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Water consumption in 10 residential civil works in the city of Boa Vista, Brazil: A case study applying the calculation of Water Footprint as an estimation method

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***Abstract*— *The use of water resources is highly employed in the civil construction industry, and good management of this resource enables a more favorable environmental impact to the environment. This article is a case study on water consumption in 10 works in the municipality of Boa Vista-RR, Brazil. Thus, the Water Footprint (WF) calculations were applied in order to estimate the total demands of water consumed and the portions of these that will be lost in your works. The methodology had a descriptive, bibliographical and case approach. Of the calculations performed, work 2.1 had the lowest water volume value consumed per m² built and construction 4.3, the highest value, represented in m³/m². At the end, it was concluded that the results obtained were satisfactory, encouraging companies and construction companies with the possible implementation of these calculations in their works, with the purpose to gain greater control over water management.*

I. INTRODUCTION

With the growth of civil construction and population, combined with carefree environmental, lead to an increase in water consumption in housing works, in most of the times, without worrying about how this water is being used, or even in the increase of the generation of liquid and/or gaseous effluents and solid waste that results in higher quantities of materials extracted for the manufacture of raw materials, which often, causes great damage to river environments. Which represents an increase in the loss of water quality and negative environmental impacts.

Thus, making it difficult to obtain and treat it for the purposes of public supply and consequently increasing costs. Since water represents one of the most important components in the production of mortar and concrete, in addition to being fundamental in the compaction of landfills and in the humidification of the soil, as well as it is used in secondary services such as cleaning works and equipment and, in the process of curing the concrete. Because according to Pessarello [1] for the production of a cubic meter of concrete, spends an average of 160 to 200 liters of water, and also in the compaction of one meter cubic landfill can be consumed up to 300 liters of water.

According to Comploier [2], it is estimated that there is a waste of approximately 20 liters of water per m² built, possibly due to damaged hoses or connected unused, leaks in hydraulic installations and negligence on the part of workers. As a result, the same author cites that civil construction has rates that range from 25% to 30% of waste of natural resources such as water.

This can occur in Roraima as there was a population increase of 40.11% in last 10 years [3], which leads to a significant increase in civil construction and with that to the excessive consumption of water in works. According to Souza [4] there is usually no meters to measure the water demand in the works, or rather, there is no prior control of the amount consumed in the state's construction sites.

Faced with these problems mentioned above, the choice of the object of study of this work arose from the need to understand how water management works that consumed in civil constructions in the city of Boa Vista-RR, Brazil. In this way, looking for present a dynamic calculation method that estimates the amount of water consumed in the residential construction sites, in order to help companies and builders with the possible reduction of water waste, as well as an improvement in the management of water resources.

In view of this, the general objective of this work aims to apply the calculation of the Water Footprint (WF) as an estimation method, in order to determine the water demands that possibly will be consumed and lost on their construction sites, carrying out a study of case in ten residential works in the city. With that, the specific objectives will be: carry out a bibliographic survey about the material; survey the works aimed at the collection of water consuming processes at the construction sites (direct) and from the materials used in constructions (indirect); perform the calculation of the Total Water Footprint of the works; perform an analysis of water consumed between works through indicators specific.

II. THEORETICAL REFERENCE

2.1 Water consumption in construction

Regarding water consumption, civil construction has great potential consumer, dealing directly in the use of processes such as concrete production, mortars, dust suppression and cutting, and indirectly in the manufacture of its materials and products used in the works [5]. According to Silva and Violin [6] water is also used in the consumption of workers, cleaning and curing concrete activities, and because of this, it presents a high rate of water use for the execution of works.

In this sense, Pereira [7] emphasizes that the share of water consumption per year for uses in small-scale civil construction in Brazil is around 17% of the total volume existing in the country, and 11% worldwide, with concrete being the main consumer. Tied to previous quote, Ghrair et al [8] states that only the concrete industry consumes 1 billion m³ of water per year globally, in addition, large volumes of drinking water are used to wash trucks, concrete mixers, equipment, concrete pumps, aggregates, and for healing.

With regard to water management, it is a highly complex matter, and the performance of civil society (public and private) must be articulated at multiple levels, generating policies and methods of raising awareness in the population. In the case of civil construction, to obtain a improvement in the form of this management, was developed in 2019 by the Civil Construction Union From the State of São Paulo (SindusCon-SP) a method that makes it possible to estimate the consumption of water that a work will use, as well as the amount of lost water it will have, through the WF calculations, which will be explained below.

