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# SMART MANAGEMENT OF WASTE FROM CONSTRUCTION SITES: MOBILE APPLICATION TECHNOLOGY IN THE CITY MANAUS, AMAZONAS, BRAZIL

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**Abstract**

This study was carried out in the city of Manaus, Amazonas, Brazil, a municipality surrounded by the Amazon Rainforest. This world heritage site, with a great diversity of fauna and flora, requires the care and attention of both the authorities and the population. The research involved studies on four construction sites to collect data regarding the waste generated and the environmental management practices, especially regarding waste disposal, considering that this item causes major environmental impacts in the Amazon Forest surrounding the city of Manaus. There is only one public landfill, managed by the Municipality of Manaus, and several clandestine landfills, which end up being the final disposal of many construction waste due to lack of inspection and population neglect. The consequences are serious for the Amazon rainforest that suffers the impact of the pollution generated by these residues, such as plastic, paper, metal, and debris which is a major contaminant since it may contain paints, solvents, oils and other materials toxic to nature. Two of the construction sites under study were residential buildings and the other two were thermoelectric power plants (industrial). After data collection through interviews, statistical studies were carried out to analyze and discuss the results obtained, aiming to make the characterization of the current production of construction waste in the city of Manaus, Amazonas, Brazil, and understand how these wastes affect the environment of the Amazon Forest. The collected data enabled the identification of the types of construction waste produced, their respective volumes, and their environmental management practices regarding reuse, sale or disposal. After analyzing the results, it was concluded that the sampled construction companies do not reuse nor recycle construction waste, and discard them in municipal or clandestine landfills. To minimize the identified problem regarding the disposal of construction waste in the city of Manaus, a proposal for the environmental management of construction site waste was developed through mobile application technology, with the aim of mitigating the environmental impacts of these wastes in nature. The mobile application serves as a tool for environmental managers in construction sites, and even for citizens who want to make a renovation in their home and do not know how to allocate the generated construction waste in a responsible and sustainable way. The mobile application was developed on the Android platform and had as premises the main construction waste identified in the construction companies studied in the city of Manaus, which would be plastic, paper, metals, rubble, and demolition remains, such as broken bricks, broken tiles, damaged wood, coatings, paints, mortar and other debris, with potential for contamination and pollution of the environment. The structure of the computer program was developed in order to enable the purchase, sale, exchange, recycling or donation of construction waste through the mobile application itself, which can be acquired for free at the virtual stores. The application was tested by construction professionals, interested in the allocation of small or large amounts of construction waste in safe and legalized sites, controlled either by the municipal or federal government. The application was also presented to and tested by waste disposal companies and urban citizens, to verify the efficiency of the application in the intelligent management of construction waste. Although the application is still in the test phase and not yet commercially available, the results obtained so far demonstrate a higher degree of acceptability and user satisfaction. The results showed

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widespread interest in the mobile app among urban citizens, construction professionals and waste collection companies, although these latter reveal some concern regarding possible increased monitorization and fiscalization associated with a wider use of the mobile application in the urban area of the city Manaus.

