Evaluation of Construction Waste Management in the Project and Construction Stages

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***Abstract*— Construction waste has become a major public health and management challenge in Brazil. Given the existence of a large number of feasible practices for effective construction waste management, it is important to assess which critical successful practices are to be implemented both in the project and the construction stages in order to provide effective waste management. In order to identify these critical practices, seven successful practices related to the project stage and eight successful practices related to the construction phase were listed based on a bibliographical review. Subsequently, a questionnaire aimed at projecters and engineers was applied, where they evaluated their knowledge of the laws and regulations related to construction waste, the importance of each practice previously listed and whether these practices are implemented in their company. The results of this study also demonstrate that practices related to the project stage have a much lower percentage of implementation when compared to implementation levels related to the construction phase, 29% versus 52%. In addition, it is verified that most of the successful practices considered as critical by the respondents of the questionnaire are in agreement with the bibliographic review.**

***Keywords*— Construction Waste, Critical Successful Practices and Waste Management**

I. INTRODUCTION

Currently, with increasing industrialization, a continuous generation of new technologies, population growth, increasing population density in large urban centers and diversification of consumed goods and services, a generation of municipal solid waste (MSW) has become a major public health concern [1]. Data published by [2] show that in 2015 there was a generation of approximately 79 million tons of urban solid waste, representing an increase of 1.7% over the year 2014. More aggravating than the generation itself increasing MSW is the fact that about 30 million of the waste generated is being destined to landfills or controlled landfills, which do not have a set of systems and measures indispensable for the protection of the environment.

Most of the generated MSW consists of construction waste, about 61% [3]. This waste generated originates in all activities related to the construction industry and in all construction stages, project, execution and use [4]. Given that construction waste management is expensive and complex due to the high volume and mass that is generated, besides the fact that these residues do not receive adequate solutions, implying, among other effects, the proliferation of vectors of diseases in the urban environment [5], Construction waste have become a major managerial problem for cities and for builders [6].

Due to the growing awareness and concern on the part of public and private entities related to environmental issues, in addition to the need to establish criteria and methods related to the municipal solid waste management (MSWM) and construction waste management (CWM), CONAMA Resolution No. 307/2002 and the National Policy of Solid Waste (NPSW), regulated by Law 12,305 of 2012. Both CONAMA Resolution No. 307/2002 and NPSW seek, through instruments, to implement criteria for an integrated and efficient management of the waste generated, minimizing its impact on the environment. One of the elaborate instruments that seek to improve the management of construction waste is the Construction Waste Management Plan (CWMP). This search, through a sequencing of activities, establishes the necessary guidelines for an adequate and efficient waste management during the construction phase [7].

Although NPSW and CONAMA Resolution No. 307/2002 define guidelines for proper management of construction waste, a company's human, financial and material resources for carrying out these activities are often limited and scarce. Thus, it is important to evaluate where to use them in order to boost the results generated. Thus, an extensive literature review was carried out, selecting, according to research already published, the most important managerial practices to be executed both in the project phase and in the execution / construction phase for effective and efficient CWM.

The general objective of this work is to define the critical successful practices related to the project and construction stage for the effective CWM and to verify the actual implementation of these, according to the professionals involved in the construction stages.

II. CONSTRUCTION WASTE MANAGEMENT (CWM)

To manage, according to [8], is to solve problems. In the case of construction, one of the major problems is

construction waste, since all waste is a loss and any loss is an unwanted result (problem). In this way, the manager must, through management always seek to minimize the generation of waste, reducing its loss. When this is not possible, one should seek to reuse and recycle this waste in order to minimize the impacts of its loss. When none of these alternatives is possible, this waste must be handled properly and adequately projected to meet current standards and laws [9].

According to [10], efficient waste management can result in up to 50% savings in CWM costs, 15% reduction in waste generation and 43% in waste disposal in landfills. Although the benefits of efficient management are evident, it is clear that many works have an inadequate and ineffective CWM process [11]. Fig. 1 demonstrates the stages of the CWM process in chronological order, according to [12].

