REDUCING EMBODIED CARBON IN HEAVYWEIGHT ACOUSTIC DESIGN

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1 INTRODUCTION

Heavyweight materials are a common feature of good acoustic design, for several key reasons outlined in the following section. Unfortunately, heavyweight materials are typically correlated with increased levels of embodied carbon, both in terms of production as well as material handling. This paper examines potential avenues for reducing embodied carbon within heavyweight acoustic design, with minimal or no loss in performance. The aim of this paper is to be agnostic to the supplier of the acoustic isolators; for the purposes of this analysis, only the embodied carbon of the mass layers is considered, with the aim to make the findings applicable to all suppliers and installers of acoustic isolation systems.

2 HEAVYWEIGHT MATERIALS IN ACOUSTIC DESIGN

2.1 Reasons for use

Heavyweight materials are a mainstay of acoustic design for one principal reason: performance. The generally accepted golden rule of acoustics comes down to, “the heavier, the better”. For a given amount of disturbing energy in the form of sound or vibrational energy, a heavier material will respond with a correspondingly lower amplitude response; the more mass, the harder it is to move. Given that practical limits are unavoidably placed on the allowable depth for a given acoustic system, high density heavyweight materials become a practical necessity.

Within the context of this paper, heavyweight materials are defined by their high mass, or relatively high mass within their product category; cement particle board for example will have a significantly higher mass at a given thickness than acoustic rated plasterboard, but both would be considered heavyweight materials owing to their positioning compared to lightweight options within their category (plywood and standard plasterboard respectively in this example). Cementitious screeds, concrete and steel are the main other materials under consideration as heavyweight materials.

One idea often put forward is to design out the need for such materials and this is unquestionably the best strategy for achieving the most significant carbon savings. However, that is not within the scope of this paper, wherein the working assumption is that the heavyweight constructions being considered are necessary to achieve the required level of performance, which is a realistic boundary condition in practice; sometimes there is no workable alternative to a heavyweight system from a practical and performance standpoint.

2.2 Sustainability Issues

The principal concern with heavyweight materials comes down to their relatively high embodied carbon content. Concrete and other cementitious materials account for approximately 8-9% of all carbon emissions worldwide[1], for example, while steel production accounts for approximately 7% of global carbon emissions[2].

By contrast, timber-based materials can actually have negative global warming potential (GWP_{total} as defined within the context of an Environmental Product Declaration (EPD)) owing to their negative $GWP_{biogenic}$ value, explained by the planting of new trees to replenish stock of trees felled in production[3]. Nuance should be considered when using this figure, as the GWP_{fossil} figure quoted in an EPD can be quite high and the practical reality of the situation should be considered; is it really correct to say that adding unnecessary timber materials to a building will bring down its overall content of embodied carbon? Common sense would dictate that can't be correct.

For this reason, the end of life of a material has to be considered when using including carbon storage for GWP comparisons, as that carbon will be returned to the environment at the end of service life, either by decaying in landfill or through incineration for energy production.

3 COMMON HEAVYWEIGHT MATERIALS

3.1 Concrete

Concrete is composed of four basic ingredients: cement, aggregate, sand and water. There are other minor additives, but the vast majority is comprised of those four ingredients and of those, over 70% of the embodied CO_2 comes from the cement content alone[1].

Cement comes in a variety of forms, from CEM I through to CEM IV, with the Portland cement content varying depending on the type, with cement replacement content varying in accordance. See figure 1 for a comparison of the material properties of different cement types relative to CEM I.

