Environmental and economic assessment integrated into laboratory-based scenario development for the valorization of dredged sediment

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Abstract
This study discusses the potential environmental and economic benefits of dredged sediment valorization in concrete in the framework of the circular economy. The goal is to find a sustainable way to use the sediment in concrete while maintaining its strength and not compromising the economy or environment. The maximum rate of sand substitution in concrete with sediment was found to be 40%, but sustainability was negated for rates above 20%. To optimize sustainability, a compromise between concrete strength and workability, economic and environmental impacts, and sediment transport must be reached. Lack of environmental and economic assessments in valorization scenarios may lead to non-sustainable practices.

Keywords: life cycle assessment, dredged sediment, valorization, concrete

1. Introduction

The annual dredging of millions of tons of sediment in Europe poses significant economic and environmental challenges. However, adopting the circular economy concept and valorizing sediment may present an opportunity to address these challenges. Previous studies have shown that sediment can be partially substituted in construction materials (Kasmi et al., 2017; Bellara et al., 2021; Samara et al., 2009; Beddaa et al., 2020; Ez-zaki and Diouri, 2018; Amar et al., 2020; Hadj Sadok et al., 2022; Hayek et al., 2023). Nonetheless, the sustainable rate of sediment incorporation in construction materials has not been comprehensively studied through combined life cycle assessment (LCA) and life cycle cost assessment (LCCA). In this study, LCA and LCCA were integrated into laboratory-based experiments to identify technically feasible, economically, and environmentally sustainable solutions for the valorization of large quantities of sediment dredged from the port of Camargue in the south of France. Laboratory evaluations were conducted on the workability and strength of trial concrete formulations affected by partial sand substitution by sediment, with the objective of the industrial-scale application. Economic and environmental LCAs were integrated into the technical evaluations to determine the sustainable threshold for sand substitution by sediment. This comprehensive approach aims to identify viable scenarios for sediment valorization that are technically feasible, as well as economically and environmentally sustainable.

2. Material and methods

2.1. The experimental lab's concrete scenario

In this study, concretes of grade C30/37 were prepared with partial sand substitution by sediment using the modified Dreux-Gorisse method. The workability of the fresh concrete and the compressive strength of the hardened concrete was evaluated to determine the maximum substitution of sand by sediment while maintaining the desired performance.

Superplasticizer was incorporated to maintain the expected slump level. The quantity of the ingredients in each cubic meter of the lab-formulated concrete scenarios with sand substitution by sediment at varying rates (10-50%) are listed in Table 1.

Materials	Control Concrete	Port Camargue				
		Scenario PC1 10%	Scenario PC2 20%	Scenario PC3 30%	Scenario PC4 40%	Scenario PC5 50%
Gravel (16-14)	785.5	835.5	882	901.5	927.5	951
Sand (0-4)	1059.5	894.15	736.8	614.6	503.4	400
Sediment	0	99.35	184.2	263.4	335.6	400
CEM I 52.5	238	238	238	238	238	238
GGBS	102	102	102	102	102	102
Superplasticiser	0.2475	0.66	1.65	3.3	4.785	6.6
Water	202	208.5	205.5	208	207.5	212.5

Table 1. *The quantity of the ingredients in $1m^3$ of the lab-formulated concrete scenarios with sand substituted by sediment at varying rates (10-50%)*

2.2. Environmental life cycle assessment (LCA)

Life cycle inventories of experimental concrete scenarios were developed to conduct a comparative life cycle assessment (LCA) and the Recipe midpoint (H) was used to assess environmental impacts in 18 impact categories. The impacts of $1m^3$ of ordinary concrete were used as a control for comparison. The functional unit was $1m^3$ of concrete at the gate of the concrete plant, and all processes within the cradle-to-gate system boundary were considered. The environmental impacts of sediment dredging were allocated to the dredging operation and the sediment was considered to have zero environmental impact as it was recyclable. The study aimed to provide a unitless single score to facilitate decision-making.

2.3. Economic life cycle assessment

The evaluation of the economic aspects is an essential requirement for decision-making concerning the sustainability of sediment management and exploitation options. To perform a Life Cycle Cost Analysis (LCCA), the expenses related to raw materials, energy, transportation, labor, equipment, and maintenance were collected from the French market. The Excel software was used to determine the cost of 1 cubic meter of each concrete scenario based on the rate of materials incorporation and production processes along with their respective market prices. The untreated raw sediment was assessed at zero market value, while its transportation cost was considered in the calculation.

3. Results and Discussions

3.1 Experimental performances of concrete scenarios

The slump cone test was used to evaluate the workability of fresh concrete scenarios, which showed that the fluidity of the concrete decreased in proportion to the amount of sediment added, even with the addition of excess water. To maintain the desired slump class of S4, additional superplasticizer was added to the mix. The mechanical strength of the hardened concrete showed a significant reduction, but partial substitution of sand with sediment up to 40% maintained the C30/37 concrete class. However, according to a contribution analysis (Soleimani et al., 2023), it was found that the increased incorporation of superplasticizer to improve workability had negative economic and environmental impacts.

3.2 Comparative environmental and economic impacts of experimental concrete scenarios

The environmental impact categories of 18 mean values were normalized to those of the control concrete, and a single score was integrated to obtain insight into the sustainability of concrete scenarios. A graph was created to illustrate the economic and environmental impacts of each scenario (Fig.1) which showed that for PC1, the impacts were lower than those of the control concrete. However, for PC2, the additional impacts of modifications in concrete composition neutralized the benefits of sand substitution. For substitution rates higher than 20%, both the economic and environmental impacts were higher than those of the control concrete. The use of additional superplasticizer to offset the negative impact of sediment offset the benefits of sand substitution. A sustainable threshold for sand substitution rate in concrete could be optimized through a compromise between workability, concrete class, superplasticizer impact, and sediment transport.

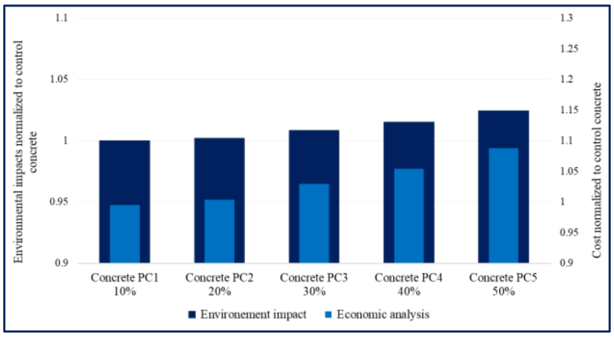

Figure 1. *Normalized single score environmental impacts and costs of experimental concrete scenarios, with sand substituted by sediment at varying rates (10-50%), in comparison to the control concrete.*

4. Conclusion

The aim of this research was to assess the feasibility of using sediment as a substitute for sand in concrete. The findings suggest that the absence of life cycle assessment (LCA) and life cycle cost analysis (LCCA) in conjunction with experimental development of valorization scenarios could lead to unsustainable practices. Integrating LCA and LCCA into laboratory-based valorization scenario development can identify the sustainable limit for sediment incorporation. The study determined that substituting 20% of sand with sediment from the port of Camargue in C30/37 concrete class is a practical and sustainable threshold.

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