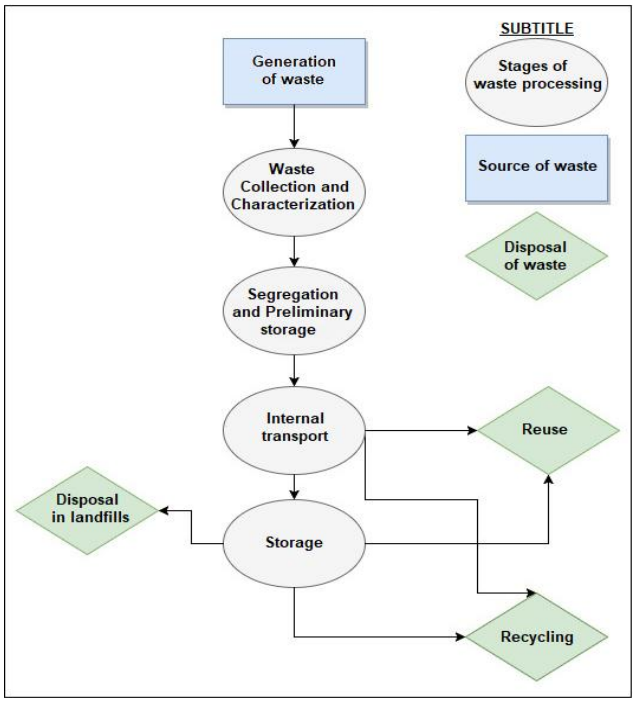

Fig. 1. CWM process, Adapted from [12]

In the flowchart of Fig. 1, the rectangle shows the source of waste, which is the very generation of the waste. Lozenges are the possible destinations that can be given to the waste generated, reused, recycled or disposed of in landfills. The circles represent the very steps of the CWM process. All of these processes are governed and conditioned by the CWM plan, which must be prepared in advance.

In order for the entire CWM process to be effective and efficient, [13] points out that good environmental education is essential. Through environmental education, agents involved in construction activities are sensitized and become aware of its importance in this management, reducing the possibility of failures during the management stages. In addition to environmental education, [14] and [15] emphasize that adequate technical training of workers is also of utmost importance for reducing the amount of waste generated, since it reduces the rate of rework and the generation of during the execution of the activities. According to [13], environmental education should be carried out through lectures, trainings, dynamics and other educational approaches throughout the construction process. Currently, many workers either are hired without training or receive very short training, less than a week [16].

III. METHODOLOGY

To identify critical successful practices (CSP), [17] summarized the procedures in some key steps:

- To identify, from the scope of the literature, the successful practices (SP) that are related to the stages of the CWM process and that provide, directly or indirectly, a more sustainable and environmentally correct CWM;
- Correlate each selected practice (SP) to the project / project or construction / execution stage;
- Elaborate a questionnaire to identify the importance of each PS previously identified.

In this way, a vast bibliographical review was done, with the purpose of identifying managerial successful practices (SP) that are important and effective, according to the articles researched, for the following effects: Non-generation, Reduction, Reuse, Recycling, Treatment or Proper disposal of waste.

In total, 15 SP were selected, of which seven of the 15 are related to the project stage and the remaining eight are related to the construction / execution stage. In Table I and Table II presents a summary of all selected practices, as well as the author of the article from which the practice was withdrawn and its correlation with the project or construction step. After the selection of SP, the questionnaire was elaborated.

TABLE I:
IMPLEMENTATION OF SUCCESSFUL PRACTICES IN THE PROJECT PHASE

Code	Practice	Reference
P1	Specification, in project, of technologies that produce little residue, such as prefabricated, metallic forms and dry walls.	Tam (2008) Lu & Yuan (2010) Formoso et al. (2002) Poon, Yu & Jaillon (2004)
P2	Planning the site layout for waste management (example: waste storage points).	Tam (2008)
P3	Definition of those responsible for each stage of CWM.	Wang et al. (2010)
P4	Specification, in the project, of techniques and procedures to minimize the waste generated during the construction stages.	Osmani, Glass & Price (2008)
P5	Specification, in the project, of the constructive procedures that can be reused of the waste generated.	Merino, Garcia & Azevedo (2010)
P6	Specification, in the project, of materials with high percentage of recycled materials.	Audos, Charles & Evans (2010)
P7	Minimization of changes of the executive project after the beginning of the construction process.	Osmani, Glass & Price (2008)

Codes "P1" to "P7": referring to the project stage.