Property	Cement (or equivalent combination)						
	Portland Cement CEM I	Silica fume cement CEM II/A-D (CIIA-D)	Portland Limestone Cement CEM II/A-LL or L	Portland fly ash cement CEM II/B-V (CIIB-V)	Blastfurnace Cements		Pozzolanic cement CEM IV/B-V (CIVB-V)
					CEM III/A (CIIIA)	CEM III/B (CIIIB)	
Early Strength	High	High	High	Moderate	Moderate	Low	Low
28-day Strength	Normal	High	As CEM I	As CEM I	As CEM I	< CEM I	< CEM I
Long term Strength	Normal	High	As CEM I	High	High	High	High
Workability retention	Normal	< CEM I	Longer than CEM I	Longer than CEM I	Longer than CEM I	Longer than CEM I	Longer than CEM I
Bleeding/plastic settlement	Normal	Less likely than CEM I	Less likely than CEM I	Less likely than CEM I	More likely than CEM I	More likely than CEM I	More likely than CEM I
Plastic shrinkage	Normal	High	As CEM I	As CEM I	Less likely than CEM I	Less likely than CEM I	Less likely than CEM I
Setting finishing times	Normal	Normal/ Moderate	Normal/ Moderate	Normal/ Moderate	Moderate	Slow	Slow
Low heat	Poor	As CEM I	Modest	Moderate	Moderate	Very good	Very good

Figure 1. Table of comparison for different cement types[5].

Portland cement is manufactured by heating limestone with aluminosilicate minerals (usually in the form of clay) to form relatively large lumps, referred to as clinker, which is then ground into a fine powder with approximately 5% gypsum added[1]. CO_2 is released as a direct by-product of this process, as well as from the combustion of the fuel needed to heat the mixture up to 1450°C.

Given that the manufacturing process of cement is so energy and carbon intensive, this explains why it contributes the vast majority of the embodied carbon in any given concrete mixture. As an aside, the sand, water and aggregate needed as the other main constituents of concrete are locally sourced and as such their secondary contribution varies from region to region. Given that cement is both the main source of embodied carbon and a centrally manufactured product compared to the other constituents, as well as having the most actionable routes for reducing carbon contribution, this will be the main focus of this portion of the paper.

The main strategy for reducing embodied carbon in cement is to increase the quantity of cement replacement material, chief among which are fly ash, which is a by-product of coal fired power stations, and ground granulated blast furnace slag (GGBS), which is a by-product of steel production. These cement types are typically referred to as “blended” as opposed to standard “OPC” (Ordinary Portland Cement aka CEM I).

Various manufacturers offer so called, “eco concrete” under a variety of different brand names, with claims ranging from 30% to 85% reduction in embodied carbon depending on the specific product in question[6,7,8]. While they vary in some of the specific details, all of these individual product lines rely on blended cement to achieve embodied carbon reduction, with certain cement types replacing as much as 80% of the OPC with GGBS[5].

See figure 2 for a table comparing concrete using different cement types in terms of embodied CO_2/m^3, and see figure 3 for a breakdown of the embodied CO_2 by constituents. All graphs were produced using the Circular Ecology ICE Cement, Mortar and Concrete model v1.1[9] with a consistent mix design, wherein the only difference between each is the cement type. Steel reinforcement was not considered in this example.