2.2 Water Footprint Concepts (WF)

The water footprint (WF) serves as “an indicator of water use that does not only its direct use by a consumer or product, but also its indirect use" [9]. WF also refers to water lost in a given process, usually by incorporation into the product or by evaporation, that is, one that does not it becomes effluent (sewage), in the case of direct consumption [4].

According to SindusCon-SP [10], water footprint assessment in construction civil is composed of three main stages and which are examined through direct and indirect water in a given work, which are: definition of goals and scope: clarify the objectives of the water footprint assessment; quantification (calculation) of the water footprint: estimate the amount of water that will be used in the work; and analysis of final result with the sustainability of the work: relationship between the water footprint and the setting.

Thus, the use of WF as an assessment mechanism is linked to the agricultural products, however, studies on the water footprint of certain materials used in civil construction, such as: mortar, steel, concrete and cement. Therefore, the WF calculation results in volume values (m³) of water used, being which depends on the area of the project, depending on the total built area (At), having as unit o m³/m², as per the author above.

For Pereira [7], the largest portion of WF is related to indirect uses (from the materials), and not to the direct on site, that is, the indirect WF is given above 85% of the total, while the direct WF is below 15%. Already according to SindusCon-SP [10], the calculation of the Total Work Water Footprint (WF_T) is defined by the sum of Direct Work Water Footprint (WF_{DIRECT}) and Indirect

Work Water Footprint ($WF_{INDIRECT}$), according to equation (1), having as unit the m³. And in equation (2), there is the Specific Work Water Footprint (WF_{SPE}), which lists WF_T as a function of area total built (At), having as unit the m³/m².

$$WF_T = WF_{DIRECT} + WF_{INDIRECT} \quad (1)$$

$$WF_{SPE} = WF_T / At \quad (2)$$

2.3 Direct Water Footprint Calculation (WF_{DIRECT})

According to SindusCon-SP [10], WF_{DIRECT} is related to the consumption of estimated water at the construction site, in processes such as: concrete curing, preparation of mortars, washing and sanitary uses by employees.

Since generally, as there are no meters to measure the demand for water in the works, and as a first step, Souza [4], through his studies on the water consumption in the works visited, reached the conclusion of two coefficients, the demand for area (DPA) and per capita demand (DPC), whose values are: DPA = 0.25 m³/m².At and DPC = 2.0 m³/empc.month. The second step is to estimate the total demand (DT) with base on each coefficient, equations (3) and (4), then take the mean between the two.

$$DT_{DPA} = At \cdot DPA \quad (3)$$

$$DT_{DPC} = Nf \cdot Da \cdot DPC \quad (4)$$

Where: DT_{DPA} – Total Demand per Area, measured in m³; DT_{DPC} – Total demand per capita, measured in m³; At – Total constructed area, measured in m²; Nf – Average number of employees per month; Da – Duration of the work, measured in months (estimate).

So the third step is to estimate the demands for sanitary uses (Q_{SAN}) in the temporary toilets in the works, where they are used for flushing toilets, washbasins, showers, etc.; and for processes (Q_{PROC}), where they are used, for example, for concrete curing, mortar preparation and floor cleaning, using equations (5) and (6).

$$Q_{SAN} = D_{SAN} \cdot Nf \cdot Jt \cdot Da \quad (5)$$

$$Q_{PROC} = DT - Q_{SAN} \quad (6)$$

Where: D_{SAN} – Average daily demand for sanitary uses, whose value varies between 10 to 80 l/empc.day, according to the quantities of toilets, sinks and showers in the flowerbed; Nf – Average number of employees per month; Jt – Average working hours per days/month; Da – Duration of the work, measured in months (estimate).

Finally, WF_{DIRECT} is calculated, according to equation (7), using the coefficients of return Csan = 0.80 and Cproc = 0.20, in which, for sanitary uses 80% of the water demanded converts to sewage and for process uses only 20%.

$$WF_{DIRECT} = Q_{SAN} \cdot (1 - C_{SAN}) + Q_{PROC} \cdot (1 - C_{PROC}) \quad (7)$$

It was defined by the Brazilian standard NBR 15491/2010: Dump box for cleaning of sanitary basins - Requirements and test methods [11], that from 2010 all basins toilets manufactured in the country meet the reduced volume with the discharge of 6 liters per flow, as the standard mentions that before the water consumption was 12 liters per flow to the basin with attached box and 10 liters per flow for basin with well-regulated wall valve.

