Development of indicators to assess waste management sustainability at construction sites in the city of Recife, Brazil

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ABSTRACT

Civil construction activities promote a considerable increase in waste generation which negatively impacts the environment. Although there are sustainable technologies and practices for reusing these wastes, the disposal and inappropriate destination of these wastes still prevails. Faced with this problem, this article presents a development of indicators to assess sustainability at construction sites. Thus, 30 sustainability indicators related to solid waste management at construction sites were prepared, divided into six matrices, and related to construction management, documentation control, waste segregation and initial conditioning, waste transport and final conditioning, final destination and hazardous waste management, as based on CONAMA Resolution no. 307/2002. The indicators composed six sub-indices to enable assessing sustainability and the composition of a final sustainability index. The diagnosis of the result by group of indicators shows that the focus on waste transport and final conditioning obtained the highest sustainability degree by the projects studied, while the lowest degree of sustainability presented by the projects was observed in the construction waste segregation and initial conditioning matrix.

KEYWORDS: Construction waste. Environmental legislation. Sustainability indicators.

INTRODUCTION

The civil construction industry is one of the pillars of the world economy. For Souza (2020), this segment favors growth of the Gross Domestic Product (GDP) and contributes to the economic and social development of a country through infrastructure production, reduces the housing deficit, and also generates employment and income. For Marques et al. (2020), despite the economic representativeness of this sector, civil construction also promotes environmental degradation.

Menegaki and Damigos (2018) state that around 35% of the generated amounts of construction and demolition waste in the world are directed to landfills, without any additional treatment. It is essential to determine efficient management mechanisms to reuse the potential of these wastes and minimize their disposal. Bovea and Powell (2016) argue that alternative methods of reducing waste should be explored to reduce waste in construction processes. According to Meng et al. (2018), practices of inserting sustainable products at construction sites should be encouraged to curb waste production.

Introducing sustainable practices in construction implies the possibility of achieving sustainability in a society (PASCHOALIN FILHO et al., 2017). In the paradigm of sustainable development, this sector has the opportunity to incorporate management techniques which prioritize the recovery of waste over disposal. Leal (2019) states that sustainability in civil construction is related to a long-term business vision which incorporates social and environmental dimensions into the strategy of the company's economic objectives. Jappur and Franciscon (2018) emphasize the growing search by organizations to assess their performance through performance indicators.

For Almeida et al. (2020), indicators can help companies in strategic processes and management control. In this perspective, Silva (2019) points out that indicators are important in developing public and private policy instruments, as they are essential tools for the decision-making process of these organizations.

This article aims to develop sustainability indicators to evaluate the management of solid waste from civil construction in accordance with CONAMA Resolution no. 307/2002.

METHOD

The descriptive exploratory method was applied in this research on civil construction waste management to obtain sustainability indicators at construction sites in the city of Recife in Pernambuco, Brazil. Bibliographic surveys were conducted on the proposed theme in developing the work with the objective of presenting a theoretical basis.

The development of sustainability indicators regarding construction and demolition waste (CDW) management at construction sites was based on the methodology of Paz (2014), which formulated 15 specific sustainability indicators for CDW management, with 5 indicators related to waste segregation, 5 indicators for transport and storage, and 5 indicators for final waste disposal.

For the present study, 30 sustainability indicators were prepared referring to the management of solid waste at construction sites, divided into six matrices related to the management of works, documentation control, waste segregation and initial conditioning, waste transport and final conditioning, final disposal of waste and hazardous waste management, all based on CONAMA Resolution No. 307/2002.

Values for each indicator were assigned to the sustainability trend parameters graduated in three levels from 0 to 1, corresponding to: positive (+) = 1 point, median (+/-) = 0.5 points, and negative (-) = 0 points (no points), as proposed by Peace (2014). The sum of the scores generates the sub-indices and a final index, the Construction Site Waste Management Index (CSWMI), according to Equation 1:

$$CSWMI = I_{wm} + I_{dc} + I_{sc} + I_{tc} + I_{df} + I_{hw}$$ (Eq. 1)

In which: I_{wm} is the Works Management Sub-Index;

I_{dc} is the Documentation Control Sub-Index;

I_{sc} is the Segregation and Initial Conditioning Sub-Index;

I_{tc} is the Transport and Final Conditioning Sub-Index;

I_{fd} is the Final Destination Sub-Index;

I_{hw} is the Hazardous Waste Management Sub-Index.