**Key words:** sustainable construction; smart waste disposal; startup company of waste

## 1. Introduction

Construction and demolition waste (CDW) can be defined as a mixture of surplus materials generated from construction, renovation and demolition activities, including site cleaning, road works and demolition (Shen et al., 2004). Inadequate management of CDW, affects the environment, the economy and society (Jin et al. 2019). Besides increasing construction costs and real estate prices, CDW can have major negative impacts on the environment (Borja et al., 2019), namely the contamination of soil and watercourses with heavy metals that can cause diseases in the population and wild animals. These negative impacts are of major importance in sensitive natural environments, justifying the relevance of this research in the city of Manaus, in the central Amazon, Brazil. A previous study involved the quantification of CDW produced at 4 construction sites in the city of Manaus, and the costs involved in its management and disposal (Oliveira et al., 2019). The results showed that high quantities of wood and paper waste are produced, with considerable disposal costs, in spite of the high potential to recycle and re-use these types of waste. Metal waste was found to be the only CDW that was being adequately recycled in the construction sites under study, showing the importance of the implementation of an organized system to collect and recycle CDW in the city of Manaus (Oliveira et al., 2019). A similar case study conducted in the city of Santiago, capital of Chile, led to a quantification of the CDW volume for further management improvement proposals (Bravo et al., 2019). According to this study, in Santiago the generated volume of CDW per building area is 0.186 $m3/m^2$, with a management cost of 75.47 $US\$/m^3$ (Bravo et al., 2019). These values are of the same magnitude as the ones found in the research study conducted in Manaus (Oliveira et al., 2019). Ogunmakinde et al. (2019) describe CDW management in Nigeria, highlighting the existing corruption and unethical practices of large companies who prefer to dig and bury the CDW in clandestine landfills, refusing to comply with environmental laws to avoid loss of profits. This lack of social and environmental responsibility in construction companies is unfortunately also a reality in Brazil. However, surveillance and monitoring of CDW production and disposal may not be the solution to combat clandestine landfill, as demonstrated in the study of Tsiliyannis et al. (2019), conducted in Athens, Greece. Environmental education and good practice are the best weapons we have in environmental management, and adequate CDW management requires a change in the behavior and attitude of each citizen (Mak et al., 2019). The studies conducted in the present investigation sought to define the current model of CDW management in the construction sites of the city of Manaus, its advantages and disadvantages, in order to verify the possibility of implementing a Circular Economy system (Farooque et al., 2019). This system could result in cost savings in civil construction and in the reduction of negative environmental impacts caused by the illegal disposal in clandestine landfills, which harms the lives of the citizens of the city of Manaus and the surrounding environment, the Amazon rainforest itself. Circular Economy CDW management systems have already been implemented in European cities (Fratini et al., 2019; Kravchenko et al., 2019), so why not extend this practice to cities in Latin America, which are also affected by the environmental and financial impacts of inadequate waste management on urban construction sites. In order to implement a Circular Economy model, construction companies must be adequately involved in



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this system, for example through the promotion of sharing and renting equipment, customers access and involvement, or the redesign of a product in order to make it more durable and easier to reassemble if repair is needed (Kravchenko et al., 2019). Scientific initiatives to develop new materials using CDW raw materials are very important for the sustainability of CDW management, such as ultra-high performance concrete (UHPC) which uses a fraction of waste together with natural sand (Wang et al., 2019). Technological developments are of the utmost importance in the process of improving environmental management in a Circular Economy model: digital networks and robotics are increasingly inserted in the context of environmental management, accompanying the development of the new “Industry 4.0” in the manufacturing sector (Sarc et al., 2019). Although the Circular Economy model is not yet implemented in Brazil, good practice initiatives are encouraged, as the one described in this paper regarding CDW waste management in constructions sites in the city of Manaus through the use of start-up technologies like mobile applications. These have an exponentially growing market worldwide, demonstrated by the increasing use of mobile applications running on smartphones, tablets, laptops and other mobile devices (Kaur & Kaur, 2019). The main objective of this research is to enhance adequate environmental management in construction sites through the development of a mobile application for CDW management. This tool can be used by construction companies, waste disposal companies, and even urban citizens who need to dispose construction waste.

## 2. Materials and Methods

The present paper describes the continuation of the field study conducted by (Oliveira et al., 2019), through the application of questionnaires in construction sites in the city of Manaus, Amazonas, Brazil. The city of Manaus is located at the geographic coordinates 3º6'0”S and 60º1'0” W according to Figure 1.