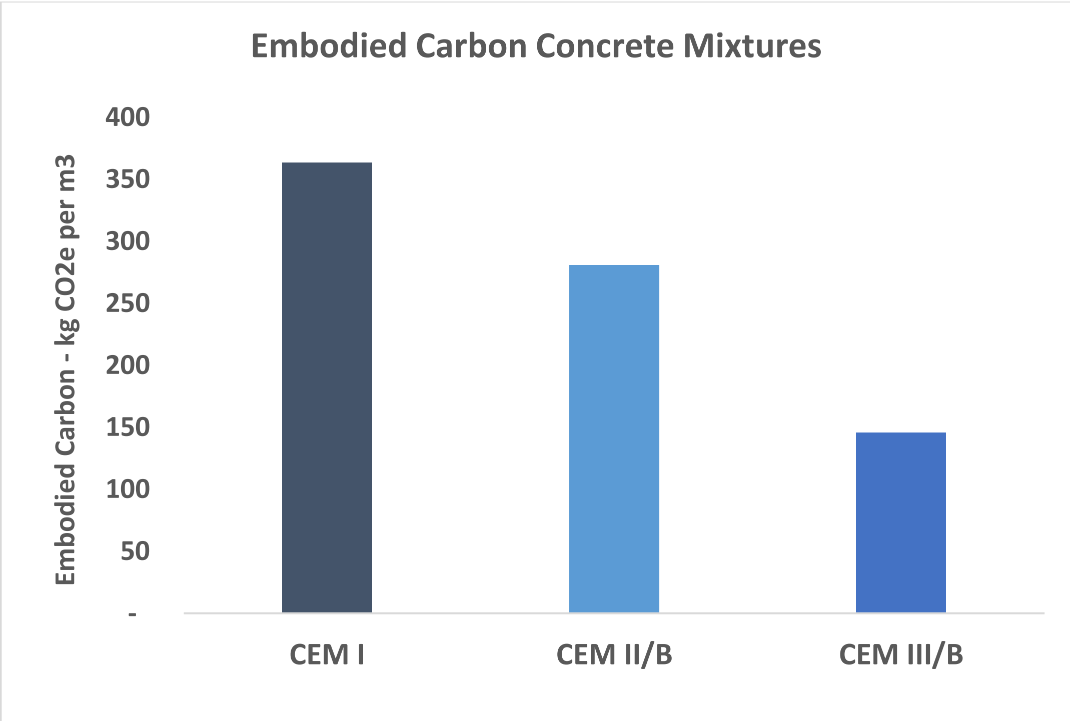

Figure 2. Comparison of embodied CO_2 for concrete using different cement types.