The CSWMI enables an analogy between construction sites in terms of their sustainability, and also enables identifying strengths and weaknesses in each waste management stage. It is noteworthy that in the study the indicators and indices were not submitted to any weighting proposal in their sustainability analyses.

The qualitative representation regarding the index decoding was used to obtain the sustainability condition of the construction sites. According to Table 1, the sustainability degree of each sub-index is observed, so that a low sustainability degree refers to a score lower than 40% of the total, while a high sustainability degree refers to a score greater than 80% of the total. The same percentage was applied to the final CSWMI index.

Table 1: Sustainability degree of the sub-indexes.

Sustainability index (Scoring)	Sustainability degree
0 to 1.9	Low
2.0 to 3.9	Medium
4.0 to 5.0	High

Source: Paz, 2014

According to Cruvinel (2016), studies to obtain the indexes promote estimation of the positive and negative points regarding sustainability, enabling companies to implement strategies and actions which minimize environmental impacts.

The CSWMI validation was performed by applying it in three construction sites located in different neighborhoods in the city of Recife, Brazil. The works were coded by numbers so as not to be recognized in their areas of expertise.

The number of works to be analyzed was determined through convenience sampling, according to the interest of the construction companies in relation to the research, with the study being delimited in terms of multi-storey housing works, carried out from September to December 2020. According to Marotti et al. (2008), convenience sampling is widely used to generate ideas in exploratory research.

The construction sites studied belong to construction companies with more than 20 years in the construction area in the city of Recife, in Pernambuco, Brazil. The summarized profile of the characteristics of these sites covered in this research can be seen in Table 2.

Table 2: Characteristics of the construction sites

Project	Construction area (m²)	No. of floors/levels	Start and end date of the work	Construction phase	ISO 14.001 Certification	Other Certification
1	9,873.26	4	Mar./20 – Dec./21 21 months	Structure	No	ISO 9.001
2	7,012.05	16	Jan./17 – Sept./21 56 months	Finishing	No	PBQP-H-n ISO 9.001
3	5,859.03	19	Aug./18 – Jun./22 48 months	Structure	Yes	OHSAS 18001

Source: Paz, 2014

Project 3 has environmental certification by ISO 14.001, while Projects 1 and 2 do not have environmental certification. According to Schmidt and Osebold (2017), ISO 14.001 provides guidelines to help manage the environmental aspects of production processes and minimize environmental impacts.

A semi-structured questionnaire was prepared based on specific norms related to civil construction waste, CONAMA Resolution no. 307/2002 and its respective updates (also in the bibliographic references), which was applied in loco to verify the procedures and practices of waste management used by the projects.

It should be noted that an analysis and verification of technical reports and the Construction Waste Management Plan (CWMP) of the construction sites was also carried out in order to verify the documentary compliance with the management practices used during the period of diagnosis of the projects to achieve the objective of this study. After the diagnosis, the

data were systematized in the CSWMI indicators and improvements were proposed in the environmental performance of the projects based on the final result of the index by analyzing the strengths and weaknesses of each thematic group.

RESULTS AND DISCUSSION
Determining the sustainability indicators

The sustainability indicators referring to the sub-index of works management, which reveal the planning behaviors for waste minimization, environmental legislation and others are presented in Chart 1.

Chart 1: Sustainability indicators for construction management.

Sustainability Indicators	Trends to sustainability		
	+	+/-	-
Waste minimization planning (GO1)	Cleaner production methodology / Rationalization, standardization and optimization techniques	Waste segregation control and monitoring programs	High waste and residue generation
Execution of services on site (G02)	Control of the standardization and use of adequate equipment to perform the services / Diagnosis of losses at the construction site	Control of the standardization and use of adequate equipment to perform the services	Inadequate equipment to perform the services
Supplies / purchases (G03)	Integrated Purchasing and Inventory Management	Purchasing and Inventory Management	Purchasing Management without Inventory Management
Environmental Policy (G04)	Printed for consultation at the Work site / Disclosure in writing / Presentation to all interested parties	Printed for consultation at the construction site / Presentation to workers at the construction site	Does not have
Environmental Legislation / Technical Notes (G05)	Compliance with Legal Requirements and Technical Notes	Good Environmental Management Practices in the Project	Non-compliance with Legal Requirements

Source: The authors

The waste minimization planning indicator (GO01) was established in the matrix of sustainability indicators for project management in order to determine the focus linked to decision-making in the planning phase. For Wang et al. (2014), determining the construction method in the design phase has a positive impact on construction operations at the site, as it promotes waste minimization.