Figure 1. **Map of city Manaus, Amazonas, Brazil, in the World**


Source: https://geology.com/world/world-map.shtml

The applied methodology was based on the application of questionnaires to collect information and data, in order to characterize the present situation regarding environmental management in local construction sites. The questionnaires were approved by the Ethics Committee of the Fernando Pessoa University (Porto, Portugal). One questionnaire was applied to 4 construction sites in the city of Manaus, operated by the main construction companies in the Amazon region. The construction sites were named A, B, C and D correspond to residential building works (sitesB and C) and construction works for thermoelectric power plants (sites A and D). The area

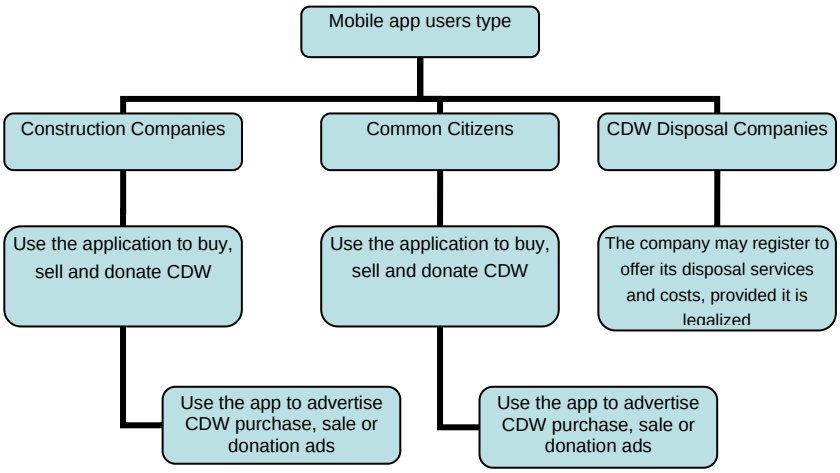


ISSN e: 2604-6512

of the construction sites is 57,000 $m^2$ for site A 12,381 $m^2$ for site B, 10,430 $m^2$ for site C and 9,527 $m^2$ for site D.

The city of Manaus is an isolated city, surrounded by the Amazon Forest, with access only by air and river, located on the banks of the Rio Negro. This river converges with the Solimões River to form the Amazon River that flows into the Atlantic Ocean, on the Brazilian coast. The city of Manaus has an urban area of 427.085 $km^2$ and a population of approximately 2,145,44 inhabitants. In the metropolitan region of Manaus there are approximately 113.2 hectares of land degraded by dumps and a licensed landfill, of this total area we have 66 hectares, equivalent to 58.3%, destined to a licensed landfill and 47.2 hectares, which corresponds to 41.6%, is destined to open dumps. The Manaus City Hall manages this landfill area through machines and equipment for waste removal daily. n the Manaus Metropolitan Region there is not yet an organized system for the collection, treatment, disposal or recycling of CDW waste. Currently, 44 companies are authorized to transport and discard / dispose of CDW waste at the public landfill in the city of Manaus (PRSCS, 2017). Smart cities of the future should manage waste through modern technologies (Esmaeilian et al., 2018). For this reason, the present research adopted mobile application technology to solve the waste management problems in construction sites operating in the city of Manaus. Based on the detected needs, the mobile application software was developed on the Android Studio platform, with the objective of reducing CDW reuse / recycling costs, publicizing the sale, purchase, exchange and donation of CDW to a maximum number of users of CDW applications. and, finally, to increase competition between CDW disposal companies, forcing them to legally regulate and to offer a sustainable service that does not harm the environment and the Society. The action methodology to meet the demands required for smart environmental management of CDWs through a mobile application is shown in the flowchart of Figure 2.

Figure 2. **Mobile app stock flow chart**




Source: Own elaboration.

Upon completion of the algorithms, the codes were written in Java code for compilation in Android Studio. At the conclusion of the mobile application, it was tested using the methodology proposed by (Kaur & Kaur, 2019), through questionnaires applied to construction professionals (Table 1), to CDW disposal companies (Table 2) and also to urban citizens (Table 3). The algorithm has been built on the needs identified for CDW waste management at construction



ISSN e: 2604-6512

sites for transport, disposal, disposal and storage as well as recycling and reuse. CDW waste can be donated, sold or purchased by urban citizens, environmental engineers or construction companies. The application intends to register CDW collection companies, which can offer their specialized services and their differentiated prices, contributing to lower the cost of these services by the free competition in the market.

