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# Perception on the employment of treated sewage in concrete production

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ABSTRACT

Civil construction is responsible for the consumption of large amounts of water in concrete manufacturing, hydration of cementitious materials, equipment cleaning and aggregate washing. Therefore, the employment of reclaimed water in concrete production could be a relevant possibility for large-scale recycling, cost reduction and conscious use of raw materials, whose potential is currently little explored in the world. This study is aimed at understanding how civil engineers and architects see the applicability of reclaimed water, both as part of the concrete mixture and in its production process. A total of 94% of the professionals interviewed accepted the reclaimed water; however, they observed that the greatest difficulty for the commercialization of such concrete is the low acceptance of the product by consumers.

KEYWORDS

Reuse. Recycling. Civil construction. Decision makers.

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## 1. Introduction

Concrete is a widely used material in civil construction. According to Silva and Naik (2010), it is the most used construction material in the world, and one of the industrial sectors that consumes the most water.

Its production process and other stages of its life cycle brings great environmental implications, mainly due to the scale of production, which include relevant carbon dioxide emissions, high energy consumption, pollution, depletion of natural resources, and generation of large amounts of solid waste (Meddah, 2017).

According to Miller et al. (2018), concrete production in 2012 accounted for about 9% of water withdrawals for industrial purposes in the world - representing approximately 1.7% of total water withdrawals. The projection for 2050 is that 75% of water demand for concrete production will occur in water-stressed regions (Miller et al., 2018).

Considerable volumes of drinking water are also consumed by the construction industry for other purposes, such as cleaning trucks intended for mixing and transporting concrete, called concrete mixer trucks, and other equipment. According to estimates by Yahyaei et al. (2021), the production of a cubic meter of concrete requires approximately 500 L of water, while the washing of a concrete mixer truck consumes around 300 L.

Therefore, considering the high demand for water in concrete production and curing and the high volume of sewage generated daily in sewage treatment plants around the world, some authors have developed research on the use of treated sewage in concrete production and its influences on physical and mechanical properties (Asadollahfardi et al., 2016; Duarte et al., 2019; Ghrair & Al-Mashaqbeh, 2016; Hassani et al., 2020; Meena & Luhar, 2019; Rao et al., 2014; Raza et al., 2020; Shekarchi et al., 2012; Tonetti et al., 2019; Tumediso et al., 2014).

The work conducted by De Matos et al. (2020) investigated the effect of using water from washing concrete mixer trucks on the fresh and hardened properties of concretes produced with partial and total replacement of drinking water. In general, the authors concluded that the concretes containing reclaimed water presented compressive strength values higher than the reference between 3 and 7 days. After 28 days the obtained strengths were lower than the reference, mainly due to the higher demand of water to reach the target slump range.

Despite this, it was possible to produce concrete with partial and total replacement of drinking water by reclaimed water without significant losses in the fresh and hardened properties. In a similar study, Borger et al. (1994) found that the use of wash water from concrete mixer trucks can be successfully employed in the production of fresh concrete, even immediately after unloading from the truck.

Asadollahfardi et al. (2015) also investigated the feasibility of using concrete-mixer truck wash water in fresh concrete production and found that the employment of reclaimed water resulted in decreased setting time and compressive strength of hydraulic cement mortars. However, there was no significant change in the compressive strength of the concrete samples. Based on the results obtained, the authors concluded that the washing water can be feasible for use in the production of fresh concrete.

Saxena and Tembhurkar (2019) found that the total replacement of drinking water with treated domestic sewage in a constructed wetlands system in the concrete mix did not promote significant changes in slump value and air content, but entailed reductions in compressive (3%-4%) and tensile (9%-10%) strength. However, there were increases in water absorption (6%-9%) and chloride penetration (16%).

Karthikeyan and Asha (2014), in turn, evaluated the impact of drinking water replacement fractions by treated effluent on the compressive strength of concrete after 7 and 28 days. The authors found an increase in values for higher substitution fractions, but obtained better results in samples with 35% of treated effluent, for both analyzed ages.

Peighambarzadeh et al. (2020) concluded, based on a study with beams molded from five different combinations of drinking water and treated domestic sewage that the use of the latter does not cause significant changes in workability values, although it promotes an increase in the onset and end of setting times. Similarly, Asadollahfardi et al. (2016), in a study aimed at understanding the feasibility of using treated domestic sewage before the chlorination step in the production and curing of concrete, showed that the reuse is suitable for these purposes and that there is good compatibility between the compressive strength of concrete produced with drinking water and treated domestic sewage.