The indicator referring to the execution of services in the work (GO02) was defined with the perspective of observing the positions in the construction process and to control losses at the construction site. Bovea and Powell (2016) affirm the need to develop alternative methods of waste reduction to mitigate waste in construction processes.

The supplies and purchases indicator (GO03) was defined according to CDW generation resulting from material losses in managing purchases and stock of construction materials. Ajayi et al. (2017) emphasize that efficient management of material logistics implies the use of the Just-in-Time technique, which is equipped with the ability to prevent excess orders and material storage.

The environmental policy (GO04) was used as an indicator to obtain information on the commitment of construction companies to protect the environment in view of the paradigm of sustainable development. It is noteworthy that environmental policy are the general intentions and principles of an organization in relation to its environmental performance, providing a structure for action and definition of its environmental objectives and goals in accordance with NBR ISO 14.001/2015 (ABNT, 2015).

The indicator referring to environmental legislation (GO05) and technical notes aims to address the fulfillment of technical and legal compliance related to the promotion of environmental quality in the execution of activities and services of the works studied. For Menegaki and Damigos (2018), compliance with general and specific legislation for CDW and good practices at the construction site are favorable factors for reducing waste generation.

Chart 2 shows the matrix of indicators for document control, which presents CWMP implementation practices and forms of contract control, training and waste disposal.

Chart 2: Sustainability indicators for documentation control.

Sustainability indicators	Trends to sustainability		
	+	**+/-**	**-**
Implementation of the CWMP (CD01)	At the work site / Compliance of the Periodic Report compatible with the Project phases	On site / No Monthly Report	CWMP is not implemented
Manifest Weighing Tickets and/or Waste Control (CD02)	Documentation stored in physical and digital media	Documentation stored on physical media	There is no control of weighing tickets
Contract for the provision of services for waste collection, transport and disposal (registered) (CD03)	Contract with a company registered with *EMLURB*	Contract with a company not registered with *EMLURB*	Information not available / There is no contract
Control of the Waste Management Training Program (CD04)	Program for Training / Personnel Qualification / Periodic Training	Program for Training / Personnel Qualification Training according to need	Non-existent program
Control of Disposal of Solid Waste from Civil Construction (CD05)	Partnerships with contracted cooperatives	Sporadic donation	Does not have

Source: The authors

The CWMP implementation indicator (CD01) was specified in order to verify its implementation at construction sites. In addition, the Manifests weighing tickets (CD02) and/or waste control indicator was established to verify *in loco* the legal compliance regarding the environmentally correct destination through the control of these documents, which concern collecting necessary documentation in the final report of the CWMP.

The proposal for the service provision contract indicator (CD03) whether for collection and transport or final destination was specified to verify application of control procedures regarding documentation in the construction sites related to the contract with companies that are registered with *EMLURB* (*Empresa de Limpeza Urbana do Recife*), responsible for the analysis and approval of the CWMP.

Moreover, there is a focus on training workers with regard to the control of the training program (CD04) in waste management indicator. For Miranda et al. (2019), the training of

employees must imply a holistic view in their training in the knowledge of waste related to their classes and correct segregation at the jobsite, as well as the environmental relevance of performing this activity.

The matrix of indicators for solid waste and CDW segregation and initial conditioning can be seen in Table 3, which reveals the approaches related to selective collection, signaling, segregation, initial conditioning, and monitoring.

Chart 3: Sustainability indicators for CDW segregation and initial conditioning.

Sustainability indicators	Trends to sustainability		
	+	+/-	-
Waste segregation (SA01)	Sorting at the origin of the generation by type of material of their respective waste classes	Sorting the generation source by waste classes	Does not perform sorting at the waste generation source
Initial conditioning (SA02)	Cans / collectors / packaging bags / raffia bags / stacks formed separated by classes close to the internal transport places on the respective floors	Stacks formed separated by classes close to the internal transport locations on the respective floors	Stacks formed but not separated by classes near the internal transport sites on the respective floors
Disposal of selective collection equipment (SA03)	Complies with CWMP and compatible with the project phases	Existence of devices	Does not have
Signaling (SA04)	Adequate signage of storage places	Signaling of storage places, but barely visible	No signage of storage areas
Monitoring (SA05)	Monitoring of screening / segregation / conditioning / Autonomy for preventive and corrective action	Monitoring of screening / segregation / conditioning	Does not have

Source: The authors

The segregation indicator (SA01) present in the matrix of sustainability indicators for waste segregation and initial conditioning was prepared with the purpose of verifying sorting practices at construction sites. In accordance with CONAMA Resolution 307/2002, the generator must carry out the screening, preferably at the origin of its generation.