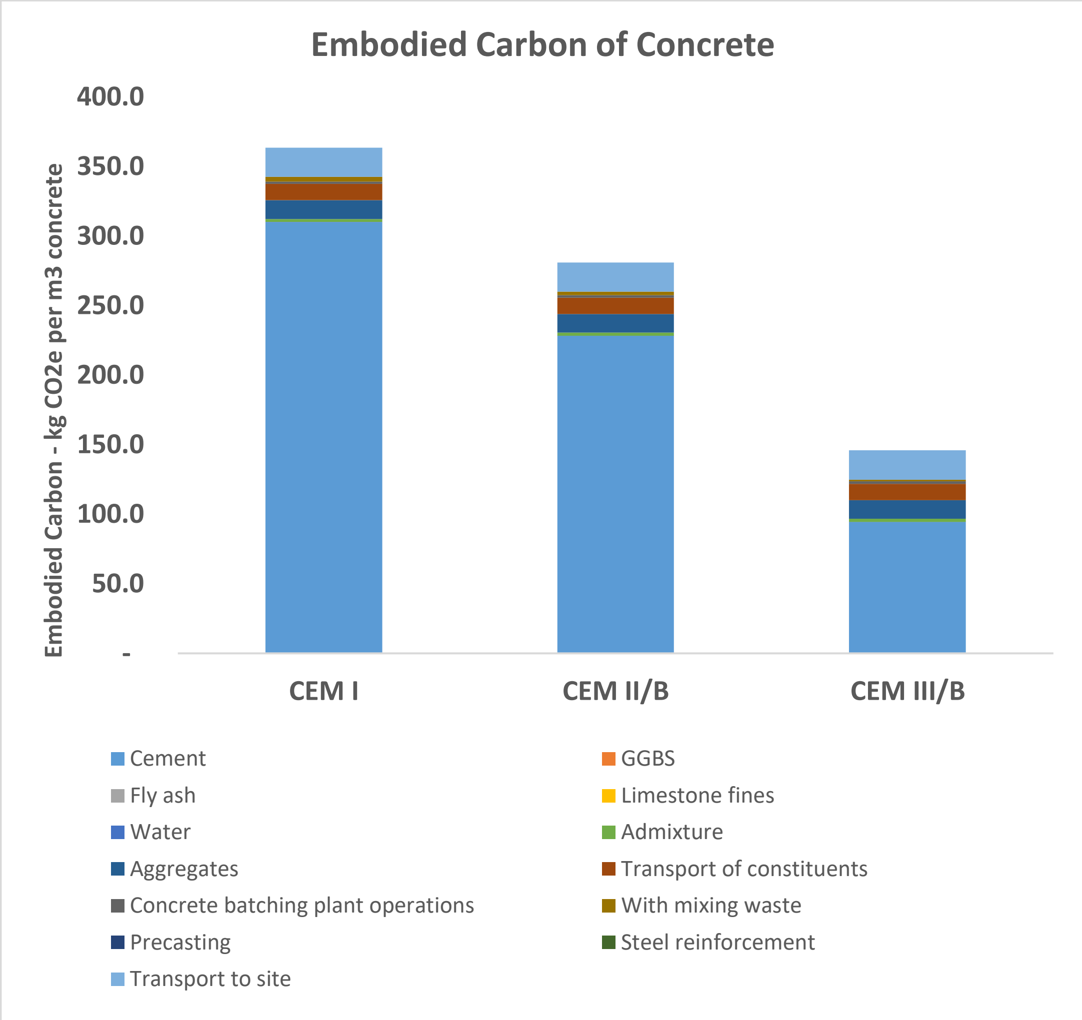

Figure 3. Breakdown of embodied CO_2 by constituent components.

If such large reductions in embodied CO_2 are possible, why aren't they currently used ubiquitously, both in construction generally and acoustics specifically? Speaking from our practical experience as suppliers and installers, there are two barriers to adoption: cost and curing time.

Cost is obviously a factor in a competitive bid, both in terms of concrete suppliers looking to secure business and as an installer looking to win projects. Unless you explicitly state the cement type you are looking for, typically you will receive a price for a CEM I or CEM II/A mix in our experience. To speculate on why this is, it probably comes down to a combination of cost and customer expectations, wherein providing a cost-effective option is balanced with providing a mix that will achieve acceptable early strength; while concrete is specified based on its 28 day strength, in practice there is an expectation of being able to walk on and load out areas on a much shorter timescale than this, which is a challenge for highly blended mixes, as is covered below.

Referring back to figure 1, you can see that "early strength" is listed as "high" for both CEM I and CEM II/A, with "early strength" dropping off as the proportion of OPC replacement rises. Figure 4 below shows the indicative relationship between strength and curing time based on the cement type.

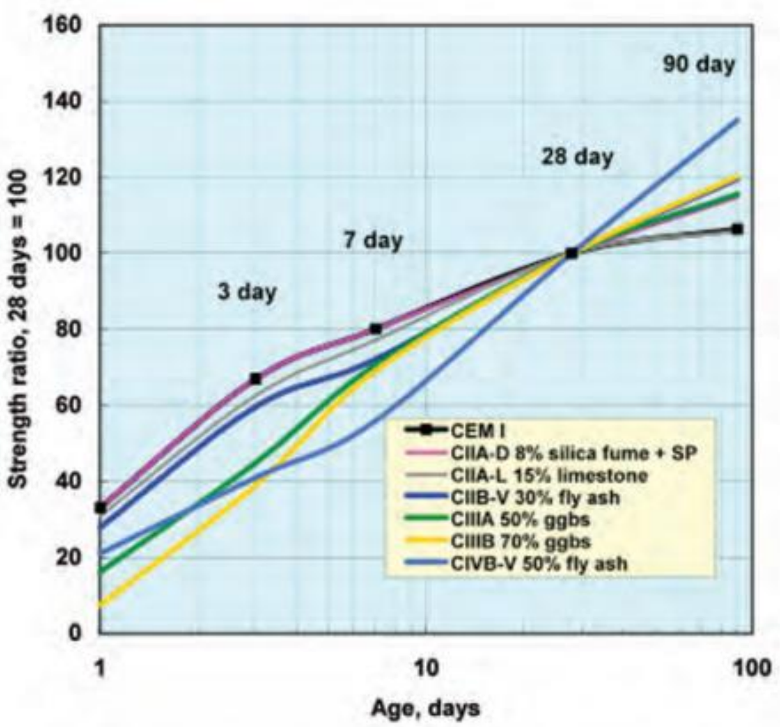

Figure 4. Strength vs. curing time for different cement types[5].

Figure 4 shows that while all types should reach the specified strength at 28 days (with more heavily blended cements actually exhibiting higher long-term strength), the higher OPC content gives significantly higher early strength, which is almost always viewed as beneficial for construction programming. This is especially true for something like a jack-up floor system, where a certain level of strength is needed before the floor can even be jacked-up at all. To give a practical example, it is very common for contractors to expect a floor to poured at the end of one week, with the floor jacked-up and levelled by the end of the following week. This practically means that the 5-7 day curing time is critically important.

