ABSTRACT
Civil construction courses have laboratories for the development of educational activities. The activities involve the production of construction elements that require the consumption of treated water to prepare materials and wash equipment, generating liquid effluents at the end of each class. The reuse of liquid effluents generated in the civil construction educational laboratory was studied with the...
aim of reducing the demand for treated water and reducing the liquid waste discharged into the public sewage system. The effluent generated was collected, quantified and treated by primary decantation, generating reused water. Concrete was produced with reused water as a replacement for treated water, with contents of 20, 50, 80 and 100% and compared to the control concrete, 100% treated water. Parameters of axial compression strength and durability by natural carbonation were evaluated. Concretes with up to 50% reused water presented the same carbonation as the control concrete, and concretes produced with 80 and 100% reused water presented carbonation (2.5 mm), a result slightly higher than the carbonation of concretes produced with up to 50% reused water (1.5 mm). Considering the test results, it can be concluded that it is possible to reuse up to 50% of the reused water in the production of concrete without compromising mechanical resistance and durability. For educational purposes, it is possible to use 100% of the reused water produced, that is, pure, contributing to sustainability and with the guarantee that such use does not cause any harm to the health of teachers, technicians or students. It should also be considered that such use becomes efficient and can be an alternative to treating the waste and its subsequent release into the public network or directly into nature.

**Keywords:** Water Recycling. Sustainability. Teaching Laboratories. Concrete.

**RESUMO**
Os cursos de construção civil contam com laboratórios para o desenvolvimento de atividades didáticas. As atividades envolvem a produção de elementos construtivos que exigem o consumo de água tratada para preparação de materiais e lavagem de equipamentos, gerando efluentes líquidos ao final de cada aula. A reutilização dos efluentes líquidos gerados no laboratório didático de construção civil foi estudada com o objetivo de reduzir a demanda de água tratada e diminuir os resíduos líquidos lançados na rede pública de esgoto. O efluente gerado foi coletado, quantificado e tratado por decantação primária, gerando água de reúso. O concreto foi produzido com água reutilizada em substituição à água tratada, com teores de 20, 50, 80 e 100% e comparado ao concreto de controle, 100% água tratada. Foram avaliados os parâmetros de resistência à compressão axial e durabilidade por carbonatação natural. Os concretos com até 50% de água de reúso apresentaram a mesma carbonatação do concreto de controle, e os concretos produzidos com 80 e 100% de água de reúso apresentaram carbonatação (2,5 mm), resultado ligeiramente superior à carbonatação dos concretos produzidos com até 50% de água de reúso (1,5 mm). Considerando os resultados dos ensaios, pode-se concluir que é possível reutilizar até 50% da água de reúso na produção de concreto sem comprometer a resistência mecânica e a durabilidade. Para fins didáticos, é possível utilizar 100% da água de reúso produzida, ou seja, pura, contribuindo para a sustentabilidade e com a garantia de que esse uso não cause nenhum dano à saúde de professores, técnicos ou alunos. Deve-se considerar também que esse uso se torna eficiente e pode ser uma alternativa ao tratamento dos resíduos e seu posterior lançamento na rede pública ou diretamente na natureza.

RESUMEN
Los cursos de la industria de la construcción cuentan con laboratorios para el desarrollo de las actividades docentes. Las actividades son la producción de elementos constructivos que requieren el consumo de agua tratada para la preparación de materiales y lavado de equipos, generando efluentes líquidos al final de cada clase. Se estudió la reutilización de efluentes líquidos generados en el laboratorio docente de construcción civil con el objetivo de reducir la demanda de agua tratada y reducir los residuos líquidos vertidos a la red pública de alcan tarillado. El efluente generado fue recogido, cuantificado y tratado mediante decantación primaria, generando agua de reutilización. El concreto se produjo con agua reutilizada en reemplazo de agua tratada, con niveles de 20, 50, 80 y 100% y respecto al concreto control, 100% de agua tratada. Se evaluaron parámetros de resistencia a la compresión axial y durabilidad por carbonatación natural. Los concretos con hasta 50% de agua de reuso presentaron la misma carbonatación que el concreto control y los concretos producidos con 80 y 100% de agua de reuso presentaron carbonatación (2,5 mm), resultado ligeramente mayor que la carbonatación de los concretos producidos con contenidos de hasta 50% de agua de reutilización (1,5 mm). Teniendo en cuenta los resultados de las pruebas, se puede concluir que es posible reutilizar hasta el 50% del agua reutilizada en la producción de hormigón sin comprometer la resistencia mecánica y la durabilidad. Para fines docentes, es posible utilizar el 100% del agua reutilizada producida, es decir pura, contribuyendo a la sostenibilidad y además con la garantía de que dicho uso no causa ningún daño a la salud de docentes, técnicos o estudiantes. También hay que considerar que dicho uso se vuelve eficiente y puede ser una alternativa al tratamiento de residuos y su posterior vertido a la red pública o directamente a la naturaleza.