Initial conditioning (SA02) is an important indicator regarding waste management practices, in which waste storage must be guaranteed after generation until the transport stage, ensuring conditions for reuse and recycling. At this stage, mixtures of waste from different classes, and even from different products of the same class, must be avoided (BITTENCOURT, 2012). It is emphasized that the waste must be segregated from its production, meaning in the area where the service is performed.

The selective collection equipment disposal indicator (SA03) and the signaling indicator (SA04) were proposed to verify the distribution of waste collectors in various areas of these construction sites and to observe the use of signaling in accordance with CONAMA Resolution No. 275/01, as well as to evaluate the effectiveness of the CDW segregation and storage practices at the construction sites.

The monitoring indicator (SA05) was presented to verify the waste management at the construction site in order to establish the best use of this waste, whether reuse or recycling, and environmentally appropriate disposal in order to enable preventive actions to the detriment of corrective actions.

Table 4 shows the indicators for waste transport and final conditioning related to internal transport, final storage, cleaning, and external transport.

Chart 4: Sustainability indicators for waste transport and final conditioning.

Sustainability indicators	Trends to sustainability		
	+	+/-	-
Internal transport (TA01)	Use of segregated vertical and recyclable ducts	Use of a wheelbarrow or jib together with a freight elevator or crane in the manual transport of unmixed CDW	Transport of mixed CDW waste by wheelbarrow
Final storage in dumpsters/containers (TA02)	Segregation between plaster/drywall, wood and rubble residues	Single dumpster/container without segregation between plaster, wood and rubble residues	Dumpster / container mixed with other types of waste
Final storage in bags/bays (TA03)	Well segregated waste / signposted location	Segregated waste bays / bags too full	Mixed waste
Cleaning (TA04)	Absence of waste in the vicinity of the waste storage area	Existence of waste in the vicinity of the storage area / signposted location	Existence of waste scattered in the vicinity of the waste storage area / without signage
External transport (TA05)	Class A and C waste transported in a truck with multi-crane equipment or truck with a tipper body always covered with tarp / Class B waste transported in a truck or other cargo vehicle, provided that the bags are removed closed to prevent mixing with other waste in the bodywork and dispersion during transport	Class A and C waste transported in truck with tipper body not covered with tarp / Class B waste transported in truck or other cargo vehicle, not mixed with other waste in the body / no concern for dispersion during transport	Transport of mixed waste of different classes in truck with tipper not covered by a tarp / transported in truck or other cargo vehicle, waste mixed with other waste in the body / no concern for dispersion during transport

Source: The authors

The study of the indicator referring to internal transport (TA01) aimed to observe how this circulation is carried out at the construction site, as it is considered a significant focus on waste management. According to Cabral and Moreira (2011), wheelbarrows and jigs are generally used for horizontal waste displacement, while freight elevators, cranes, and debris collection ducts are used for vertical displacement.

The indicators related to the final storage of waste were specified regarding their conditioning in dumpsters (TA02), bags and bays (TA03) in order to observe the performance this procedure according to the technical guidelines regarding waste conditioning for its final destination. This conditioning must be located in order to facilitate its removal and final destination (LIMA; LIMA 2009). It also ensures that waste continues to be segregated and the characteristics necessary for recycling are maintained.

The cleaning indicator (TA04) was defined with the purpose of highlighting the organization and cleaning practices regarding the flow of waste in the construction sites. These

practices within the construction site positively enable the progress of construction processes, minimizing contamination and CDW losses arising from the work.

Next, we sought to highlight sustainable practices for removing waste from the construction site regarding the external transport indicator (TA05). External transport is considered to be waste removal from the places of origin to transfer stations, treatment centers or its final destination (BEZERRA, 2019). External transport must be carried out by a waste carrier, which must be registered by the municipal supervisory body, *EMLURB*.