With the goal of reducing concrete embodied carbon in mind, material choice is only half of the solution; allowances in terms of both cost and curing time have to be considered at the design and construction programming stages.

3.2 Cement Particle Board

A common heavyweight alternative to plywood for acoustically sensitive applications is cement particle board. With a typical density of ~1200-1500kg/m^3, cement particle board is approximately twice as dense as plywood and significantly more dense than even acoustic rated plasterboard (~840kg/m^3).

Cement particle board is manufactured from a combination of cement, cellulose fibres from wood pulp, sand, and water. From a sustainability perspective, it therefore sits in the middle compared to cementitious and timber materials, with an example GWP_{total} value of 0.200 kgCO$_2$/kg and a GWP_{fossil} value of 0.767 kgCO$_2$/kg[10]. It should be noted that I have used the AMROC EPD to arrive at the above figures, which uses data from the fabrication plant in Germany. The reason for using this data is that AMROC are one of the only manufacturers of cement particle boards in Europe that have published an EPD to date. With that in mind, it should be noted that figures for other manufacturers may differ significantly depending on the source of wood pulp used in production, as well as the cement type used and the local method of power generation, and there are not a lot of other datapoints currently available to compare against.

3.3 Acoustic Rated Plasterboard

Another common heavyweight material is acoustic rated plasterboard, available under a variety of different brand names, such as SoundBloc and Soundshield. The primary difference between standard wall board and acoustic rated boards is their density, with standard British Gypsum wallboards rated at 630kg/m^3 and SoundBloc boards rated at 840kg/m^3 or a 33.3% higher density[11,12].

On a unit mass basis, the figures for standard wall board and acoustic rated plasterboard are very similar, with a GWP_{total} value of 0.137 kgCO_2/kg and a GWP_{fossil} value of 0.214 kgCO_2/kg[13,14]. In other words, for a fixed board thickness, the acoustic rated plasterboard will have approximately 33% higher embodied CO_2, owing to the increased density.

Comparing the values for acoustic rated plasterboard and cement particle boards illustrates the nuances that have to be considered when doing embodied carbon analysis; on face value, the GWP_{total} figure per unit mass is around 46% higher for the cement particle boards. However, looking at the GWP_{fossil} figures shows an even starker difference, wherein the cement particle board is a full 3.6 times worse. Add into that the fact that plasterboard is not recyclable, whereas the recyclability of cement particle boards is still somewhat of an open question, plus the fact that cement particle board has a significantly longer service life than plasterboard and is more resistant to moisture and other environmental damage, it becomes obvious that there is no straightforward answer. The entire lifespan of the installation has to be considered.

3.4 Steel

As outlined in section 2.2, steel production accounts for around 7% of global carbon emissions[2] and 52% of global steel production goes into building and infrastructure[15]. There are two main methods of steel production currently in use; the blast furnace, wherein coke, iron ore and flux (in the form of limestone) are fed into the top of the furnace, with hot flue gas rising from below facilitating the reaction as the material falls downward, and the electric arc furnace, wherein recycled scrap steel is heated by electrodes in a furnace, to which other elements can be added to purify the steel as needed[16].

Currently, the blast furnace method accounts for the majority of global steel production at 71.1%, with electric arc furnace production accounting for 28.6% (other methods account for only 0.3%). This figure though is very region dependent, with some regions producing a significantly higher level of electric arc furnace steel, others a much higher level of blast furnace steel. The UK data for 2023 shows that ~80% of domestically produced steel was manufactured using the blast furnace method[15].

Owing to the reliance on recycled steel as the principal raw ingredient, electric arc furnace steel tends to have a much lower embodied carbon content, with electric arc furnace steel having only around one fifth of the embodied carbon content compared to blast furnace steel. In addition to this, while the global average of blast furnace steel production is ~2kg eCO_2/kg, in practice this varies considerably from foundry to foundry, with some less efficient foundries in China especially estimated to be closer to ~3kg eCO_2 /kg[2].