Despite many studies proving the appropriateness of reclaimed water application in the concrete production process, there is an obstacle that often prevents its implementation in practice: the resistance of the consumer population. In Canada, for example, experts argue that among all the potential barriers to the reuse of treated wastewater, the barrier of public perception may be the greatest, particularly with regard to exposure to treated sewage (Schaefer et al., 2004). A practical experience in Walkerton (Ontario) showed that the public expects high levels of human health protection, involving the application of government regulations and precautionary and due diligence principles (Schaefer et al., 2004).

The state of California in the United States is at the forefront with regard to reclaimed water, treating wastewater to a high enough degree that it can be reused in the supply for a variety of beneficial uses, such as irrigation, cooling and industrial processing, and indirect potable reuse (Bischel et al., 2012; Sokolow et al., 2017).

In a study conducted by Bischel et al. (2012) to assess the key challenges and motivations that influenced the implementation of reclaimed water programs in Northern California, a survey of 71 managers of such programs was conducted in 2010. The authors indicated that projects initially implemented due to wastewater requirements could expand or find new reuse benefits due to water supply challenges. One respondent illustrated this paradigm shift by stating the following, […]

> […] *15 years ago when we started our program, public acceptance was a problem. People didn't understand recycled water and we spent a lot of time educating potential consumers and marketing recycled water. There was a "fear factor" slowing down the expansion. However, things have completely changed with the worsening drought, water issues in the delta, climate change awareness, and the public's new desire to be "green" and recycle everything. Now we can't get the water to consumers fast enough* (Bischel et al., 2012).

In Latin America few countries consider reuse as an integral part of their water resources (Jiménez & Asano, 2008). However, according to a study of these authors, most countries recognize unplanned reuse, albeit indirectly, through control regulations, mainly directed at agricultural irrigation. The authors recognize that the water resources management strategy is oriented towards the re-adaptation of current reuse practices, rather than the promotion of new planned reuse projects.

In Argentina, the main reclaimed water experiences take place in the province of Mendoza, the only one with a specific resolution for the direct reuse of treated wastewater (Higa et al. apud Calcagno, 2019). According to Higa et al. (2019), such legislation also provides for complementary measures to protect workers and consumers by promoting environmental education campaigns, restricting reuse to certain types of crops, and allowing harvesting only four weeks after the last irrigation. According to the authors, there are also other reuse experiences, although much more limited, in the provinces of Chubnut, Córdoba, Neuquén, and Río Negro.

In Brazil, there is still no legislation at the national level that regulates the employment of reclaimed water and determines its quality standards, but seven states have their own legislation and norms on the matter (Moura et al., 2020). In addition, knowledge about reclaimed water and its applications among the general population is still heterogeneous. For Hespanhol (2008), the acceptance of reuse depends on a new vision of water resources management by the government and civil society, requiring demand to be effectively implemented.

González and Vieira (2020) sought to understand the perception of the population of the city of São José dos Quatro Marcos (state of Mato Grosso, Brazil) about the supply and domestic use of water for human consumption through the application of a questionnaire. The authors found there were negative perceptions on the treatment, distribution, and quality of water supplied by the public network, which would encourage the use of alternative sources, even with low coverage of sanitary sewage. Moreover, according to the study, there is still ignorance on the possibilities of reuse: only 32.7% of respondents admitted knowing that the water used in the household can be reused.

Ferreira et al. (2020) conducted a study with the purpose of, among other objectives, investigating the applicability of sewage reuse and its influence on the quality of life of the population of Parelhas and Pedro

Velho, municipalities in the semiarid and northeastern Brazilian coast, respectively. The authors verified that the population in general understands the importance of reuse, especially in agriculture and fish farming. However, among those who showed knowledge of agricultural reuse practices for human consumption, an exclusive relationship was attributed to farmers and landowners, which contributes to the lack of interest in expanding reuse in a collective way by the residents.

Similar research, conducted with family farmers in the Brazilian semi-arid region (state of Bahia), indicated that reuse is perceived as an opportunity to improve the conditions of access to water with environmental advantages, but the perception of risk is still quite strong, especially in relation to the health of the worker and the consumer (Barbosa, 2012). The study makes evident the perception of family farmers regarding health safety when it shows that most of them would accept the reuse on the condition that the sewage was properly treated.