Table 1. **Mobile app acceptability questionnaire directed to construction professionals**

| Number | Question |
|---|---|
| 1 | Do you expect this application to be useful for your company? |
| 2 | Do you expect this application to contribute to the insertion of the environmental professional in the job market? |
| 3 | Do you expect this application to contribute to reducing the disposal costs of construction and demolition waste? |
| 4 | Do you expect this application to contribute to reducing construction and demolition waste storage time? |
| 5 | Do you expect this application to contribute to environmental protection? |

Source: Own elaboration.

Table 2. **Mobile app acceptability questionnaire directed to waste disposal companies**

| Number | Question |
|---|---|
| 1 | Do you expect this application to contribute to improve the quality of waste disposal in construction? |
| 2 | Do you expect this application to contribute to a process of segregation of construction waste, which facilitates the sorting of it for later recycling or disposal, resulting not only in the organization of waste, but in the organization and cleaning of the construction site? |
| 3 | Do you agree that currently the greatest difficulty in reducing or recycling solid construction waste is lack of awareness and low skilled labor? |
| 4 | Do you expect this application to contribute to reducing construction and demolition waste storage time? |
| 5 | Do you expect this application to contribute to environmental protection? |

Source: Own elaboration.

Table 3. **Mobile app acceptability questionnaire directed to urban citizens**

| Number | Question |
|---|---|
| 1 | Do you expect this application to be useful for reducing waste disposal in watercourses and reducing obstruction of urban drainage devices? |
| 2 | Do you expect this application to contribute to the insertion of the environmental professional in the job market? |
| 3 | Do you expect this application to favor best price options for collecting construction waste? |
| 4 | Do you expect this application to be useful for the urban citizen who wants to renovate their residence? |
| 5 | Do you expect this application to contribute to environmental protection? |
| 6 | Do you expect this application to contribute to the legalization of construction waste disposal companies? |
| 7 | Do you expect this application to contribute to the reduction of landfill disposal by urban citizens? |

Source: Own elaboration.

The application tests were conducted through lectures for construction professionals, businessmen and urban citizens (Figure 3), who were asked to answer questionnaires at the end of the event.



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Figure 3. **Lecture about the mobile app for professionals, businessmen and urban citizens**

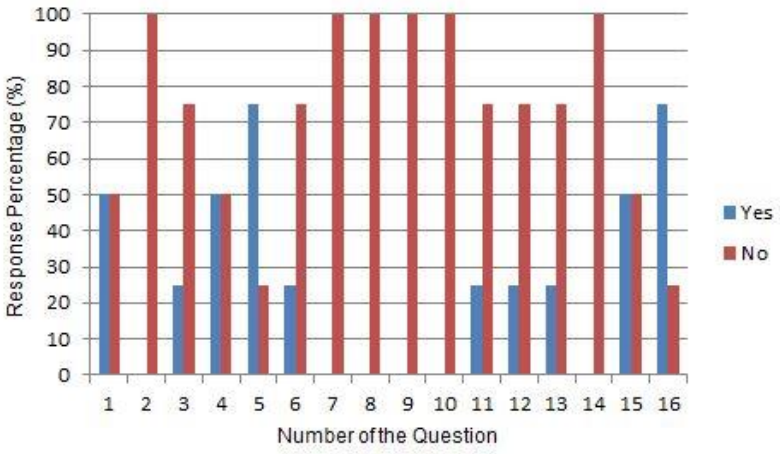
Source: authors.

## 3. Results and Discussion

### *3.1 Characterization of the current situation regarding CDW management in Manaus*

The results of the questionnaires applied to 4 construction companies in the city Manaus, described in Table 1, are shown in Figure 4.

Figure 4. **Results obtained in the questionnaire applied in 4 construction companies**




Source: Own elaboration.