TABLE II
IMPLEMENTATION OF SUCCESSFUL PRACTICES IN THE CONSTRUCTION PHASE

Code	Practice	Reference
C1	Use of concrete and mortar machined.	Merino, Garcia & Azevedo (2010)
C2	Education, awareness and training of those involved in the CWM and in the construction stages.	Merino, Garcia e Azevedo (2010)
C3	Recycling of waste at the construction site.	Wang et al. (2010)
C4	Respect to the executive project that was elaborated from the project stage.	Rouce (1998)
C5	Control of materials and waste generated (quantity and types).	Osmani, Glass & Price (2008)
C6	Proper sorting and storage of the waste generated at the construction site during the construction stages.	Lu & Yuan (2010)
C7	Use of crusher or compacting machine at the construction site.	Poon et al (2004)
C8	Requests and storage of raw materials at appropriate times and locations.	Formoso et al. (2002)

Codes "C1" to "C8": referring to the construction stage.

The research work questionnaire was composed of three sections. The first section aims to evaluate the profile of the respondent and their knowledge regarding the CWM and its regulations (laws and resolutions). The second section assesses whether the previously selected successful practices are implemented or not by the company in which the respondent works or worked. In this section, the respondent evaluates only the execution of the practices that are related to his area of activity (project or construction). In the third and last section, all respondents, regardless of their area of activity, evaluate all selected PS according to their importance in relation to: no generation, Reduction, Reuse, Recycling, Treatment and Proper disposal of waste. The evaluations were performed on a scale of 1 to 5, where: 1 denotes that in the respondent's view, that PS is not at all important, 2 slightly important, 3 moderately important, 4 very important and 5 very important.

IV. RESULTS AND DISCUSSIONS

From the application of the questionnaire, which occurred between August 28, 2017 and September 30, 2017, a total of 54 responses were received. Of the 54 responses received, two were invalidated because the respondents indicated note 5 in all PS presented and one was invalidated, since the respondent had never worked in any stage of the building cycle. This left 51 valid answers for analysis.

A. *Respondent profile and knowledge about waste*

From the first section of the questionnaire, it was possible to identify the profile of the respondents and their knowledge regarding the CWM (Fig. 2). More than half of the respondents, 27 people or 53%, were people who worked on the construction stage. Of the others, 24 people, 21 worked or worked in the project stage, two in the maintenance phase and one in the planning stage.

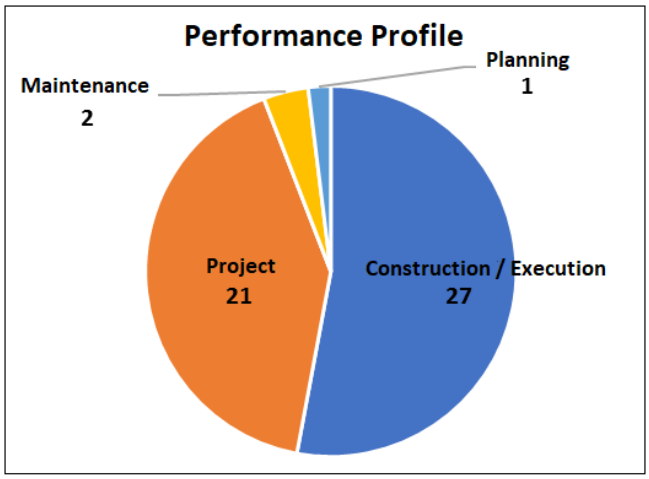

Fig. 2. Profile of respondents' performance. Prepared by the author

B. *Evaluation of the execution of successful practices (SP)*

The second section of the questionnaire sought to verify if the successful practices selected from the bibliographic review were performed or not in the work and area of action of the respondent. For this, the second section of the questionnaire was divided into two subsections, one with the SP related to the project stage and another with the SP related to the construction phase. The interviewee thus evaluated only those practices related to his area of performance.