A study conducted by Bakare et al. (2016) showed that the support of a community in Durban, South Africa, was critical to the implementation and expansion of reuse in activities involving low human contact. For the authors, public acceptance is a key issue for the success of this on-site water conservation concept.

In this context, it is essential that reuse practices are disseminated and understood by the population served, and that dialogue with the authorities responsible for implementing the actions is encouraged. Therefore, the viability of reuse is highly dependent on social and political factors, and its greater acceptance requires alignment among local and regional water policies and public values. It is also important to find ways to incorporate such values into the planning process (Ormerod & Scott, 2013).

According to Hartley (2006), there are five critical issues for building and maintaining public trust in water resource management and decision-making regarding reclaimed water: managing information for all stakeholders, maintaining individual motivation and demonstrating organizational commitment, promoting communication and public dialogue, ensuring a fair and safe decision-making process, and building and maintaining trust. For the author, the human side of decisions regarding reclaimed water can often be more challenging than finding solutions to technical and scientific issues.

Thus, it is of utmost importance to understand the obstacles that prevent reclaimed water practices from being implemented in practice. A path towards such an understanding is presented in this paper, which sought to assess the perception of decision-makers (architects and civil engineers) on the use of treated sewage to replace drinking water in civil construction projects.

## 2. Method

A cross-sectional and qualitative questionnaire was developed specifically to understand the way in which former students at the School of Civil Engineering, Architecture and Urbanism at the State University of Campinas (FECFAU/Unicamp) view the applicability of treated sewage (reclaimed water), both as part of the concrete mix and in its production process. In addition, it also aimed at listing main reasons that justify their positions. The questionnaire was developed in the online platform Google Forms.

The target population of the study was the former students of the courses offered by the Civil Engineering and Architecture and Urbanism School at Unicamp, who received the questionnaire from a mailing list of the school directed to this group.

The respondents work in companies in the civil construction area and are decision makers regarding the use of new materials or processes within companies. The survey lasted for 14 days, and a reminder was sent to all registered e-mails after seven days.

The initial questions of the questionnaire sought to characterize the profile of each participant by determining the undergraduate degree and year of graduation, area of professional activity and position or function performed. The main purpose of collecting such information was to understand if the perception of the employment of reclaimed water in concrete production was influenced by the professional's year of graduation or area of work.

Then, the respondents were asked to answer the following question: Would you accept employing reclaimed water (safely treated sewage) in the production of concrete? Based on this answer, the next step sought to understand the reasons justifying the acceptance or refusal of the participant through options pre-defined by the questionnaire.

If they answered yes, the justifications for employing reclaimed water in concrete included cost, environmental issues, less vulnerability during a water crisis, increase in product competitiveness, commercialization of a more environmentally friendly product, efficient distribution infrastructure, existence of partnerships with sanitation companies, increase in product acceptance, lower price of reclaimed water in relation to drinking water, and fiscal and/or financial advantages granted by the government.

Next, the respondents had to answer whether they already employed reclaimed water in the production of concrete or in other activities. If the answer was affirmative, the next step consisted in listing the main difficulties in employing reclaimed water through pre-defined options, which included costs, low acceptance of the product, lack of specific laws, prejudice of the population regarding the employment, deficient distribution infrastructure, difficulty of access, decrease in competitiveness of the product, and lack of government incentive.

Conversely, if the answer was negative, the participants should answer what were the main reasons that hindered the application of reclaimed water in concrete production based on their opinion and professional experience. In this case, the alternatives were also pre-defined and included exactly the same points as the question for affirmative answers.

The respondents who declared they would not accept employing reclaimed water in concrete production had to choose among the following reasons: cost, lack of knowledge about techniques and use, lack of specific laws, resistance of the population on the consequences of use, lack of access to reclaimed water, decrease in product acceptance, lower price of reclaimed water in relation to drinking water, deficient distribution infrastructure, lack of government incentive, and concern for public health.

The following question was then asked: If lower costs were guaranteed and health and legal requirements were met, would you use reclaimed water for concrete production and other activities? In this case, the respondents simply had to choose between yes or no.

In all questions with multiple options, the respondents could choose as many alternatives as they wanted to justify their answers. The questionnaire was then concluded with a question about the participants' interest in knowing more about the study and assisting in its possible expansion.