2.4 Indirect Water Footprint Calculation ($WF_{INDIRECT}$)

As for $WF_{INDIRECT}$, according to SindusCon-SP [10], it is related to materials used in the works such as concrete, steel, cement, mortar and ceramic block, or that is, it is considered the appropriations of water that occur outside the construction site, such as water incorporated during all manufacturing processes of these materials.

It is important to highlight that design decisions directly influence this part of the calculation, where the categorization and quantity of materials to be used will be defined, with the project's budget being the main guide for this calculation.

Souza [4] highlights that WF of secondary materials, for example, for materials electrical and hydraulic, can be considered irrelevant compared to materials such as concrete and steel, as the construction budget usually does not contain quantities of piping, parts, hydraulic connections, wiring, etc.

According to SindusCon-SP [10] the formula of each WF of the material is formed by the product between the quantity of materials and their water footprint coefficient (CWF), consistent in equation (8), then sum up all these WF of the materials to obtain the $WF_{INDIRECT}$ represented in equation (9).

$$WF_{MATERIAL} = quantity \cdot CWF \quad (8)$$

$$WF_{INDIRECT} = \sum WF_{MATERIAL} \quad (9)$$

Therefore, in table 1 the main materials are represented contributors to the WF in the works. And in table 2 the water footprint coefficients (CWF), which corresponds to the volume of water required for manufacture of these materials.

Table 1 Contribution of main construction materials to WF

Material	% average	accumulated average
Concrete	42.6	42.6
Steel	40.5	83.0
Concrete block	4.0	87.1
Prefabricated slab	3.4	90.5
Electric	2.3	92.8

Mortar	1.9	94.7
Hydraulics	1.3	95.9
Screen	1.2	97.2
Ceramic block	0.8	98.0
Cement	0.8	98.8
Coating	0.3	99.1
Wood shapes	0.3	99.4
Floor	0.2	99.7
Plaster	0.1	99.8
Ink	0.1	99.9
Stone	0.1	99.9
Wood	0.0	100.0
Monocoat	0.0	100.0
Sand	0.0	100.0

Table 2 CWF for the main materials that consume water

Material	CWF (L/UF)	Unity
Steel	67.3	L/kg
Sand	7.5	L/kg
Mortar	0.8	L/kg
Ceramic block	4.7	L/unity
Concrete block	13.4	L/unity
Cement	2.7	L/kg
Concrete	3840	L/m³
Plaster	2.8	L/m²
Prefabricated slab	8541	L/m³
Wood	11.4	L/m²
Monocoat	4.0	L/m²
Floors	18.2	L/m²
Tiles	12.0	L/m²
Stones	93.8	L/m³
Ink	1.1	L/m²
Glass	79.5	L/m²

III. METHODOLOGY

This research was bibliographical, quantitative and descriptive, being categorized as a case study, whose methods were based on the Methodological Guide of Water Footprint Calculation for Buildings, a guide developed by SindusCon-SP [10]. And for better understanding of water consumption in civil construction, it was sought pertinent information in articles, books, theses, dissertations and monographs, with the in order to obtain technical knowledge on the topic addressed.

The work began with the analysis of water consumption in 10 residential works in 5 companies in Boa Vista/RR, Brazil, whose companies have been in the civil construction market for more of 6 years, where visits were carried out in these works in order to estimate how many volumes of water will be needed to run them and how much of this water will be lost during your constructive process, through the applications of WF calculations.

And in obtaining the data, information was collected through the companies performers to be included in the WF calculations, in order to analyze in their works the direct and indirect water consumption.

To perform the direct WF calculation, data were sought in the projects and in the report of construction control, in order to collect information on: Total constructed area; average number of workers per month; duration of the work (estimate); number of days weekdays/month that employees work.

Subsequently, it was analyzed in loco in the works in order to determine the demands of water for sanitary and process uses, by employees. To calculate the consumption demands of employees, only the sanitary use of the temporary toilets of the works, belonging precisely to their temporary use, and also as it is the only variable that enters the WF calculation formula. It should be noted that the companies were chosen for the respective study precisely because they contain an installation of temporary use bathroom in his works, which serves as a requirement in the calculation part.