In questions 2, 7, 8, 9, 10 and 14 the negative statements show a scenario of inefficient recycling and reuse of CDW in the city of Manaus. In questions 5 and 16 the positive statements demonstrate a partial compliance in the transportation legal requirements regarding of CDW, and in the supervision of the final disposal of this waste in the legal landfills of the city of Manaus. In clandestine landfills there is no supervision. The questionnaire showed that companies are deficient in the items covered by questions 6, 7, 10, 11, 12, 13, 14, 15 16, 17 and 18, revealing inadequate management regarding the reuse and recycling of CDW. This lack of organization for reuse and recycling undermines the environmental management of CWD in



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construction companies as it allows this waste to be transported to municipal or clandestine landfills, which harms the city and the environment in its vicinity. Construction companies outsource recycling and disposal services, but poorly oversee these services.

The results of the questionnaire applied to construction companies A, B, C and D demonstrated the need for actions in the environmental management of the CDW of Manaus city construction sites, as follows:

a) Little reuse/recycling of CDW due to the costs involved;
b) There is no disclosure of immediate actions for the sale, purchase and donation of CDW, which hinders the “supply and demand” for its reuse or recycling; and
c) Little competition between CDW disposal companies, which leads to the hiring of companies that make use of clandestine landfills, for lack of social and environmental responsibility.

These results show that construction and demolition waste management in construction companies in Manaus needs to be improved through modern management tools, such as Circular Economy, a waste management model implemented in Europe, but not yet in Brazil.

### *3.1 Development of the mobile application for CDW management*

Given the problems detected in characterizing the current situation of CDW management in Manaus, this research proposed the development of a mobile application that can be widely used by all urban citizens and not only by a restricted category of engineers and technicians in the area. environmental, construction companies or companies in the field of disposal and disposal of construction and demolition waste. It is an easy-to-use screen application with interactive user interface that contributes to the generation of a value-added circular economy for the disposal of CDW waste in the municipality of Manaus. The splash screen is shown in Figure 5 and the interaction screen is shown in Figure 6. The search screen for waste types is shown in Figure 7 and the filters for easier search of a waste are shown in Figure 8.

Figure 5. **Mobile App Logo**


Figure 6. **Mobile Application Home Screen**


Source: App



ISSN e: 2604-6512

Figure 7. **Searches screen**

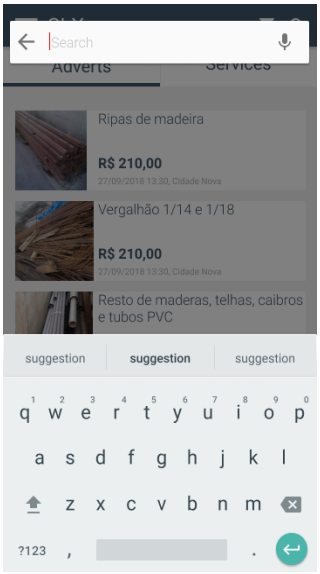
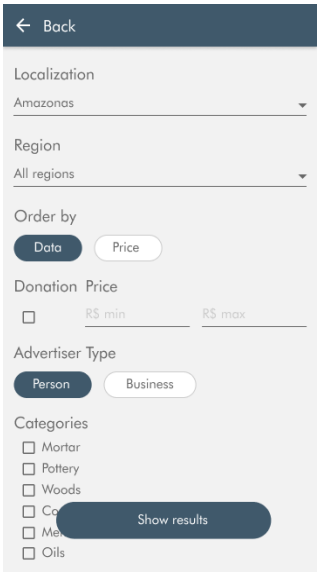



Figure 8. **Search filter**




Source: App

Through this mobile application the user can access ads dealing exclusively with the donation, purchase and sale of CDW. This enables construction companies to implement environmental management practices interacting with other construction companies, or with companies from other branches that use CDW as raw material for industrial or commercial production. Advertisements can also be accessed by urban citizens who may be involved in the renovation or construction of private buildings and want to dispose their CDW, or to reuse any CDW for landfill in the scope of a foundation, or sidewalk construction.

The mobile application promotes sustainability in the destination of CDW for those companies or citizens who need this raw material for some useful purpose. The idea of the application is to minimize CDW that goes to the municipal landfill or clandestine landfills, promoting the reuse of CDW in the whole municipality of Manaus. Donation announcements are used for quick disposal at no cost to those who need CDW raw material, which contributes to reducing the length of time CDW stays on site. CDW buying and selling announcements are to warm the city's economy through a sustainable CDW reuse and recycling market.

