Engineering Proposal: Self-healing Concrete

A solution to long-term building maintenance

City College Of New York

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Summary:

Sporosarcina pasteurii, a naturally occurring bacterium, plays a key role in this project by activating a biochemical process when introduced to moisture. The bacteria are encapsulated within the concrete during its production. When cracks form and water seeps in, the bacteria become active and start producing calcite, a mineral that fills the gaps, effectively healing the concrete.

This self-healing mechanism reduces the need for manual repairs, enhancing the sustainability of structures and decreasing maintenance costs. The project aims to revolutionize the construction industry by promoting eco-friendly, long-lasting infrastructure. The implementation of self-healing concrete has the potential to mitigate the environmental impact caused by frequent repairs and increase the resilience of buildings and infrastructure against wear and tear. The project's budget is allocated at $9.56, equating to $0.29 per kilogram of the self-healing concrete, incorporating Sporosarcina pasteurii bacteria.

The project focuses on addressing the fragility of concrete, a widely used material, by exploring self-healing concrete using Sporosarcina pasteurii bacteria. This solution is deemed effective for long-term maintenance without compromising the material's strength. The comparison of traditional and bacteria-infused concrete production costs reveals an 81% increase in upfront expenses for the latter. Despite this, the potential for significant savings in maintenance costs over the concrete's lifetime is highlighted.

Introduction:

Concrete is one of the most used construction materials in the world, concrete is durable and strong. How concrete came about first we have to go back to 1300 B.C where “Middle Eastern builders found that when they coated the outsides of their pounded-clay fortresses and home walls with a thin, damp coating of burned limestone, it reacted chemically with gases in the air to form a hard, protective surface. This was not concrete, but it was the beginning of the development of cement in Israel natural deposits were formed by reactions between limestone and oil shale that were produced by spontaneous combustion.” In the Industrial age, they added iron bars in the concrete to help reinforce the concrete and over time people started adding additives and admixtures to help increase the strength and durability of concrete. However, it is inevitable for damage to happen to concrete over time, which can lead to costly repairs and maintenance. In response to this problem, an innovation to solve this problem is self-healing concrete specifically Sporosarcina pasteurii. Self-healing concrete using Sporosarcina pasteurii can repair cracks in the concrete by its ability to precipitate calcite and solidify sand and gravel together. It also helps reduce maintenance costs and have longer durability than regular concrete. This can help transform the construction industry by contributing more sustainability to the environment, fixing more implications in the future of infrastructure, and help save money overall as it reduces the amount of concrete used.

Project Description:

As Engineers, it is an obligation to think of the most cost-effective ways to improve societal needs, this does not always mean finding the cheapest up-front costs on materials, despite it being the instinct. With concrete being one of the most readily used materials in society, focusing on improving its fragility would help with long-term maintenance of buildings. When looking at the viable solutions to help the longevity of concrete, the concept of self-healing concrete, an idea that has been explored in multitudes by different researchers, continued to show itself as the most feasible. Although there are several types of self-healing concrete, we believe that the use of Sporosarcina pasteurii bacteria is the most effective solution. *Sporosarcina pasteurii* is "the most common biomineralizing microorganism, is a nonpathogenic, ureolytic bacterium that has become the model organism for construction biomineralization research..." (Beatty, D. N., Williams, S. L., & Srubar, W. V. (2022) and according to research done at *Delft University of Technology* the addition of the bacteria does not change the material characteristics of the concrete, therefore not changing the strength.

With the implication of self-healing concrete using Sporosarcina pasteurii bacteria as the main form of concrete utilized for new construction, the savings for future maintenance outweigh the upfront cost differences. As populations continue to grow, and the need for more infrastructural improvements and projects continues to also grow, the need for long-term solutions become more important to builders. Although now we are unable to know just how long the improved concrete can last, there are similarities between this discovery and the ones of the Ancient Roman building practices that can help to give reason to think that this can outlast ongoing climate change. The Ancient Romans used the addition of 'lime clasts' to give the concrete the self-healing properties found in the Sporosarcina pasteurii bacteria concrete (News, E., & Cusick, D. (2023, January 26). By adding water to the cracked concrete and allowing it time, the lime clasts were able to repair the cracks, this material was used to build the Pantheon in Rome, which is still beautifully intact today, giving us reason to believe that the concrete using Sporosarcina pasteurii bacteria will be able to withstand the same test of time. This will be a concern for many companies because of the high upfront costs, however given that in 2022 alone over 100,000 buildings in NYC initiated construction permits or new building permits, which was an 11% increase from 2021, according to the NYCDOB, there is a large need for renewable materials in our city.

Implementing the change of standard concrete to a self-healing solution requires up-front costs of around 81% increase in price, which to most people is an immediate turnoff all together. The largest obstacle to be faced when implementing change is convincing companies, governments, and other consumers that this change is the lasting solution to saving on repair costs. This will depend on the size of the project, the climate, and if the building is being repaired or is a completely new build. These factors will all play into how much the construction will cost, and if the increase in price to not worry about certain factors later is worth it to most consumers. In a city like NYC, where the climate is constantly changing, and the scale of repairs and buildings are large, a change to self-healing concrete is far more feasible than somewhere more temperate.