And to measure water flows in liters per minute of bathrooms that included showers and sinks, the following methodology was used: a 5 liter pot was used for perform the measurement, at an average water speed, performing in 3 repetitions and taking the medium, where the measures of the pot were 31.8 cm long, 13.5 cm thick and water height depending on the value to be filled with water every minute, according to figure 1, in which, by multiplying the three variables, the volume of water was obtained and then multiplied by the clocked time, obtaining the flow in L/min.

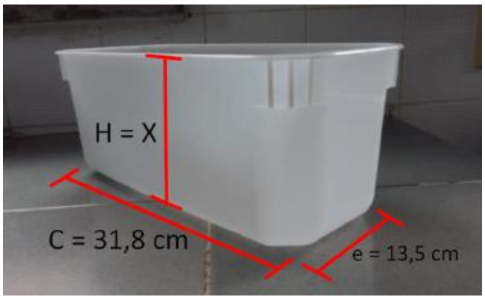

Fig.1: Pot measurements to measure water flows in L/min

After this, the estimates of the daily sanitary water demand per employee of the works were carried out, through a structured interview, using a questionnaire with the employees, which consisted of: how often did each one use the toilet per day, so that he could estimate the water consumed in liters with the flush; average time of use of the sink in seconds, for hand hygiene, in order to estimate the water consumed in liters with the sink; and if they used the temporary shower, how many times a day and the average time of use in minutes, in order to estimate the water consumed in liters with the shower.

Then, to perform the calculation of indirect WF, data were sought from the budget worksheets of the works, in order to collect information on the quantities of the main materials that lead to water consumption in their works, which have higher WF rates. In view of this, in this work were addressed the quantities of concrete, steel, mortar, cement, ceramic blocks and concrete blocks.

Thus, he performed the two calculations of the WF of direct and indirect work (WF_{DIRECT} and $WF_{INDIRECT}$), and then was made the calculation of the Total Water Footprint of the work (WF_T).

And when obtaining the WF_T of the works studied, a comparison was made using specific indicators, which consists of comparing the amount of water consumed that each of them will possibly have, depending on the total constructed area, through the estimates made in the calculation.

IV. RESULTS AND DISCUSSIONS

Starting with the analysis of direct water consumption, table 3 shows the data that were collected from the companies.

Table 3 construction works data

Construction Company	Work	Neighborhood	Total built area (m²)	Monthly average of employees	Duration of the work (months)	Workday (days/month)
1	1.1	Paraviana	179,79	10	08	22
2	2.1	Caçari	125,12	07	06	26
3	3.1	Caçari	1915,92	19	23	22
4	4.1	Paraviana	215,30	09	09	22
	4.2	Caçari	307,18	11	10	22
	4.3	Paraviana	213,94	09	10	22
5	5.1	Paraviana	265,81	08	09	26
	5.2	Caranã	99,24	06	08	22
	5.3	Caçari	254,69	09	11	22
	5.4	Caçari	305,12	08	08	26

According to table 3, it is highlighted that the work 3.1 is a residential type of condominium work with 12 houses, and the 9 remaining works are of the residential types of houses. And according to the installations of the temporary restrooms of these works, it was observed that the installations present in works 2.1, 4.1 and 5.3 contained only toilets. Works 1.1, 3.1 and 5.2 contained toilets and sinks. Works 4.2 and 4.3 contained toilets and showers. Finally, works 5.1 and 5.4 contained toilets, sinks and showers.

Then, table 4 presents the values of the flow measurements carried out in the sinks and showers of some temporary bathrooms in the works.

Table 4 Measurements of water flows from faucets and showers

Construction Company	Work	Faucet flow (L/min)	Shower flow (L/min)
1	1.1	4,74	-
3	3.1	4,50	-
4	4.2	-	4,21
	4.3	-	4,30

5	5.1	5,32	3,40
	5.2	3,54	-
	5.4	3,26	3,93
Total	-	21,36	15,84

It can be seen in table 4 that work 5.1 had the highest flow in its faucet, having approximately 25% of the total flow, and work 5.4 the lowest flow, about 15.3% of the total. Regarding the shower flow, work 4.3 had the highest flow, having around 27.2% of the total, and work 5.1 the lowest flow, around 21.5% of the total.

Subsequently, the daily sanitary water demand per employee and the total water demand that the work will possibly consume was estimated, the latter divided for sanitary use and for the use of processes such as concrete curing, mortar and concrete dosing, activities of cleaning, etc., as shown in table 5.