Table 5 shows the matrix of indicators for the destination of recycled solid waste and construction which covers indicative points on non-recyclable waste, waste routing, recycling and reuse of construction waste.

Chart 5: Sustainability indicators for the final destination of waste.

Sustainability indicators	Trends to sustainability		
	+	+/-	-
Destination of recycled solid waste (DF01)	Forwarded to companies, cooperatives or selective collection associations which sell or recycle these wastes	Sporadic donation	Has no concern with the proper destination
Non-recyclable waste (DF02)	Reverse logistics	Disposal in sanitary landfill (Class C)	Inadequate disposition
Forwarding construction waste and plaster / drywall (DF03)	Permanent disposal in a CDW recycling plant / company specialized in the proper disposal of plaster / drywall	Landfill of construction waste and inert waste / company specialized in the proper disposal of plaster / drywall	Destination in landfills or inappropriate locations
Recycling of construction waste (DF04)	Uses recycled aggregates in mortar or concrete	Uses recycled aggregates for less noble purposes such as in curbs / sidewalks and others in the project	Does not use aggregates in the work
Reuse of construction waste (DF05)	Reuse of waste on site	Sale of waste to be reused elsewhere	Does not reuse waste

Source: The authors

The destination of recycled solid waste (DF01) indicator was formulated to analyze the use of the destination of this waste according to legal precepts. The final destination of environmentally adequate CDW must be in accordance with their classes, following the guidance of CONAMA Resolution no. 307/2002.

The indicator referring to non-recyclable waste (DF02) had the objective of presenting the actions regarding the use of reverse logistics, and when not applied, verifying the destination of this waste to the landfill. For Santos and Marchesini (2018), reverse logistics is a strategy which enables preserving resources, having wide application in the civil construction sector, although this sector has some technological and information obstacles for its insertion.

The forwarding of construction waste and plaster / drywall (DF03) was established as an indicator to verify the destination of these wastes regarding their reintroduction in the construction process or their recycling. For Cabral and Moreira (2011), plaster / drywall, which belongs to class B, must be conditioned separately from other waste in its class for future

recycling. Care must be taken with segregating plaster / drywall and its separate conditioning so that it does not mix, making it unfeasible for recycling.

With regard to recycling of construction waste indicator (DF04), we sought to investigate the practice of recycling recycled aggregates at the construction site. Brasileiro and Matos (2015) highlight the importance that recycled aggregates have regarding the possibility of not extracting natural, non-renewable raw materials.

The indicator for reuse of construction waste (DF05) had the purpose of verifying the practice of reusing class A waste at the construction site studied. According to CONAMA Resolution No. 307/2002, reuse is defined as the process of reapplying waste without transforming it.

Table 6 shows the indicators for hazardous waste management with the approaches related to hazardous waste segregation and conditioning, training, transport and disposal.

Chart 6: Sustainability indicators for hazardous waste management.

Sustainability indicators	Trends to sustainability		
	+	+/-	-
Segregation and initial conditioning (RP01)	In drums / in crates / in the packaging itself / in a leak-resistant container / with identification and signage	In drums / in crates / in the packaging itself / in a leak-resistant container / without identification and signage	Collector / container which is not leak resistant
Final conditioning of hazardous waste (RP02)	In containers / in drums / with signage / well ventilated / in a covered area / on an impermeable base to prevent leaching and seepage into the ground.	In containers / in drums / with signage / well-ventilated / in an uncovered area / on unprotected ground	In containers / in drums / without ventilation / in an uncovered area / on unprotected ground
Training workers (RP03)	Program for Training / Personnel Qualification / Periodic Training	Program for Training / Personnel Qualification Training according to need	Non-existent program
Transport of hazardous waste (RP04)	Transported by truck or other cargo vehicle / always covered	Transported by truck or other cargo vehicle / not covered	No care regarding the transport of waste
Destination of hazardous waste (RP05)	Forwarded to licensed landfills for the reception of hazardous waste / and the return in the container itself to the supplier company (reverse logistics)	Forwarded to licensed landfills to receive waste. It does not perform reverse logistics	Forwarded to sanitary landfills / inappropriate disposal

Source: The authors

The segregation and initial conditioning indicator (RP01) was prepared to verify the practices of sorting and initial conditioning of hazardous waste from the construction process, such as solvents, paints, oils, fiber cement with asbestos and other harmful products to health and the environment.