To achieve a change like this can be approached multiple ways, one would require showing research to the city to prove that this change in cost upfront is necessary for saving money in the long-term, and request that the city implements this change in their building codes. This would be the most widely effective way but will take many years to do. Another option is to go to individual companies that are large purchasers of concrete and approach from the same angle and have the examples of companies that have already agreed to make this change to convince others to do the same. This approach is more immediate, as competition between companies will influence others to make environmental changes as that continues to be a larger contributing factor in consumer focus. By recommending to individual companies the likelihood of use is quicker. A combination of both can also be utilized, as continuing to market to smaller companies while negotiating with city governments will create more opportunities to show its successful use.

Budget:

In comparison to other building materials concrete is infamous for its poor strength and sensitivity to cracks, but on the other hand it is a popular choice due to its durability and shock absorbency. Scientists have produced a way to maximize the natural process of breaking down by introducing bacteria. Traditional concrete is lower in price meanwhile the upfront price of microbiological concrete will be, but it is more durable and will last longer due to few maintenances needed.

Tables 1 and 2 show the total production cost per kg of refusal traditional concrete and bacteria infused one. Keeping the water consumption negligible in the total cost, by referring to

Table 2, the cost to produce bacteria infused concrete is $9.55 for 34.428 kg which produces a ratio of $0.28 per kg of concrete produced. To note the difference between two concretes, 1 kg bacteria infused concrete will consume 0.005 gram of bacteria, considering that estimated cost for 0.450 kg is $796.00. Hence, since 0.005 g of bacteria was used per kilogram of concrete, the estimated cost is an extra $0.01 per kg of microbiological concrete. Bringing down the cost of traditional concrete to be $0.16 per kilogram and $0.29 per kilogram for Sporosarcina pasteurii infused concrete.

	Table 1. Composotion of Concrete	
type of material	Traditional Concrete (kg)	Sporosarcina pasteurii infused concrete (kg)
Cement	9.73	9.73
Artificial sand	6.28	6.28
Natural sand	9.43	9.43
Clay	3.42	3.42
Gravel	11.8	11.8
Additive	0.045	0.045
Water	3.89	3.89
Calcium lactate		0.048
Bacteria		0.005 g
	Source: Adapted from Leite et al. (2019b)	

Table 1. Composition of Concrete. Adapted from Leite et al. (2019b)

	Table 2. Cost production of bacteria infused concrete		
Material	Unit Price (USD$/kg)	Quantity (kg)	Amount (USD$)
Portland Cement CP II-32	0.09	9.73	0.9
Commercial sand	0.03	9.43	0.32
Commercial gravel	0.03	11.8	0.4
Clay	1.39	3.42	4.75
Calcium lactate	66.36	0.048	3.18
Bacteria	796 (0.450 kg)	0.005	0.01
Total		34.428	9.56
$9.56 / 34.428 =	**$0.29 (Total Price Per Kg)**		

Table 2. Cost production of bacteria infused concrete

Comparing the cost between the two, per kilogram of concrete produced between traditional one and microbiological one there is an 81% difference increase in price. It might look like bacteria infused concrete is more expensive to buy and does not come out to be a cost saving option. However, bacteria infused concrete has a great benefit of reducing maintenance cost for fissures in the structures and tension regions, and is estimated to save up to 50% of concrete's lifetime cost,

Conclusion:

In conclusion, **t**he project focused on self-healing concrete, incorporating Sporosarcina pasteurii bacteria, offers an innovative solution to the challenges of long-term building maintenance. By harnessing the natural repairing abilities of these bacteria, this groundbreaking approach significantly extends the lifespan and durability of concrete structures, reducing the need for costly manual repairs. The ability to autonomously heal cracks and fissures within concrete introduces a sustainable and eco-friendly element to construction practices.

The potential longevity of self-healing concrete is promising, drawing parallels with ancient Roman building practices that utilized similar principles. The utilization of water-activated self-repair mechanisms, whether through ancient lime clasts or modern bacteria, presents a durable alternative for long-lasting infrastructure.

While the initial cost of microbiological concrete may be slightly higher compared to traditional concrete, the significant reduction in maintenance expenses over the lifespan of the structure makes it a cost-effective and practical choice. The data presented demonstrates the potential economic advantages, despite the initial investment.

This project encourages the construction industry to embrace the power of microbial activity within concrete, transforming it into an initiative-taking, resilient, and sustainable building material. This innovative approach has the potential to revolutionize construction practices, promoting both economic and environmental benefits for a more sustainable future.

Furthermore, transitioning from standard concrete to self-healing Sporosarcina pasteurii bacteria-infused concrete presents a promising solution for long-term durability. Although the upfront costs pose a challenge, the potential savings in maintenance expenses offer a compelling reason for consideration. The comparison with Ancient Roman practices and the relevance to contemporary construction needs, especially in a city like NYC, underscores the urgency for sustainable materials. Convincing stakeholders through a combination of research-driven appeals to city governments and immediate engagement with large concrete purchasers appears to be a pragmatic approach for widespread adoption. This project signifies a strategic shift toward innovative, sustainable construction practices that align with both economic and environmental imperatives.

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