1 INTRODUCTION

One of the most important sectors for the development of countries is the civil construction, which has demand for infrastructure and housing works. Natural resources must be explored rationally, providing for sustainable growth. In the production of concrete and mortar, components such as: fine and coarse aggregates (inert materials), binders (materials based on cement, lime and gypsum) and water are used as a diluent and hydration agent for the binders and also responsible for workability.
The production of these materials in teaching laboratories as well as in real construction activities generates waste while still fresh. After teaching activities, this waste needs to be removed from equipment and instruments such as: concrete mixers, buckets, trowels, wheelbarrows, among others. Some companies are already investing in the reuse of construction waste, especially the solid part, which can be collected and then recycled in appropriate plants.

Figure 1 - Practical class in a civil construction technical course.

![Practical class in a civil construction technical course.](image)

Font: Prepared by the authors themselves.

Considering liquid effluent, its reuse is still neglected, especially because Brazilian standards for the production of cementitious materials were strict regarding the requirements for mixing water. But from 2009 onwards, the ABNT NBR 15900 standard started to make the requirements for the use of reused water more flexible and, as a result, the reuse of water from different sources was made possible and guaranteed the quality of the materials produced, such as structural concrete.

GHRAIR and ALMASHAQBEH (2016) show that, globally, the concrete industry consumes one billion m³ of water annually in the production of these materials, in addition to consuming treated water in the washing process of: concrete mixers, concrete pumps, aggregates, concrete curing among other activities and in this way these researchers proposed the reuse of domestic water, with primary and secondary treatment, in the production of concrete and mortar.

NAIK (2007) and KUCCHE (2015) highlight that water resources are being depleted and that drinking water must be conserved to meet life-sustaining needs.
and, therefore, argue that infrastructure needs must be met by recycling methods or reuse of water on site, avoiding the use of drinking water whenever possible.

CONAMA Resolution n. 448 (BRASIL, 2004) establishes that construction waste cannot be disposed of in solid urban waste landfills, on slopes, in bodies of water, on empty land or in other areas protected by law. As highlighted by PAULA and ILHA (2019), due to the physical-chemical characteristics of liquid effluents generated when washing educational laboratory equipment, they cannot be released into the environment without treatment, largely due to their pH of around 12.0 due to dissolution of Portland cement hydration products.

On the other hand, considering the positive aspect of the alkaline environment in the passivation of concrete, the use of water from washing processes in the production of cementitious materials appears to be a possibility. MALAGUTI et al (2017) tested the reuse of washing water from concrete mixer trucks and showed that it was possible to produce concrete without compromising mechanical resistance.

2 THEORETICAL FRAMEWORK

It is necessary to consider the use of alternative materials, reducing the consumption of natural raw materials and especially adopting recycling so that costs can be reduced, natural resources preserved, and environmental pollution reduced.

Recycling has characteristics of fundamental importance for sustainability and environmental preservation, such as:

- Reduction in the consumption of raw materials of natural origin and consequently their demand for extraction from nature.
- Reduction in the amount of waste disposed of in nature.
- Prioritization of the use of natural resources for activities essential to the survival of human beings, such as water, which must be prioritized for human consumption, animal watering, agriculture, hygiene and food preparation.

Duart et al (2008) mentions that,
We have to consider that other constituents of concrete such as sand, gravel and water are also materials obtained from natural, non-renewable resources, but with a lower polluting potential in production or extraction, but their continued use will cause a considerable and irreversible impact on nature, especially if we consider that such resources cannot be replaced under any circumstances.

In Brazil, since 1997, law n. 9.433, known as the Water Law, determines that, in situations of scarcity, the priority use of water is for human consumption and for watering animals. Later, there was a technical advance brought by the ABNT NBR 15900/2009 standard - Water for mixing concrete Part 1: Requirements, which made the use of recycled water even more viable. According to this standard.

Reused water is water treated by various processes, such as filtration and flotation, in sewage treatment plants, from the affluent already treated for non-potable uses. At the time of publication of this Standard, there was not enough history to guarantee the feasibility of widespread use of this type of water. The use of this type of water is subject to specific applications in common agreement between the water supplier and the person responsible for preparing the concrete, and all requirements of this Standard must be met.