This market for buying and selling CDW using the mobile application may in the future serve as the basis for a Circular Economy model to be implemented in the city of Manaus. As shown in Figure 5, ads are easy to interact, with photos and all the necessary information for mobile app users. The mobile application promotes good practices such as registration of origin, destination, type, class and quantity of CDW moved in the municipality, which serves as a database for environmental management of CDW, public agency supervision, control and even for research that deal with CDW.

In addition to the ads, the app has a CDW destination services tab, as shown in Figures 9 and 10.



ISSN e: 2604-6512

Figure 9. **Mobile App Companies**

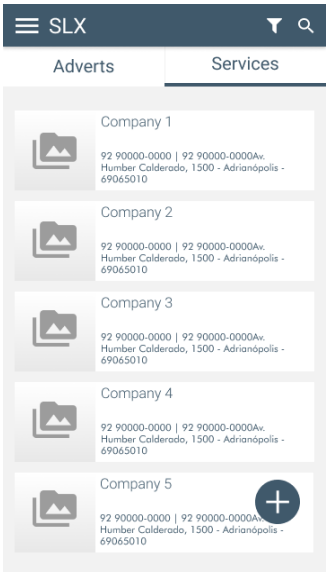
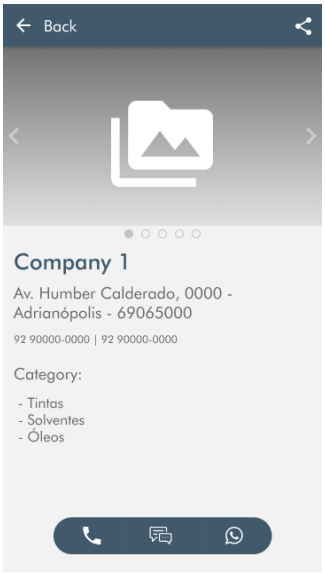



Figure 10. **Mobile App Company Service**




Source: App

This part of the services offered by the mobile application presents a list of registered companies, duly legalized at the municipal, state and federal levels, where each company offers its specialized services and costs involved in the collection, transportation, destination and disposal of CDW. Thus, the user, urban citizen or company, can quickly opt for a company registered in the cost-effective mobile application that best meets their physical and economic needs. The app contributes to healthy economic competition among companies providing CDW collection, transportation and disposal services, keeping prices affordable and inhibiting monopolies that benefit few and harm the entire population of the city. If any service provider company registered in the mobile application practices any irregularity, such as disposal in clandestine landfills, the application may exclude it from its marketing register, thereby curbing illegal practices that harm the environment. Public agencies that will be able to use the mobile application for the supervision and control of disposal companies will be favored quickly and reliably.

### *3.2 Acceptability of the mobile application by potential users*

As described in the Material and Methods section, the mobile app was introduced to construction professionals, urban citizens, and business people who were able to test the app and its particularities, handling, and functions related to CDW's environmental management. The app was presented by users through explanatory lectures to target audiences, which followed step-by-step explanations of the mobile app's tools. After the demos users tested the app and asked questions for clarification. The lectures were given to professionals in the construction sector, businessmen from construction companies, businessmen from CDW waste collection companies and to urban citizens. At the end of the presentation, users completed a questionnaire about the acceptability of the application in the Manaus city market and its usefulness for improving the environment. The questionnaire was answered through the participants' mobile phones, which captured a QRCode from the forms platform that contained the questions. After capturing the code by the mobile phones of each survey participant, the