1) *Construction / Execution Subsection*

From the 27 answers obtained through the questionnaire of construction workers, the PS that had the highest percentage of implementation was: "use of mortar and concrete machined", with 74%. Subsequently, the respondents indicated that "two respects to the executive project that was elaborated and the execution of orders" and "storage of raw materials at the right time and places" are two other practices commonly implemented in the works, with a 67% implementation (Table III).

On the other hand, only four of the 27 (15%) respondents indicated that they use crushers or compaction machines at the construction site, and only eight of the 27 (30%) indicated that the waste is recycled at the construction site.

At the end of the construction subsection, the respondent was invited to lecture on the existence of some practice that he considered important and that is or was applied in his work of performance. One of the people mentioned that a company-wide database was created where all project managers could consult with them to identify cooperatives or people nearby who were looking for waste free of charge. This practice

implies reducing the costs of correctly disposing of the waste, since it reduces the need to hire buckets and pay the companies that transport the waste to landfills.

TABLE III
RESPONSES TO SUCCESSFUL PRACTICES IN THE CONSTRUCTION PHASE

Successful practices	Number of responses	%
Use of concrete and mortar machined.	20	74%
Respect to the executive project that was elaborated in the project stage.	18	67%
Requests and storage of raw materials at appropriate times and locations.	18	67%
Proper sorting and storage of the waste generated at the construction site during the construction stages.	16	59%
Education, awareness and training of those involved in the CWM and in the construction stage.	14	52%
Control of materials and waste generated (quantity and types).	14	52%
Recycling of waste at the construction site.	8	30%
Use of crusher or compacting machine at the construction site.	4	15%

2) Project subsection

In the project subsection, seven successful practices were selected based on the bibliographic review. Thus, the 21 people who answered the questionnaire and who worked or worked in the project phase analyzed whether these seven practices are or were implemented in the works in which they acted or act.

Unlike the construction phase results, which had a relatively high percentage of implementation, the implementation results of the SP of the project stage had a low percentage of implementation. As can be seen in Table IV, only two of the seven practices selected had a response rate greater than 50%.

TABLE IV
RESPONSES TO SUCCESSFUL PRACTICES IN THE PROJECT PHASE

Successful practices	Number of responses	%
Specification, in design, of technologies that produce little residue, such as prefabricated, metallic forms and dry walls.	13	62%
Minimization of changes of the executive project after the beginning of the construction process.	12	57%
Planning the site layout for waste management (example: waste storage points).	10	48%
Specification, in the design, of techniques and procedures to minimize the waste generated during the construction stages.	5	24%
Specification, in the design, of the constructive procedures that can be reused of the waste generated.	2	10%
Definition of those responsible for each stage of CWM.	1	5%
Specification, in the design, of materials with high percentage of recycled materials.	0	0%

The two practices that are most applied in the works, according to the questionnaire, are: "Specification, in design, of technologies that produce little residue, such as prefabricated, metallic forms and dry walls" and "minimization of changes in the executive project after the start of the construction process ".

In a way, the results presented in this subsection demonstrate the need of agents related to the design stage to understand that an efficient CWM must be done in an integrated way and corroborate with the data presented by [18], the which show that 82% of the designers do not carry out their projects with a focus on reducing the generation of construction waste.

C. Evaluation of SP related to the CWM

In the last section of the questionnaire, the respondents were invited to evaluate all selected SP, both in the design and construction stages, regarding their importance in: No generation, Reduction, Reuse, Recycling, Treatment and Proper disposal of waste. For this, the 15 selected practices were evaluated on a scale of 1 to 5. Based on the quantitative model and on the given answers, the importance indexes (Vi) of each selected PS and the standard deviation were calculated.

