 cubic yard of reclaimed concrete aggregated can be bought at $ 13. The prices differ very regularly. The RCAs nevertheless might be acquired for free from multiple places. In this research, the recycled concrete aggregates were freely obtained and crushed manually. The fine and coarse concretes have been obtained at a price ranging from $16 to $19 per ton [4]. In the research area, water per 1000gallons was about $9 per 1000 gallons.

There are many other important aspects in cost analyses, such as labour costs, delivery fees, taxes, and transportation [2]. However, there are high uncertainties that might be considered in the analyses because those elements are dependent on the market variation, seasonal difference, project location, and project size. Therefore, the cost analyses for this research were concentrated on materials.

The cost analyses were carried out for natural concretes and other substitute aggregates in Tables 5-6. The cost comparisons were performed for 100% recycled concrete aggregates, 30% and 50% for fly ash concretes, and one cubic concrete yard with normal concretes [7]. Even though the strengths were 50psi lesser than the target strengths of 2500 psi, as compared to normal concretes, the fly ash concretes with 30% fly ashes were 15.20% cheaper on the basis of the accomplished costs per cubic yard. Fly ash concretes with 50% fly ashes can save 26.5%. The strength, however, satisfied the minimal of 2500 psi.

Table 5. Cost comparisons of normal concretes and reclaimed concrete aggregates per $/yd^3

Materials	Regular Unit cost ($/lb)	Concrete Quantity (Ibs/yd^3)	Total cost ($/yd^3)	100% recycled Quantity (Ibs/yd^3)	Aggregates Total cost ($/yd^3)
Recycled aggregates	$0.0066			1755.76	$11.59
Fine aggregates	$0.0090	1583.24	$13.46	1583.24	$13.46
Coarse aggregates	$0.0098	1755.76	$16.68	0	
Cement	$0.1380	433.33	$56.33	433.33	$56.33
Water	$0.0010	237.67	$0.24	237.67	$0.24
Total cost			$86.47		$81.62

Table 6. Cost comparisons of fly ashes per $/yd^3

Materials	30% fly Unit cost ($/lb)	ash Quantity (Ibs/yd^3)	Total cost ($/yd^3)	50% fly Quantity (Ibs/yd^3)	ashes Total cost ($/yd^3)
Fly ashes	$0.0175	130.00	$2.28	216.67	$3.79
Fine aggregates	$0.0090	1583.24	$14.25	1583.24	$14.25
Coarse aggregates	$0.0098	1755.76	$17.21	1755.76	$17.21
Cement	$0.1380	303.33	$41.86	216.76	$29.91
Water	$0.0010	237.67	$0.24	237.67	$0.24
Total cost			$75.83		$65.40

Even though there were no notable savings (5.6%), RCAs' application might substitute virgin concretes up to 100% [1]. Nevertheless, when the RCAs were acquired freely, they minimized the costs by 19% compared to normal concretes.

It is assumed that RCAs and FA production facilities respond to these changes by integrating certain proportions of their production to manufacturing and adequate demands for RCAs and FA prevails as concrete products in the assessments [8]. Nevertheless, the work does not cover the considerations of the demand and supply and their impacts on the RCAs and FA and their pricing [18]. In this assessment, the economic considerations offered to promote sustainable alternatives of reclaiming or using reclaimed products, such as subsidies are unconsidered. It is equally assumed that RCAs and FA factories lack the additional storage capacity to house RCAs and FA as CMCs and procedures and infrastructures of existing plants are personalized in building these capabilities [2]. This paper provided indicative analyses by classifying the existing plants to three general classifications to represent RCAs and FA's industry, even though the changes considered for a set-up of RCAs and FA plants would greatly rely on the specific plant conditions.

As the existing RCAs and FA factories would produce RCAs and FA and road-base materials are extended to generate RCAs and FA as CMCs, the assessment applied the fundamental assumptions that the reclaiming operations to generate RCAs and FA [1]. The plants' specific conditions might exist at extreme ends, while the incremental costs are approximated trying to generalize the case. The methodologies applied to any RCAs and FA factories, indicative analyses, and individual factories having specific conditions the estimations provided. In general, the results represent the industry of RCAs and FA as a whole.

To have six major products in the assessment, the portfolios of RCAs and FA factories' portfolios are customized [4]. Nevertheless, the RCAs and FA factories could have a complex variety of products and deliver to unique requirements of concretes. The results are founded on the facts that the setup of the existing plants is adjusted to produce RCAs and FA, and therefore zero-based budgeting is ignored for plants of OB type. It is equally assumed that with this initiative implementation, feasible commercial solutions would be introduced for RCAs and FA. The assessments of cost-benefits assume that there are adequate demands for RCAs and FA as concrete products. It is also assumed that RCAs and FA equipment and production plants play a big role in producing RCAs and FA at lower prices and sufficiently by integrating notable quantities of their resources to the RCAs and FA production [7]. Even though this paper appreciates that specific economic factors promote large-scale uses of reclaimed concrete materials and sustainable reclaiming, it is hard to account for the demand and supply factors and the resultant impacts on the RCAs and FA pricing.