## 3. Results and discussion

Most of the respondents (74%) graduated in Civil Engineering. This representativeness is in line with the number of students that compose each course annually: of the total number of students entering FEC/Unicamp, on average 73% are from Civil Engineering. In general, the answers given by the former students of both courses followed a very similar pattern, which shows good knowledge on reclaimed water and the suitability of its application. In addition, most of the respondents graduated between 2005 and 2014 (Table 1).

**Table 1.** Socio-demographic data of the respondents.

| | | |
|---|---|---|
| **Course** | Civil engineering | 74% |
| | Architecture and Urbanism | 26% |
| **Gender** | Male | 53% |
| | Female | 47% |
| **Graduation year** | 2020 – 2015 | 24% |
| | 2010 – 2014 | 32% |
| | 2005 – 2009 | 28% |
| | 2000 – 2004 | 6% |
| | 1990 – 1999 | 4% |
| | 1980 – 1989 | 2% |
| | 1970 – 1979 | 4% |

Regarding the area of activity of the participants, 30% declared they work in the development of civil engineering or architecture and urbanism projects; and 24% declared they were in the area of water resources and sanitation. Another 18% said they do not work directly with civil engineering or architecture and urbanism.

Based on this information it can be said that there was adequate representativeness of professionals who work directly in their areas of training. Therefore, they are probably well exposed to issues related to reclaimed water compared to the general population.

A total of 94% of the respondents declared they would accept to employ reclaimed water in concrete production. The main justifications for accepting it included environmental issues (95.7%), the commercialization of a more environmentally friendly product (66.0%), and the possible decrease in costs associated with the application of reclaimed water instead of drinking water (46.8%). Other justifications presented by the respondents included support for social security, stimulation of the circular economy, and optimization of urban metabolism.

It is interesting to note that all respondents who graduated after 2014 stated that they would accept employing reclaimed water in concrete production. However, the years of training of the professionals who said otherwise are quite different from each other, which indicate that the discussion on the subject was recently introduced in the undergraduate environment. This contributes to recently graduated professionals to have a favorable view of reuse, since they are aware of the process, its purposes and risks (Table 2).

**Table 2.** Acceptability of the application of reclaimed water in concrete production.

| | | |
|---|---|---|
| Would you accept employing reclaimed water in concrete production? | Yes | 94.0% |
| | No | 6.0% |
| Why would you accept employing reclaimed water in concrete production? * | Cost | 46,8% |
| | Environmental issues | 95,7% |
| | Less vulnerability during the water crisis | 27.7% |
| | Increase in product competitiveness | 14.9% |
| | Commercialization of a more environmentally friendly product | 66.0% |
| | Efficiency of the distribution infrastructure | 8.5% |
| | Existence of partnerships with sanitation companies | 29.8% |
| | Increase in acceptance of the product | 17.0% |
| | Lower price of reclaimed water in relation to drinking water | 36.2% |
| | Fiscal and/or financial advantages | 40.4% |

***** The total percentage exceeds 100% as respondents could mark more than one alternative.

The engagement of the younger audience is also observed in the literature. Schmid and Bogner (2018) conducted a survey with early-year university students in Germany and found that most have quite positive attitudes towards reclaimed water. However, the authors recognize that the social acceptability of a new technology takes years and must be gradual and well planned.

Next, the 94% who declared they would accept to employ reclaimed water in concrete production were asked about the main difficulties associated with this practice. Only 36.2% of this group had already applied reclaimed water in concrete production or in another activity, and the main obstacles included the low acceptance of the product (70.6%), the lack of specific legislation (47.1%), the prejudice of the population regarding the use (41.2%), and deficient distribution infrastructure (41.2%).

Other difficulties pointed out included the lack of knowledge on the part of professionals and the incorrect prioritization in the use of water as a hydric resource. This shows that, despite the interest of professionals in incorporating the employment of reclaimed water in activities that are suitable for it, there is still resistance from the population. Moreover, the lack of legislation that is valid throughout Brazil is also an obstacle to be overcome.

Of the 63.8% who answered they still do not employ reclaimed water in concrete production or other activities, 63.3% cited that the low acceptance of the product would be the main reason that would make it difficult to replace drinking water, followed by prejudice of the population regarding its use (60.0%), lack of access to reclaimed water (43.3%) and lack of specific legislation (43.3%). In addition, other reasons mentioned included important aspects such as the possibility of high treatment costs, the lack of knowledge and specific literature, the need to ensure usability without rheological risks and to living beings, and the conservatism of the construction sector (Table 3).