Table 5 Water demand for the works

Construction Company	Work	Daily Sanitary Demand of Water per Employee (L/empc.day)	Total water demand (m^3)	Demand for sanitary use (m^3)	Demand for use of processes (m^3)
1	1.1	15,38	102,47	27,07	75,40
2	2.1	15,60	57,64	17,03	40,61
3	3.1	15,87	676,49	152,57	523,92
4	4.1	13,50	107,91	24,05	83,86
	4.2	23,78	148,39	57,54	90,85
	4.3	20,09	116,74	39,78	76,96
5	5.1	19,26	105,22	36,05	69,17
	5.2	13,57	60,40	14,33	46,07
	5.3	13,50	130,83	29,40	101,43
	5.4	26,31	102,14	43,78	58,36

Regarding the sanitary demand for water per employee of the works, it can be seen in table 5 that, not always the more facilities there are in the temporary bathroom, the more water consumption it will have, an example is work 2.1 with 5.2, in which the first it only contains the toilet and the second contains a toilet and sink, and it is clear that the water consumption of the first is higher than the second, this is possibly due to the fact that the employees of the first use the toilet more often, which , using the flush, is where the most water is used.

Also in table 5, it can be seen that in relation to the total water demand, work 3.1 is the one that will be able to obtain the highest water consumption in m³ during its construction process, which is explained by the fact that it is a larger work. , as it is a condominium, and work 2.1 had the lowest water consumption overall.

In calculating the demand for water for sanitary use, it was analyzed that all the toilets in the temporary bathrooms of the works met the recommendation of NBR 15491:2010, where the consumption of water for each discharge made is 6 liters per flow.

Table 6 presented below shows the values of WF_{DIRECT}, which is an estimate of the amount of total direct water in m³ that may be lost in the works. Then, the percentage of this water was removed, making a relationship between the WF and the total water demand.

Table 6 Value of WF_{DIRECT} in the works under study

Construction Company	Work	Total water demand (m^3)	WF_{DIRECT} (m^3)	Percentage of water lost (%)
1	1.1	102,47	65,73	64,14
2	2.1	57,64	35,90	62,28
3	3.1	676,49	449,65	66,47

4	4.1	107,91	71,90	66,63
	4.2	148,39	84,19	56,73
	4.3	116,74	69,52	59,55
5	5.1	105,22	62,54	59,44
	5.2	60,40	39,72	65,76
	5.3	130,83	87,02	66,51
	5.4	102,14	55,44	54,28

Analyzing table 6, it is observed that the three highest values of WF_{DIRECT} are in works 3.1; 5.3 and 4.2, which is explained by the fact that there are longer durations of works and staff. However, work 4.2 has one of the lowest lost water ratios in percentage. And the three lowest values of WF_{DIRECT} are in works 2.1; 5.2 and 5.4. However, despite the fact that work 5.4 has in its temporary bathroom the three sanitary facilities (flush, faucet and shower) and being the largest work with daily sanitary water demand per employee, the amount of water lost is the third smallest among the 10 works studied, this is possibly due to the fact that the work has one of the smallest staff and the flow in liters per minute is one of the lowest, which means that its percentage of lost water ratio is the smallest of all.

Continuing, for the calculation of indirect water consumption, table 7 presents the quantities of the main materials used in the works, according to the budget spreadsheets made available by the companies.

Table 7 Quantitative of the main materials used in the works

Construction Company	Work	Material					
		Concrete (m^3)	Steel (kg)	Mortar (kg)	Cement (kg)	Ceramic block (unity)	Concrete block (unity)
1	1.1	39,45	2412,01	2834,53	11127,94	16360,18	229,57
2	2.1	31,13	1566,74	2074,96	9604,74	10899,12	-
3	3.1	489,24	31909,71	49652,84	113305,68	163399,96	-
4	4.1	87,60	4415,87	4003,65	15662,10	17603,59	-
	4.2	129,31	6533,93	4635,20	21380,47	37632,48	-
	4.3	91,11	5072,97	3848,30	16424,73	22164,12	-
5	5.1	104,10	5858,79	4702,65	16806,35	19244,19	-
	5.2	26,88	1275,28	1798,89	5728,98	9579,03	-
	5.3	98,14	4801,34	5322,91	17043,07	17823,43	562,50
	5.4	120,51	6156,58	5862,84	16479,32	22416,33	537,52

In table 7, it is observed that works 3.1; 4.2 and 5.4 are the three works that contain the largest quantities of materials used. And the works with the smallest of these numbers employed were in works 5.2; 2.1 and 1.1.