1) Successful practices of construction / execution

Table V shows the already ordered results of the PS with the highest Vi for the lower relative to the construction stage. The mean indexes of importance were 3.90. Therefore, those PSs with higher than average indices were considered as critical, which totaled in a selection of 5 practices. The critical successful practices were: "Education, awareness and training of those involved in CWM and in the construction stages", "Respect for the executive project that was elaborated from the project stage", "Screening and appropriate storage of the waste generated at the site works during the construction stages", "Control of materials and waste generated (quantity and types)" and "Requests and storage of raw materials at appropriate times and places".

TABLE V
INDICES OF IMPORTANCE IN THE CONSTRUCTION PHASE

Successful practices	Vi	Standard deviation	CSP
Education, awareness and training of those involved in the CWM and in the construction stage.	4.35	0.80	CSP1
Respect to the executive project that was elaborated in the project stage.	4.27	0.83	CSP2
Proper sorting and storage of the waste generated at the construction site during the construction stages.	4.16	0.88	CSP3
Control of materials and waste generated (quantity and types).	4.08	1.00	CSP4
Requests and storage of raw materials at appropriate times and locations.	4.04	1.02	CSP5
Recycling of waste at the construction site.	3.82	1.05	-
Use of concrete and mortar machined.	3.41	1.19	-
Use of crusher or compacting machine at the construction site.	3.04	1.13	-

It is not surprising that the "Education, awareness and

training of those involved in the CWM and in the construction stages" was considered the most important PS by the respondents to the questionnaire. In a survey conducted by [15] with builders, the "education and training" practice was identified as the second most important practice for proper CWM. [14] also conducted research to identify those critical practices for proper CWM and in their research, awareness and training were also identified as one of the critical success practices. According to research published by them, the awareness of builders and other agents involved in the construction industry is a slow but essential process for proper CWM. In addition, training is necessary and very important, since activities, when performed incorrectly, imply a high percentage of rework and waste generation.

Although this was the SP defined as most important by the respondents to the questionnaire, it is verified that only 54% of the respondents indicated that this practice is adopted in the works of action. This highlights a gap and opportunity to improve the CWM system at the construction stage, focusing on the elaboration of training and education and awareness programs.

The second CSP identified was the "Respect to the executive project that was elaborated in the project stage". Failure to comply with the executive project and the need for future interventions necessarily entail impacts on the time and costs of the work, as well as increasing the generation of waste, since it is necessary to carry out interventions, such as partial or total demolitions, structures already built. In this way, it is very important that managers and builders pay attention to the project that was previously elaborated. This practice is performed by 67% of the respondents in the respective works that work or have already performed, an above average value, but that needs to be increased, since this practice does not require application of extra resources, but only discipline and commitment of the agents involved in the constructive stages.

2) Successful practices of project

Regarding the 7 SP of the selected project stage, the average importance indexes were 4.02, higher than the average identified in the construction phase, which was 3.90. Accordingly, CSP 3 of the 7 selected practices were considered: "Layout of the construction site layout for waste management (example: storage points of the waste)", "Design specification of technologies that produce little such as prefabricated, metallic forms and dry walls" and "Specification in the design of techniques and procedures to minimize the waste generated during the construction stages" (Table VI).

Among the selected SP related to the project stage, the SP that had the highest level of importance identified by the respondents was "Layout planning of the construction site for waste management (example: storage points of the waste)." In a study by [19] with constructors it was identified that the existence of a suitable space and space for waste management is essential for the CWM, mainly for the screening of the same. [20] further reinforces that the accomplishment of the residue sorting step is extremely dependent on the available space to perform this activity. More than the sorting, the storage of the waste is also important to be defined previously, choosing storage points compatible with the residue that will be stored [15]. According to the respondents of the questionnaire, this practice has a level of implementation of 48%, a percentage considered small given its importance for the occurrence of an appropriate CWM.