The water used to wash equipment and accessories used in the production of cementitious materials such as: concrete and mortars in teaching laboratories and courses in the construction sector has a high pH (around 12.0) due to the dissolution of hydration products from the Portland cement as Calcium hydroxide, Ca(OH)₂.

According to Dilonardo et al. (2015) in the production of Portland cement concrete, especially for structural purposes, pH control is important to avoid acidity that causes corrosion of the steel reinforcement.

It is then verified that in the alkaline environment (non-carbonated concrete, with a pH range between 11.5 and 12.5) it is a passivator and protects the steel reinforcement of the structural reinforced concrete against corrosion.
3 METHODOLOGY

In the production of specimens for laboratory tests, materials such as: cement, granite crushed stone and natural sand extracted from rivers were used. All were purchased in a single batch on the local market.

The aggregates (sand and crushed stone) underwent characterization processes, in accordance with ABNT NBR 15116 (2021).

In the production of concrete, compositions of crushed stone (crushed stone 1 and crushed stone 2) were tested for better plasticity of the concrete and then their workability was tested by slumping a cone trunk in accordance with ABNT NBR 16889 (2020).

The cement used was Portland Pozzolanic cement type CP IV-32. The choice of this cement was because it is the most widespread cement on the market and, likewise, in construction teaching laboratories. Furthermore, it has a wide variety of uses and is affordable.

This cement is also suitable for the purpose of this research as its chemical composition, according to ABNT NBR 16697/2018, must contain the addition of pozzolanic material (15 to 50%) which is reactive with the Ca(OH)$_2$ generated in the hydration of the cement as well as diluted in alkaline water (recycled water).

Two types of water were used to produce samples for testing: treated water (T) (distributed by the public Sanitation Service), and reused water (R) (produced by primary decantation).

In the production of concrete (control), 100% treated water (T) was used, both to mold samples for simple axial compression tests and for durability tests, based on natural carbonation.

Reused water (R) was used to replace treated water for the production of concrete samples. The percentages of 20, 50, 80 and 100%, in relation to the amount of water treated according to Table 1.
Table 1. Composition of mixing water in the production of concrete samples.

<table>
<thead>
<tr>
<th>Concrete variations</th>
<th>Water composition</th>
<th>Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>100% T</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>20% T + 80% R</td>
<td>C20</td>
</tr>
<tr>
<td></td>
<td>50% T + 50% R</td>
<td>C50</td>
</tr>
<tr>
<td></td>
<td>80% T + 50% R</td>
<td>C80</td>
</tr>
<tr>
<td>Total reuse</td>
<td>100% R</td>
<td>C100</td>
</tr>
</tbody>
</table>

Font: Prepared by the authors themselves.

3.1.1 Collection, storage and treatment of washing water (liquid effluent)

The water from the washing process of instruments and equipment used in the teaching laboratory was collected in the washing tank. Hydrometers were installed to measure the volumes of water used in practical classes.

The collected water was stored in fiber tanks where the primary decantation process was carried out for a period of 48 hours. In this process, the liquid and solid phases were separated (figure 1 and figure 2).

The liquid phase was used as mixing water.

Figure 1 - Primary decantation process.

Figure 2 - Fiber tanks Primary decantation process and treated water produced.
3.1.2 Determination of the pH of mixing water

The pH of the mixing water was determined using a pH meter (Me controterm MT 610) previously calibrated with a pH buffer solution (4, 7 and 10).

3.1.3 Sample preparation for simple axial compressive strength tests

45 samples were produced for simple axial compression testing with dimensions of 10x20 cm (diameter x height), with 09 specimens for each concrete sample. Curing was done by submersion in water until the test date (14, 28 and 91 days).

3.1.4 Sample preparation for natural carbonation tests

15 samples were produced with dimensions of 5x10 cm (diameter x height). For each concrete composition, 3 specimens were molded. After the 28-day submerged curing process, the samples remained outdoors for a period of 24 hours and then taken to the oven at 50°C for 2 hours. After cooling to room temperature, the specimens were identified and then exposed to the external environment for natural carbonation for a period of 200 days.

3.1.5 Sample preparation for natural carbonation tests

To determine the pH of concrete hardened in 28 and 91 days, 400 g of concrete fragments obtained shortly after carrying out the compressive strength test of the samples were collected and taken to the oven at 50°C for 30 minutes, crushed manually with the using a sledgehammer (removing the coarse aggregate at this stage) and subsequently reduced in a pounder. The material was then passed through a 2.0 mm mesh metal sieve, with 100 g of each sample collected, packaged, identified and stored until analysis. For pH and natural carbonation analyzes after 200 days, the specimens
Exposed to the environment were sliced into five parts (figure 3).