The indicator for final conditioning of hazardous waste (RP02) was proposed with the purpose of observing the storage procedures at the work sites in terms of safety for workers and the environment. The conditioning of hazardous product residues at the construction sites must meet the specifications of the Chemical Product Safety Information Sheet - CPSIS (or *Ficha de Informação de Segurança do Produto Químico - FISPQ*), which is attached to the products purchased.

The indicator related to worker training (RP03) was established with the objective of verifying the existence of training. The training and qualification of employees regarding waste segregation, conditioning and disposal in accordance with CONAMA Resolution No. 307/2002 and understanding the environmental importance for good waste management are essential (MIRANDA, 2019).

The hazardous waste transport indicator (RP04) was established with the purpose of verifying how class D waste is transported to its final destination. These residues must be transported in a truck or other cargo vehicle, always covered. This protection prevents environmental pollution during transport (CRUVINEL, 2016).

The specification of the hazardous waste destination indicator (RP05) proves to be important in terms of complying with the legal precepts of waste disposal implementations. CONAMA Resolution No. 307/2002 defines the environmentally appropriate destination for each class of waste.

Comparative analysis of the sustainability indicators

Table 7 presents the sustainability matrices for the six sub-indices related to the sustainability of construction sites.

Chart 7: Scoring of the sustainability indicators.

Sub-index	Indicator	Projects			Mean
		1	*2*	*3*	
Project management	GO1	+	-	+	0.7
	GO2	+/-	+/-	+	0.7
	GO3	-	-	+/-	0.2
	GO4	-	-	+	0.3
	GO5	-	+/-	+	0.5
	Index	**1.5**	**1**	**4.5**	2.3
	Degree	**Low**	**Low**	**High**	
Documentation control	CD1	-	+/-	+	0.5
	CD2	-	+/-	+/-	0.3
	CD3	+/-	+	+	0.8
	CD4	+/-	+/-	+	0.7
	CD5	-	+/-	+	0.5
	Index	**1**	**3**	**4.5**	2.8
	Degree	**Low**	**Medium**	**High**	
Waste segregation and initial conditioning	SA01	-	+/-	+	0.5
	SA02	-	+/-	+	0.5
	SA03	-	-	+	0.3
	SA04	+/-	-	+	0.5
	SA05	-	-	+/-	0.2
	Index	**0.5**	**1**	**4.5**	2.0
	Degree	**Low**	**Low**	**High**	
Waste transport and final conditioning	TA01	-	+	+	0.7
	TA02	+	+	+	1.0
	TA03	+	+/-	+	0.8
	TA04	+/-	-	+/-	0.3
	TA05	-	+/-	+	0.5
	Index	**2.5**	**3**	**4.5**	3.3
	Degree	**Medium**	**Medium**	**High**	
Final destination	DF01	-	+/-	+	0.5
	DF02	-	+/-	+	0.5
	DF03	+/-	+	+	0.8

	DF04	-	-	-	0.0
	DF05	-	+	-	0.3
	Index	**0.5**	**3**	**3**	2.2
	Degree	**Low**	**Medium**	**Medium**	
Hazardous waste management	RP01	-	+/-	+	0.5
	RP02	+/-	+/-	+	0.7
	RP03	+/-	+/-	+	0.7
	RP04	-	+/-	+	0.5
	RP05	-	+/-	+	0.5
	Index	**1**	**2.5**	**5**	2.8
	Degree	**Low**	**Medium**	**High**	
CSWMI		**7.0**	**13.5**	**26.0**	15.5
CSWMI degree		**Low**	**Medium**	**High**	

* Grades and scoring: (-) = 0 point, (+/-) = 0.5 point, (+) = 1 point,

** Degree: Low = 0 to 1.9 points, Medium = 2 to 3.9 points, High = 4 to 5 points.

It was found that none of the construction sites presented a high degree of sustainability in the sustainability analysis of Projects 1, 2 and 3 in the six groups of indicators. It is noteworthy that only Construction site 3 obtained a high degree of sustainability in more than one of the groups of indicators, while the other analyzed works did not reach this high sustainability graduation in their construction sites.

It was found that the average of 15.5 obtained by the Construction Site Waste Management Index (CSWMI) of the three construction sites studied determines an average sustainability degree. Although, it has been verified that the indexes (CSWMI) of Project 1 and 2 of 7.0 and 13.5, respectively, imply low sustainability values. Therefore, this average was influenced by the high sustainability performance value obtained by the construction site of Project 3 (26.0). It is noted that these results reflect the greater or lesser business commitment of the builders of these construction sites with sustainable development.