TABLE VI
INDICES OF IMPORTANCE IN THE PROJECT PHASE

Successful practices	Vi	Standard deviation	CSP
Planning the site layout for waste management (example: waste storage points).	4.35	0.80	CSP6
Specification, in design, of technologies that produce little residue, such as prefabricated, metallic forms and dry walls.	4.10	1.01	CSP7
Specification, in the design, of techniques and procedures to minimize the waste generated during the construction stages.	4.08	0.98	CSP8
Minimization of changes of the executive project after the beginning of the construction process.	3.98	1.05	-
Definition of those responsible for each stage of CWM.	3.98	0.93	-
Specification, in the design, of the constructive procedures that can be reused of the waste generated.	3.86	1.00	-
Specification, in the design, of materials with high percentage of recycled materials.	3.78	1.06	-

The second practice that achieved a high importance index was the "Design specification of technologies that produce little residue, such as prefabricated, metallic forms and dry walls". Numerous authors [11], [21], [15] and [14], have already addressed the fact that the use of technologies such as prefabricated, metallic forms and dry walls considerably reduce the generation of waste. The metallic forms are an environmentally viable alternative for use in the works. While wood forms are used six to seven times and then become waste, the metal forms are much more durable, considerably reducing the generation of waste construction [14].

3) Parallel between PS in construction and in project

A consideration that is important to be made relates to the fact that the SP of the design stage were evaluated with a higher importance level (4.02) than that of the construction phase (3.90). But they had a much lower average implementation percentage when compared to the construction stage, 29% of the design stage versus 52% of the construction phase (Fig. 3).

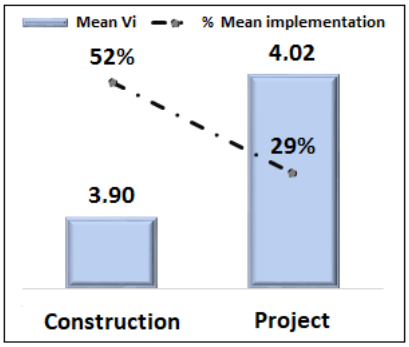

Fig. 3. Evaluation of the level of importance and implementation of SP. Prepared by the author

When considering only the CSP identified in each of the stages, the results also demonstrate that, although the CSP of both steps have an importance index equal to 4.18, the average implementation of the CSP of the design stage is still 13 % lower than the construction step (Fig. 4).

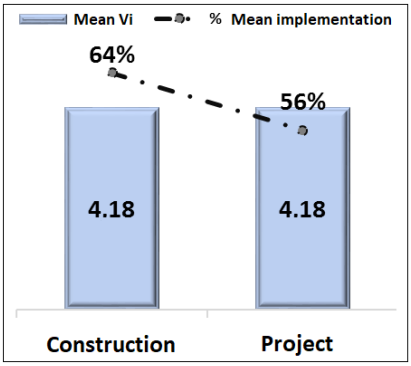

Fig. 4. Evaluation of the level of importance and implementation of CSP. Prepared by the author

V. CONCLUSION

Based on the bibliographic review, it was possible to identify 15 successful practices related to the CWM in the design and construction stages. Based on these selected SP and the questionnaire applied, it was evident how much the level of management of civil construction agents in Brazil is evident, especially when compared to countries located in the Asian and European continent, predominant regions of studies done in the bibliographic review and have a much higher level of waste management, a fact that can be noticed by the high rates of recycling and reuse of waste generated.

From the results of the questionnaire, it is clear that, although the elaboration of the CWMP is regulated by law 12,305 / 2012, the majority of the respondents, 59%, stated that this plan is not elaborated by the company in which they work. In addition, the knowledge gap between the agents involved in the constructive steps regarding the NPSW itself and the CONAMA resolution 307/2002, laws that deal with waste management in a deeper way, is evident. Only three of the 51 respondents stated that they have full knowledge of both laws.

Another point already highlighted in the literature review that was corroborated by the results of the questionnaire says about the involvement of designers in the waste management itself. Although the designers recognize the importance of some practices for the CWM, the mean implementation rate of the selected SP was only 29%. The scenario is best when looking at the SP of the constructive stage, which have a higher mean implementation rate, 52%. However, the PS that has the highest implementation rate, "Utilization of machined concrete and mortar", is considered one of the least important practices to be implemented for efficient CWM.

With regard to the CPS considered by the respondents, many of them go to international research already done, reflecting a convergence of points of view. However, practices such as "Proper sorting and storage of waste generated" and "Ordering and storing raw materials at appropriate times and places" have very divergent levels of importance when compared to international studies.

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