The top and base layers of studied specimens were used to determine the pH test, as shown in figure 3.

![Figure 3 - Hardened concrete samples for testing.](image)

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### 3.1.6 Simple axial compressive strength test

Mechanical resistance tests were carried out in accordance with standard NBR 5739/2018, on EMIC equipment, DL line, for 2000KN, at ages 14, 28 and 91 days, on cylindrical hardened concrete specimens.

### 3.1.7 Natural carbonation test

Concrete samples were exposed to the external environment without protection, for a period of 200 days in a natural environment, from November 2019 to June 2020, summer and autumn.

During this period, systematic procedures were carried out on the samples, such as:

- For every six days of exposure to air, the samples were submerged in treated water for a period of 24 hours, before being exposed to the elements again.
- The samples spent 15% of the period submerged in water and 85% exposed to the elements.
- This procedure allows CO$_2$ to enter the samples, favoring carbonation reactions.

- This technique is an alternative to accelerated carbonation tests carried out in carbonation chambers. FERREIRA (2013).

Afterwards, the carbonation front was determined using phenolphthalein to determine the carbonated areas as shown in figure 3.

When preparing the samples, after cutting and removing dust from the three layers in the center of the samples, they were immediately subjected to spraying of phenolphthalein solution (70% ethyl alcohol, 29% distilled water and 1% phenolphthalein) on each surface.

After the chemical reaction, the previously identified samples were photographed and enlarged with the help of software, formatting the images with 2mm x 2mm grids, to facilitate the analysis of the carbonation depth as shown in figure 4.

The phenolphthalein solution serves as a pH indicator, remaining colorless in acidic solutions and turning pink or purple in alkaline solutions, that is, the carbonated part of the concrete will be colorless and the non-carbonated part will be pink or purple as shown figure 4.

Figure 4 - Analysis of natural carbonation in a hardened concrete sample.

3.1.8 pH test on hardened concrete

To determine the pH of concrete hardened at 28 and 91 days, as well as in samples exposed to natural carbonation for 200 days, the method adapted
from EMBRAPA (1979) was used. The 100 g samples were homogenized and 10 g of each were placed in a 100 mL Becker cup with 25 ml of distilled water.

The mixtures were manually stirred with a glass rod for 60 s and then left to rest for a period of 60 minutes and then stirred for 60 s with a glass rod to then determine the pH by immersing the electrode.

4 RESULTS AND DISCUSSIONS

4.1 pH OF MIXING WATER AND ACIDITY OF HARDENED CONCRETE

Table 2 presents the results of determining the pH of the mixing water and acidity of the concrete produced. Alkalinity was verified for all reused water compositions used (20%, 50%, 80% and 100%). The samples had very close pH levels from the lowest dilution (20%) to pure reused water (100%). It must be considered that pH behaves as an exponential function, in this case for a variation of one pH unit, the concentration must increase 10 times.

Therefore, in this composition variation, the small variation in pH values was expected even though the addition of reused water increased considerably (from 20% to 100%).

Considering the age of the concrete, it was found that there was a slight increase in the pH of all concrete samples tested when aging from 28 days to 91 days, including the control concrete, which went from pH 12.13 at 28 days to pH 12.47 at 91 days. This same behavior was observed in sample C80, which went from pH 12.13 to pH 12.45 in the same time interval. This variation can be explained by the advancement of the chemical hydration reactions of the concrete.

The results obtained corroborate those obtained by Malaguti et al (2017), who also detected high alkalinity (pH above 12.0) in wastewater from washing concrete mixer trucks.
When analyzing samples subjected to natural carbonation (table 3), samples C, C20 and C50 were found to have the same pH in the external region (carbonated area), in the order of pH 11.9 and for traces C80 and C100 the pH was slightly lower, in the order of pH 11.3.

This can be explained because traces C80 and C100 presented (in the external area) the thickest carbonate layer. In the internal part, it was found that the pH had practically equal values for all traces. Therefore, a maximum dilution of 50% of reused water is suggested to avoid changing the pH of the concrete and consequently increasing surface carbonation.

However, 100% of reused water can be used in concrete and mortar produced in academia for teaching purposes and in non-structural concrete such as unreinforced floors, for example.

4.2 SIMPLE AXIAL COMPRESSION STRENGTH COMPARISON BETWEEN AGES 14, 28 AND 91 DAYS

At 91 days, the results showed resistance much higher than 28 days, which is the standard age. This result is very positive, as it shows that reused water did not affect the mechanical properties as the concrete ages, a key point when analyzing durability in particular.