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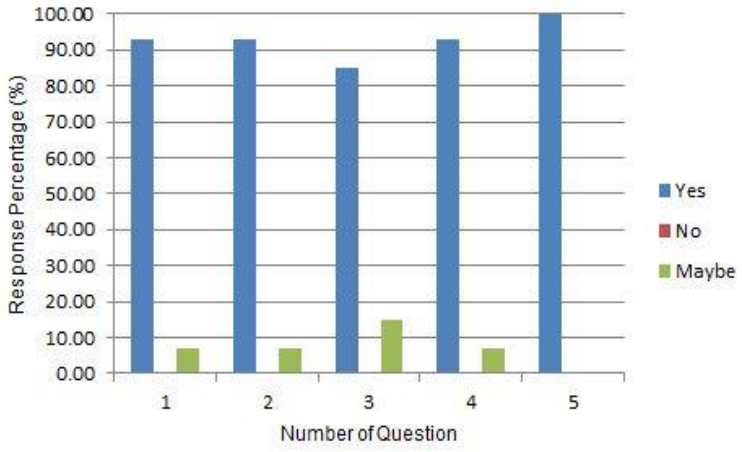
participant answered and sent their answers via their own mobile phone. The lectures had about 80 participants each and were given to a postgraduate audience, to an audience of the Engineering and Agronomy Council and to the construction companies themselves and companies whose main activity is CDW waste collection and disposal. In the audience of the Regional Council of Engineering and Agronomy were present the team of field inspectors, technicians of superior level. The professionals present at the lectures are inserted in the construction labor market in the different modalities of civil engineering, electrical engineering, mechanical engineering, environmental engineering and architecture, showed great interest in the mobile application, especially when it would be made available / commercialized in the mobile application platforms. Representatives of construction companies also showed interest for use on construction sites, in environmental management of construction waste generated in their works, as they noted that the competitiveness generated by the application can have gains and profits for their business. Representatives of CDW collection companies were concerned about the enforcement and legalization required by the mobile application when it is made available for download on platforms.

The results obtained from these questionnaires are shown in Figure 11 (160 construction professionals), Figure 12 (4 waste treatment companies) and Figure 13 (80 urban citizens).

Figure 11. **Responses obtained in the mobile app acceptability questionnaire (construction professionals)**




Source: Own elaboration.

Questions 1 to 5 demonstrate a positive response from companies participating in the mobile app test survey, with over 85% acceptance for mobile app use at their construction sites in the city of Manaus.

Waste disposal companies gave negative answers to questions 3 and 5, probably because the mobile application will favor free competition, price competition and quality of services, besides the pressure that will be exerted regarding legal compliance. Currently, In the city of Manaus, CDW disposal and disposal services at construction sites are performed by only five legal companies, with the permission of the government environmental agency in Manaus. There is a need in the city of Manaus to expand the number of companies that provide CDW waste



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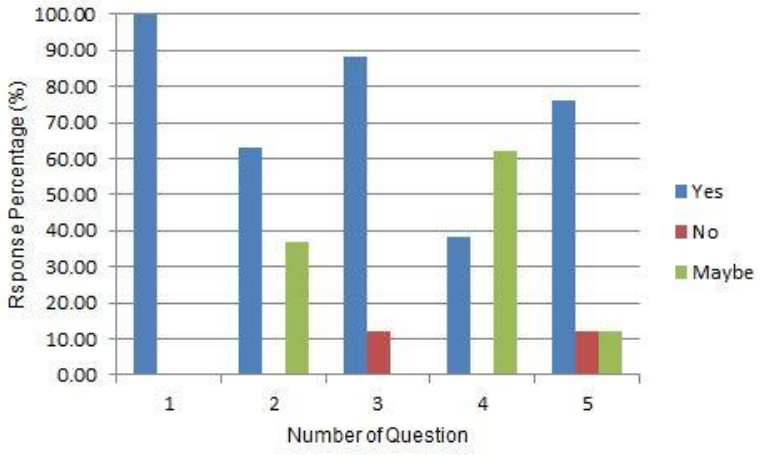
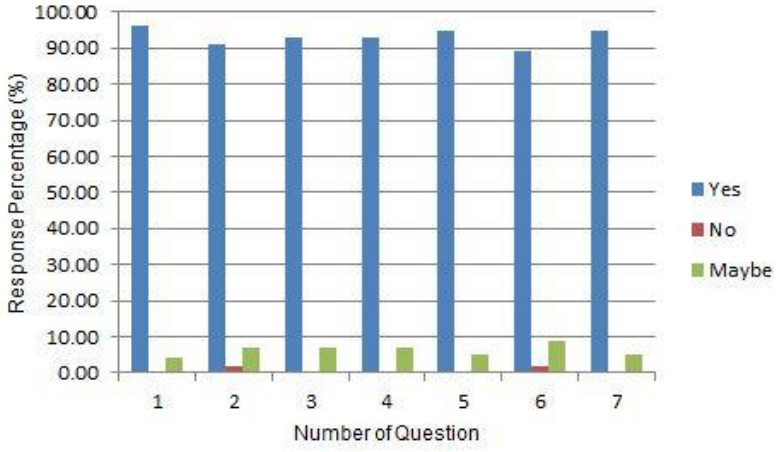
recycling and reuse services to avoid the monopoly that currently occurs in the market in the metropolitan region of Manaus.