That being said, there are several issues that prevent electric arc furnaces becoming the principal method of global steel production, chief among which is that there simply isn't enough supply of scrap steel to fulfil global demand[2], meaning that blast furnace production will continue so long as demand outstrips supply of scrap steel.

Compared to all the other materials examined in this paper, steel has by far the highest average level of embodied carbon per unit mass, meaning that it is definitely not recommended as a mass layer material for acoustic systems, and should only be considered as such where there is no suitable alternative, such as for an inertial frame for a clean room environment for example. Owing to the relatively low volume of material required, a steel frame structure may still represent a good option for a low embodied carbon building construction, but that is beyond the scope of this paper.

4 EMBODIED CARBON AT CONSTANT MASS COMPARISON

The last piece of analysis considered in this paper concerns the embodied carbon per unit mass of different materials. This is a useful comparison to make as in a scenario where a certain amount of mass is required to achieve the required level of performance, it would obviously be beneficial to understand the least environmentally damaging way to achieve this.

Figure 5 shows a comparison of different materials and the amount of embodied carbon per square metre to achieve 150kg/m^2 of load, with data taken from the Circular Ecology ICE Database[4], the British Gypsum SoundBloc EPD[14] and the AMROC cement bonded particle board EPD[10]. For the plywood, only the figures without considering carbon capture are used for sake of clarity; the negative value associated with this obfuscates the trend shown by the other data points, in addition to the issues with using this number in direct comparison as mentioned previously in section 2.2. In addition, plate steel has been omitted from the graph for the same reason; the figure is so much higher than any other option at 369 kg eCO_2 that it again obfuscates the comparison of the other materials.