Then, the indirect water consumption of the works was calculated, multiplying each material by the water footprint coefficient. Table 8 presents the values.

Table 8 Value of $WF_{INDIRECT}$ in the works under study

Construction Company	Work	$WF_{INDIRECT}$ (m^3)
1	1.1	426,10
2	2.1	303,80
3	3.1	5139,83

4	4.1	761,80
	4.2	1174,59
	4.3	842,87
5	5.1	933,62
	5.2	250,97
	5.3	841,57
	5.4	1038,84

According to table 8, it can be seen that works 3.1; 4.2 and 5.4 have higher values of water consumed in m³ through the consumption of materials used in their works, this is because they have larger volumes of concrete and kilos of steel, according to table 7, in which they are the two materials that most consume water in their manufacturing process. And works 5.2; 2.1 and 1.1 are the three works with the lowest values.

Then, table 9 shows the sum of the direct and indirect WF values, obtaining the total WF. Subsequently, the specific WF was obtained, comparing the water consumed per m² built.

Table 9 Estimated WF values of the works under study

Construction Company	Work	Total built area (m^2)	WF_{DIRECT} (m^3)	$WF_{INDIRECT}$ (m^3)	WF_T (m^3)	WF_{SPE} (m^3/m^2)
1	1.1	179,79	65,73	426,10	491,83	2,73
2	2.1	125,12	35,90	303,80	339,70	2,71
3	3.1	1915,92	449,65	5139,83	5589,48	2,91
4	4.1	215,30	71,90	761,80	833,70	3,87
	4.2	307,18	84,19	1174,59	1258,78	4,09
	4.3	213,94	69,52	842,87	912,39	4,26
5	5.1	265,81	62,54	933,62	996,16	3,74
	5.2	99,24	39,72	250,97	290,69	2,93
	5.3	254,69	87,02	841,57	928,59	3,64
	5.4	305,12	55,44	1038,84	1094,28	3,58

According to table 9, it can be seen that works with higher WF values, in m³, are not necessarily those with the highest specific values, in m³/m². For example, work 3.1 is the one with the highest total WF value, but one of the lowest specific values. On the other hand, work 4.3 is the one with the median value of the total WF and the one with the highest specific value.

V. CONCLUSION

The theoretical reference provided the understanding of water consumption in civil construction and its peculiarities, as well as a method that makes it possible to estimate the total amount of water that a work will use and its relation of the quantity of this water that will be lost, measuring through the calculation of the Water Footprint according to the two premises, direct and indirect consumption.

In order to verify the consumption of water in the 10 residential works, it was found through research and data collection that water is used in practically all activities of the work, constituting an indispensable element, being applied in the manufacture of materials that are used in construction, making mortar and concrete, cleaning works and equipment, in addition to employee consumption.

In view of the results obtained from the analysis of the 10 works, it was noted that to estimate the direct water consumption of the works, corresponding to the sanitary and process uses, it was necessary to verify the hydro-sanitary installations of the temporary toilets of the same for the use of employees, as well as flow rates were measured in L/min for taps and showers in some bathrooms in the works. In this context, it was observed that construction 5.4 had the lowest percentage of water lost (evaporated) in consumption, despite its temporary bathroom having a toilet, sink and shower.

It was also possible to estimate the amount of indirect water consumed that the works will have in relation to the materials that were/will be used in their works, through incorporations to the materials, where the highest value was in the work 3.1.

On the other hand, when comparing the volume of water consumed in the works through specific comparative volume/area values, in m³/m², it was noted that work 2.1 had the lowest value and work 4.3 had the highest value.

Therefore, given what was presented, it was observed that the proposed objectives were achieved. In this way, the relevance of the work is remarkable for contributing to the management of water resources for companies and construction companies, which can implement measures and possibly use these estimates in their works, either in the design phase or in the design phase, in order to obtain greater control in water management when they are implemented.

The research had limitations in the part of collecting data for direct water consumption, and it was not possible to estimate human consumption, which would analyze the number of glasses of water on average that employees consumed, and it was then possible to estimate only the one for sanitary use.

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