In figure 5 the growth in resistance, for all types of concrete, remained practically the same for concrete with reused water, but above that of the control
This information corroborates the idea that the Ca(OH)$_2$ present in the reused water were consumed in the pozzolanic reaction (equation 1) and contributed to the resistance.

$$3[ \text{Ca(OH)}_2] + 2[ \text{SiO}_2] = [ 3\text{CaO} \cdot 2\text{SiO}_2 \cdot 3\text{H}_2\text{O}]$$  \hspace{1cm} (1)

For Su et al. (2002), from an early age, the use of wastewater favored the gain of compressive strength. As per Malaguti et al. (2017), the gain in compressive strength is associated with the presence of CaOH$_2$ and NaOH in the washing water, which increase alkalinity and accelerate cement hydration by favoring the pozzolanic reaction of mineral additions.

The high alkalinity of the aqueous solution can be beneficial, favoring the pozzolanic reactions of some additions or even blast furnace slag in the cement, contributing to increased mechanical resistance and reducing the possibilities of carbonation according to SU et al., (2002).

After 91 days, all concrete samples with reused water showed compressive strength above the strength of the control concrete, showing uniform behavior in all mixes with reused water (figure 5).
4.3 NATURAL CARBONATION

After the natural carbonation period of 200 days, it was found that concretes C20 and C50 presented a carbonation front of 1.5 mm, equal to that of concrete c, as shown in figure 6 and table 5. Concretes C80 and C100 showed carbonation 2.5 mm thick.

These results express the increase in the carbonated region for the highest levels of reuse water addition, when compared to concrete C, C20 and C50. In this sense, it can be concluded that diluting reused water above 50% is not recommended for structural concrete.

Table 4. Carbonation test results, natural carbonation front (200 days).

<table>
<thead>
<tr>
<th>Carbonated concrete variations depth of carbonation (mm)</th>
<th>C</th>
<th>C20</th>
<th>C50</th>
<th>C80</th>
<th>C100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbonated concrete variations</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Font: Prepared by the authors themselves.

Figure 6 - Carbonation front for concretes C, C20, C-50, C80 and C100.
The increase in carbonation can be explained by the concentration of alkaline material such as \( \text{Ca(OH)}_2 \) present in the reused water. These substances favor carbonation and, therefore, it is possible to infer that the higher concentration of \( \text{Ca(OH)}_2 \) and \( \text{CO}_2 \) reactants favors the formation of the carbonated product.

This behavior explains the greater thickness of the carbonated area and the reduction in pH in the outermost region (table 4).

Possan (2010) explains that the concentration of \( \text{CO}_2 \) in the air is low (approximately 0.04% in normal atmospheres), resulting in a longer process in natural carbonation.

For Figueredo (2005), natural carbonation offers advantages in relation to real interaction with the environment, exposure to the elements and the possibility of evaluating the gradation of concrete. This author also obtained results compatible with this study, even in concrete without reuse water.

5 CONCLUSIONS

In relation to the compressive strength parameters of concrete produced with reuse water, the values are practically equal to those of the control concrete, and if this were the only parameter to be considered, the use of pure reuse water (without dilution). Considering the durability parameter, it was observed that concretes produced with a higher concentration of reused water (80% and 100%) will present a thicker layer of carbonation than other traces, including the control, therefore it is recommended to use a maximum dilution of 50% of reused water, when used in structural concrete, but also for applications in teaching laboratories, which are demolished in no more than 2 years, can be used as pure reused water. Thus, it can be concluded that it is possible to use reused water from teaching laboratories in civil construction courses and possibly in other locations where Portland cement-based materials are produced. This study can also be used in the construction sector, such as: concrete mills, pre-cast element factories and construction companies, since the decantation process used in this study can be adapted in a simple way to this type of companies. The results provide a
sure stimulus for the reuse of water both in schools and in the construction sector, and this is a real possibility of saving treated water and reducing waste in nature, which are desirable consequences because they will benefit the whole society as well as nature. Sustainable actions such as closed cycle of water use are among the most effective for the rational use of water and preserving its use for essential human activities (human, animal and agricultural consumption). Therefore, it is understood that this study makes a great contribution, especially due to its easy application and the fact that it does not involve expensive financial investments. Finally, it is understood that the study at this stage was limited to the use of liquid waste, but it is possible and recommended that such study be extended to include the objective of utilizing the solid part as well (waste of sand, stones, gravel, etc.) and thus it can be to reach the sustainable system both in teaching laboratories and also in civil construction works and thus bring real benefits for all humanity and nature.

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