Project 3 adopts sustainability practices in the projects it develops, also maintaining strict quality control of the stages of the construction processes resulting from adopting environmental certification in its projects. In contrast, Projects 1 and 2 only seek compliance with the legislation without commitment to the promotion of environmental quality.

The diagnosis of the result by group of indicators shows that the focus on waste transport and final conditioning obtained the highest sustainability degree for the studied projects, which implies I_{tc}(Final) = 10. The construction sites of Projects 1, 2 and 3 respectively obtained the following sub-indexes (I_{tc}): 2.5; 3.0 and 4.5, which correspond to a medium sustainability degree for Projects 1 and 2, and a high degree for Project 3. In other words, the construction sites presented a medium sustainability degree (I_{tc}=3.3) regarding waste transport and final conditioning.

This result is related to the waste circulation procedures at the construction site, also to the effective segregation means in the final storage of plaster and aggregates, and their respective transport, which reflect concern of the management of the construction sites with the costs related to the final destination of this waste. In addition, there is a lack of environmental awareness by the construction companies themselves, as there would be greater savings if they adopted sustainable practices in their waste management.

The lowest sustainability degree presented by the studied projects was observed in the segregation and initial conditioning of civil construction and demolition waste (CDW) matrix. The

sub-indices (I_{sc}) achieved by the construction sites of Projects 1, 2 and 3 were 0.5, 1.0 and 4.5, respectively, which correspond to a low sustainability degree for Projects 1 and 2 and a high degree for Project 3.

The low results obtained by the construction sites of Projects 1 and 2 are due to inadequate procedures used in waste management regarding waste segregation and initial conditioning, lack of signage and collection equipment at the work station and in the environments of the construction site. These factors are intensified by a lack of training for employees in this area.

It was found that the general sustainability degree regarding the final destination of waste obtained the second lowest sustainability value. The sub-indices (I_{fd}) obtained at the construction sites of Projects 1, 2 and 3 were 0.5, 3.0 and 3.0, respectively, which express a low sustainability grade for Project 1 and medium grade for Projects 2 and 3.

The negative results obtained by the construction sites regarding the final destination indicators are due to the lack of reuse of the aggregates in the construction sites, whether it is their recycling in employment for less noble purposes, or their reuse in the project itself. Factors which could reduce the costs of these works would be the acquisition of natural aggregates with the transport of waste, as well as contributing to the preservation of natural resources. This attitude of the management of the works is associated with culture, lack of trust and knowledge of the potential of reuse of aggregates in the construction process.

CONCLUSIONS

This study met the objective of evaluating the sustainability of waste management through sustainability indicators, which were prepared from data collection at construction sites in the city of Recife, which in turn made it possible to perform a comparative analysis of the sustainability indicators of these sites.

Regarding the general sustainability analysis of the construction sites, it was verified that most construction companies lack business commitment to sustainable development. This is a reflection of the negligence of these companies regarding waste management in their construction sites, since most carried out deficient practices of segregation, conditioning and destination of CDW; in addition, they did not control the waste of materials or promote the reuse of these wastes at the construction site.

The low results regarding sustainability in the construction projects is associated with the lack of availability of periodic training for workers involved in the waste management processes, as well as an absence or insufficiency of collection equipment, and/or the absence or deficiency of signaling at the construction sites. Inefficient implementation of the CWMP at the construction sites also stands out as an influencing factor, as most of them did not comply with the stages of the work.

A lack of reuse of aggregates in the construction sites was identified regarding the low sustainability result for the final destination, whether it is reuse or recycling. These procedures for reinserting waste into the production cycle could reduce the costs of these projects by acquiring natural aggregates and waste collection, transport and disposal, as well as contributing to the preservation of natural resources and mitigating pressures on licensed landfills.

Thus, the influences of managerial factors in the projects must be considered in order to improve sustainability in waste management at the construction site, which can achieve greater effectiveness through environmental awareness and technical training of site managers, who can in turn promote adopting management tools to circulate waste in order to reduce the inappropriate destination of their waste and establish reintroduction of these wastes into the production process.

This study points out the importance of applying environmental indicators in the sustainability analysis in the projects, and it is expected that the results presented in this research can contribute to better CDW management at construction sites.

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