Figure 12. **Responses obtained in the mobile app acceptability questionnaire (waste disposal companies)**




Source: Own elaboration.

Figure 13. **Responses obtained in the mobile app acceptability questionnaire (urban citizens)**




Source: Own elaboration.

The answers obtained by urban citizens were 100% positive, with an acceptance rate above 90% for the mobile application usage, which demonstrates public support for the use of mobile technology as an alternative to solve environmental problems caused by the work of construction companies installed in the city of Manaus, with a reflection on the quality of life of the general population. The results obtained in the acceptability tests show that the proposed mobile app has a very high acceptability rate among the group of construction professionals (92,3% on average) and the group of urban citizens (93,1% on average). In what concerns the group of waste disposal companies, the mobile app acceptability decreases to 72,5%, on



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average, probably due to the increased monitorization, and corresponding legal implications, associated with a wider usage of this mobile app.

The main advantage of the mobile application is the possibility of reducing costs in the disposal, disposal, recycling and reuse of construction waste and demolition on the construction site, since the application prioritizes free competition among companies that perform this type of service. Other important advantages are the obligation to legalize CDW waste disposal and disposal service companies and the traceability of CDW waste in urban and rural areas, which facilitates the supervision of government environmental agencies under the disposal ban. in clandestine landfills. The disadvantage of the application is the need for a specialized company to operate and maintain it, resulting in financial expenses to support the company's services, which may be offset by financial income from sponsorship or online advertising within the application itself. The environmental benefits deriving from the mobile application come from the stricter control of this type of CDW waste, by the users themselves, the construction companies, the urban population and the environmental agencies that use the application as an environmental management tool in the urban area of the city Manaus, Amazonia, Brazil.

## 4. Conclusions

In this research, the main objective was achieved through the insertion of a mobile technology applied directly in the control of construction and demolition waste in the construction sector, which can be used by ordinary citizens, construction companies and waste disposal companies. The mobile application achieved very high acceptability rates, according to the responses of the questionnaires applied to citizens and professionals in the construction sector, and to companies operating in the CDW waste disposal business. The management of CDW produced at construction sites in the city of Manaus can use the mobile application as a decision-making tool, since the mobile application is expected to contribute to the sustainability of the CDW reuse and recycling market, encouraging and mobilizing the economy in this area. The adequate environmental management of CDW will contribute to the sustainability of a segmented market regarding CDW reuse and recycling, and will bring improvements in the environmental area by minimizing the problems currently associated with perceived in the accumulation of waste from both public and private construction sites. This app could serve as a basis for establishing a circular economy in the Amazon region. For future research we suggest activating the app for use by the urban population and monitoring the amounts of CDW waste that is reused, donated, traded (bought or sold) and recycled using the mobile app. The mobile app will increase CDW waste traceability control, which will make it easier to monitor disposal and disposal to avoid the use of clandestine landfills that harm the environment. Based on the results of the high acceptability index of the mobile application, it can be concluded that the implementation of the application will have results that will generate a return not only in the environmental area, through the impact on the urban environment by minimizing the problem related to the residues coming from of construction sites currently perceived as also an economic and social return to the metropolitan region of Manaus.

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**Conflict of Interest:** The authors declare no conflict of interests.

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