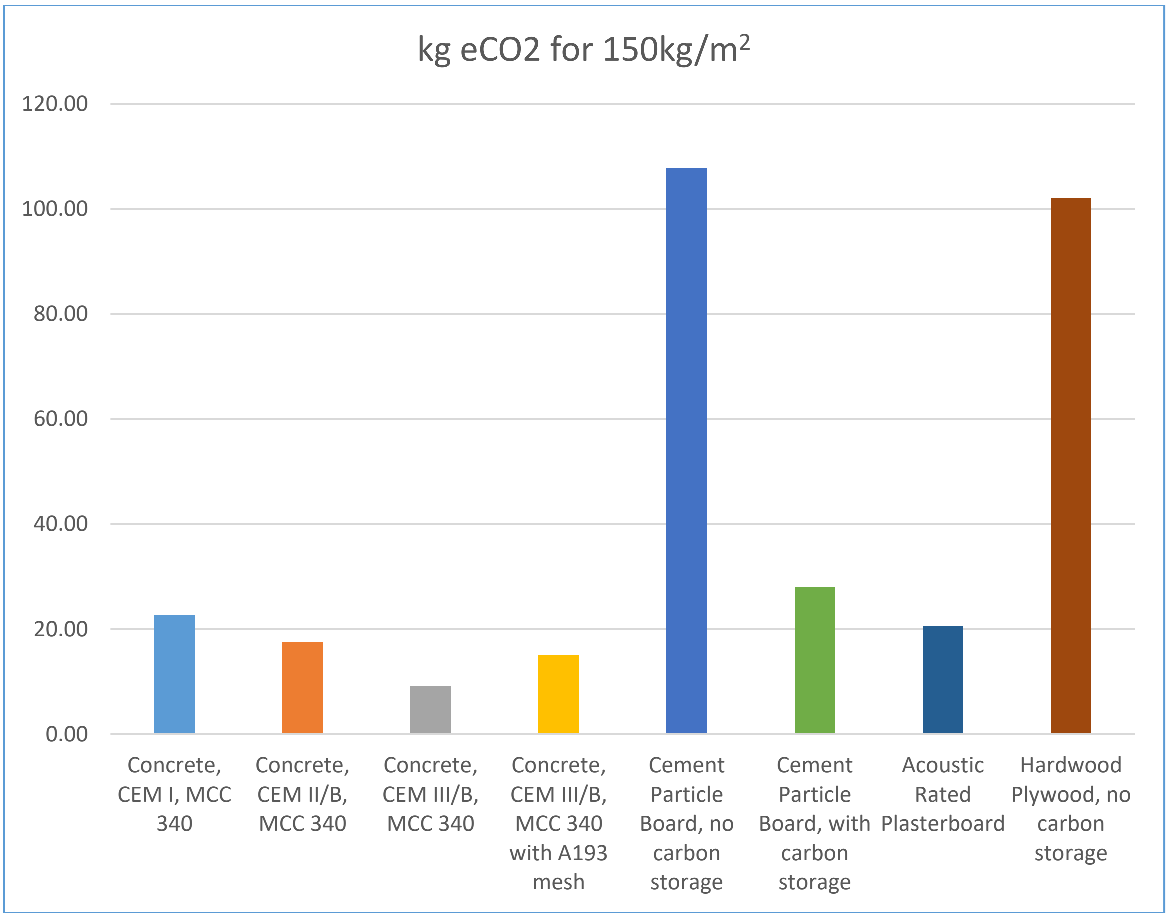

Figure 5. Comparison of embodied carbon at a constant 150kg/m^2 loading.

As demonstrated by the figure above, for a constant mass, concrete with even a moderate blended cement yields the lowest level of embodied carbon. It should be noted that adding steel reinforcing does add a significant amount to the embodied carbon content of the concrete, but even taking this into consideration it still came out ahead of all the other options considered.

5 CONCLUSION

Taking into consideration everything that has been discussed in this paper, there are a few key takeaways. The first is that reduction in embodied carbon of a heavyweight system is no substitute for designing out the need for a heavyweight system wherever possible. Taking another look at figure 5, the key context missing is the material volume required to achieve this level of mass. For the concrete at 2400kg/m^3, a mere 0.0625m^3 of material is actually required, or a layer 62.5mm deep. By contrast, to achieve this level of mass in plywood, 0.23m^3 of material would be required, or a build up 230mm thick. This is obviously an unrealistic construction in practice and the actual use case would be where the additional mass of a heavyweight material isn't required. In addition to this, in practice the thinnest section of concrete you would practically consider pouring is ~80mm deep, which would result in a larger amount of embodied carbon content.

With that said, where a certain level of mass is required, concrete somewhat in contrast to popular perception actually comes out as one of the best options in terms of minimizing embodied carbon content. Couple that with the fact that unlike timber-based materials this carbon isn't released back into the environment at the end of life and it can be recycled as aggregate. There are obviously carbon costs associated with the building demolition in this case, plus the risk of silica dust contamination to the surrounding area, but both are outside the scope of this analysis and remain a topic in merit of future research.

Given the reality that heavyweight materials are an unavoidable necessity in acoustic design, care should be taken in how and where they are deployed, with a view to minimizing embodied carbon by material choice and the associated trade-offs that come with that.

6 REFERENCES

1. https://www.scientificamerican.com/article/solving-cements-massive-carbon-problem/
2. https://www.sustainable-ships.org/stories/2022/carbon-footprint-steel
3. Metsä Wood Birch plywood EPD (S-P-02881)
4. Circular Ecology ICE database V3.
5. https://brmca.org.uk/documents/Cement_Type_Early_Age_Properties_23_Jun_11.pdf
6. https://www.heidelbergmaterials.co.uk/en/ready-mixed-concrete/low-carbon-concrete
7. https://www.aggregate.com/products-and-services/ready-mix-concrete/ecopact
8. https://www.cemex.co.uk/lower-carbon-concrete
9. Circular Ecology ICE Cement, Mortar and Concrete model v1.1
10. AMROC Cement bonded particle boards EPD (S-P-07427)
11. British Gypsum Gyproc WallBoard 15mm Product Data Sheet
12. British Gypsum Gyproc SoundBloc 15mm Product Data Sheet
13. Environmental Product Declaration – Gyproc WallBoard 15mm (S-P-12366)
14. Environmental Product Declaration – Gyproc SoundBloc 15mm (S-P-00509)
15. https://worldsteel.org/data/world-steel-in-figures-2024/
16. https://www.britannica.com/technology/steel/Electric-arc-steelmaking