**Table 3.** Main difficulties identified in the application of reclaimed water in concrete production or other activities.

| | | |
|---|---|---|
| Did you already apply reclaimed water in concrete production or other activities? | Yes | 36.2% |
| | No | 63.8% |
| What are the main difficulties you see in employing reclaimed water? (Question directed to those who apply reclaimed water in concrete production or other activities) | Cost | 35.3% |
| | Low acceptance of the product | 70.6% |
| | Lack of specific legislation | 47.1% |
| | Prejudice of the population regarding the employment | 41.2% |
| | Deficient distribution infrastructure | 41.2% |
| | Difficulty of access | 29.4% |
| | Decrease in product competitiveness | 0.0% |
| | Lack of government incentive | 23.5% |
| What are the reasons that hinder the application of reclaimed water in concrete production or other activities? (Question directed to those who do not apply reclaimed water in concrete production or other activities) | Cost | 10.0% |
| | Acceptance of the product | 63.3% |
| | Lower price of water currently used | 3.3% |
| | Lack of specific legislation | 43.3% |
| | Prejudice of the population regarding the use | 60.0% |
| | Deficient distribution infrastructure | 30.0% |
| | Difficulty of access | 43.3% |
| | Decrease in product competitiveness | 6.7% |
| | Lack of government incentive | 33.3% |

Another aggravating factor cited was the type of contract usually adopted by the utilities, which would burden those who use reclaimed water. Once again, the low acceptance by the consumer population represented the main barrier for the reclaimed water in practice. Therefore, it is extremely important that communication with the public is done in an efficient way, making clear the treatment procedures used, the associated risks and the benefits resulting from reclaimed water.

Examples described in the literature corroborate the difficulties associated with the employment of reclaimed water that were identified in this study. Sokolow et al. (2019) sought to identify the potential barriers hindering the expansion of reclaimed water employment in California by conducting interviews with individuals familiar with urban water management operations in the state. The main barriers identified by the authors included regulations, infrastructure, financing, technology, health risks, and public perception.

In another study conducted in three US cities, Li and Roy (2021) found that even individuals who exhibit pro-environmental behavior do not show an explicit preference for reclaimed water over conventional water. The authors testified that individual preferences are unstable, suggesting that social factors have the ability to play important roles in the attitudes and decisions of the general public. In this context, it is of utmost importance that water conservation initiatives take into consideration not only people who explicitly state a preference for reclaimed water, but also people who are more undecided about it (Li & Roy, 2021).

Among those who would not accept the employment of reclaimed water in concrete production (6% of the interviewees), the reasons stated included costs, lack of knowledge about techniques and use, lack of specific legislation and resistance of the population to the consequences of its employment. Aspects related to the non-homogeneity of the reclaimed water and the quality loss of the final product was also mentioned.

Although there is still no consensus in the literature about the use of treated sewage and its implications on concrete properties, it is noteworthy that the vast majority of studies that used treated effluents with physical-chemical qualities considered appropriate showed improvements or small reductions (below the 10% maximum limit required by standards) in compressive strength and did not provide large variations in fresh concrete properties, such as setting time and workability, according to De Matos et al. (2020), Asadollahfardi et al. (2015), Peighambarzadeh et al. (2020), Duarte et al. (2019) and Tonetti et al. (2019).

Therefore, it is possible to state that this practice is feasible as long as there is constant quality control of the product through periodic evaluations of the treated sewage used and the properties of the concrete produced. Furthermore, it is important to develop specific legislation for reclaimed water nationwide, so that practices are standardized and professionals are trained to perform reclaimed water actions in a responsible and beneficial way. In time, the reuse will cease to be an option and will become a necessity, especially in regions subject to water stress conditions. Therefore, the sooner these activities are put into practice, the better it will be for the consuming population and for the environment.

## 4. Conclusion

Based on the answers collected in the questionnaire, it can be concluded that the greatest hindrance to the commercialization of the concrete produced with reclaimed water consists in the low acceptance of the product by consumers.

This reflects, among other things, the low knowledge of the population about the water cycle and wastewater treatment processes. In fact, it is not uncommon for reclaimed water, to present similar or better quality than drinking water depending upon the type of treatment it has undergone. Thus, it makes sense that the vast majority of professionals interviewed have stated they would accept to employ reclaimed water in the production of concrete, since they usually have more in-depth knowledge on the effectiveness of sewage treatment methods.

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