To study the approach applied in this paper on RCA cost-benefit analyses, few existing research types, unfortunately, are applicable. Wijayasundara, Mendis and Crawford [16] nevertheless have studied the operational expenses of RMC industries in generating RCA by using the ABC (Activity-based costings). One can apply the activity-based method in identifying the appropriate activities utilizing this model and allocate the costs of different activities to the commodities on the basis of the resources used by the products during the process of production. Besides, this method estimates start by collecting the information of all costs to cost centres [16]. The cost drivers are then used to apportion costs to every commodity based on the activities' level. In this process, the steps involved consist of first, established of all appropriate actions. The second step consists in applying cost centres to coordinate the activities. The third phase includes the creation of the main classes associated with costs. This is followed by establishing cost factors to allocate the costs to various undertakings and processes to commodities. The next step involves introducing dependence matrixes on the cost activities as a way of associating the expenses with the actions [16]. The management can then identify the costs for various operations before introducing dependence matrices on commodity events as a way of connecting the undertakings to many goods, and ultimately, computing the ultimate costs for every good.

Almeida and Cunha [19] asserted that the ABC strategy necessity for its applications costs the production establishment of RCA and FA industries. The study carried out by Almeida and Cunha [19] introduced a method of identifying the current volatilities in the RMC plants shown by the plant turnovers and people. The researchers observed that fluctuations in demand have resulted in industries' closures at levels of around three per cent of all industry closures. Besides studies by Almeida and Cunha [19] indicated facts about the overall sector of RMC production and the present cost structures rotating around the RMC industries. With the capital intensiveness noted in the sector, another study by Almeida and Cunha [19] indicated that the raw concretes utilized have cost accounting for up to forty-five per cent of the yearly revenues in the sector. An examination of the industry's labour components showed that payments and salaries to subcontractors amounted to 5.10% in subcontract payments and 11.30% in wages. Whereas the depreciations represented 4.20%, inwards and outwards, the consignment expenses represented only 15.0% of the sector's aggregate revenues. Almeida and Cunha [19] argued that the operation costs and utility inputs, including natural gas, electricity, diesel, and water in companies, in general, accounted for the rest of the balance. Almeida and Cunha [19] presented a model that would manage the policy interventions that would promote recycling, control the waste recycling of C&D and manage the demands for the products recycled. Also, Almeida and Cunha [19] conducted viability research on the mechanical aims of recycling aggregate wastes and determined that the present RCA costs are greater than the NCA costs. Nevertheless, their researcher majorly focused on the RCA features and never reported RCA details in production establishments. Also, [20] carried out cost-effective analyses on construction waste minimization and determined that recycling construction wastes have overall benefits.

The cost-benefit assessments suggest enough demands for recycled concrete aggregate (RCA) as concrete products [20]. The RMC production equipment and plants can play an important role in this to effectively and sufficiently generate RCA at lower prices by integrating large amounts of their capitals to RCA's manufacturing. Nevertheless, it is hard in accounting for the elements of the demands and supplies and the subsequent impacts on the RCA pricing [20]. This paper also appreciates that specific economic factors support sustainable industrial recycling and industrialized uses of the recycled aggregate. The assessments concluded that the capacities of existing production plants could not house recycled concrete aggregate as CMC. The processes and infrastructures of existing production plants should be enhanced by customising the building capacities to reduce the manufacturing costs and improve the RCA production in high amounts [21]. Besides, the alterations to consider for the set-ups of ideal RMC production plants greatly depend on the specific conditions under where the high-performance recycled concrete aggregates would be produced in [20]. This would highly result in high costs of budgeting in the building of better RMC establishments because of the important requirements for quality materials and equipment in RCA production.

Conclusions

This research is an example of the application of multi-criteria decision method or methodology for concrete optimization. Multi-criteria decision method or methodology for concrete optimization also contributes to the validation of this study. The work presented a dynamic model of RCAs and FA production operations and the waste concrete reclaiming operations. As opposed to virgin concretes, the financial model is designed based on this to derive the RCAs and FA price and assess the financial viability of RCAs and FA production. This paper introduced an integrated model where a cost-benefit analysis framework is proposed. As compared to natural concretes, a financial model is also introduced where one can examine the financial viability for production of RCAs and FA at minimized costs based on the proposed cost-benefit analyses. By examining various mix variations such as RCAs and FA replacements, the binder compositions, and the types of strengths. The integration strategy and the fundamental framework adopted in this work can be replicated and used any global contexts, even though data from specific plants have been utilized to standardize the model developed.

Declaration of Competing Interest

The author declares no competing financial interest.

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