The Carbon Impact of Buildings' Slabs:
Hotspots, Challenges, and Opportunities

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ABSTRACT: Considering the urgent call to tackle climate change, reducing greenhouse gas emissions from the built environment becomes a priority. Slabs in multi-family houses are responsible for a high share of building's life carbon emissions due to their intrinsic multi-functional nature and high quantity of materials. This research evaluates the impact of the different functional layers within a slab component, compares alternative materials with regards to the functional requirements, and assesses promising solutions in the context of element-based carbon budgets. Life cycle assessment, following established standards, is applied to a representative library of slab components. Results reveal that material choices for the structural layer significantly influence the environmental impact, with wood structure exhibiting five times lower carbon emissions compared to a traditional concrete slab and meeting the most stringent carbon budgets for the structural layer. The screed layer is identified as a significant contributor to the overall impact, holding an important relationship between its thickness and mass and the level of acoustic insulation. Only limited options are available to replace the cement-based screed in its functionality and although the acoustic performance and thickness hold a non-linear relationship, further studies are needed to confidently replace this layer with alternative materials.
KEYWORDS: Carbon, Slabs, Life-Cycle, Emissions, Buildings

1. INTRODUCTION

As underscored in the latest IPCC report [1], the climate is undergoing unprecedented changes with tangible impacts on societies. Urgent and reinforced efforts are imperative to reduce the rise in emissions and mitigate further global warming, necessitating a fast transition towards climate-resilient development. The built environment holds an important role in addressing climate concerns, contributing approximately 40% of annual anthropogenic greenhouse gas (GHG) emissions through both operational and construction activities. Although improvements on the operational side are noticeable [2], mastering the embodied impact remains crucial for achieving overarching climate goals [3]. Within this context, multi-story building's slabs have emerged as a critical environmental hotspot, constituting 12% to 32% of a building's overall carbon footprint due to their extensive surface area, structural function, and reliance on carbon intensive materials [4]. Slabs in buildings serve multiple functions beyond structural support, i.e. thermal inertia, technical systems distribution, and acoustic properties. Given the complexity of this element, the following research questions arise: which functional layers or performance requirements most significantly contribute to this elevated impact? How do alternative materials and design options compare in terms of emissions reduction while meeting performance requirements? Finally, considering element-based carbon budgets [5], which solutions show promise for optimizing the environmental impact of slab elements? In the literature, the topic of slab elements and their environmental contribution is mainly discussed with regards to their structural function [6,7]. A research gap is identified in the relation of other functional requirements of slabs to the overall carbon impact and the challenges of using alternative materials and designs in fulfilling these requirements.

2. METHODOLOGY

To tackle the opportunities of slabs in reducing the environmental impact of multi-family buildings, a first review of existing slab systems and common practices is conducted. This review focuses on systems available in Switzerland such as those proposed in annex D of the SIA 2032 [8] and the lignum database [9] for wood-based structures but the library could be extended with further typologies and the same methodology applied. In a second step, the whole system is decomposed into functional layers following the eCCC categorization [10] to allow a straightforward comparison and to be able to pinpoint the hotspots inside each system. Intermediate slabs are comprised, as shown in *Figure 1*, of a structure (C04.01), a floor covering (G02), and a ceiling finish (G04). The floor covering is further subdivided into support G02.01 (screed and insulation) and finishing G02.02 (ex: parquet or ceramics). The screed serves multiple functions; it provides acoustic mass, it can accommodate the heating distribution, and acts as a levelling layer to prepare for the finishing layer.

Suspended ceilings can contain technical installations and provide a finishing to the lower structure.

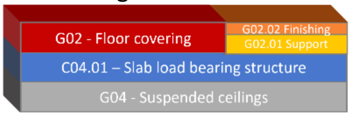

Figure 1: Decomposition of the slab into categories following the eCCC classification.

Then, a comparative life cycle assessment (LCA) is conducted by varying parameters such as thickness and materials. Results are discussed in terms of challenges and opportunities in achieving performance requirements while reducing carbon impacts. Finally, systems are compared with carbon budgets based on allocation of global budgets to Swiss buildings [11] and element-based decomposition [5].

2.1 System boundaries

The slab system, encompassing all layers from the lower to the upper finishing, is considered. Heat distribution is discussed, as floor heating systems are often part of the upper finishing, in terms of screed materials and limitations but no analysis on efficiency or carbon impacts is conducted. Horizontal distribution of ventilation ducts, electrical cables, and sanitary systems are also often integrated in the slab (either directly in the structural layer or in the false ceiling) but displacement in vertical distribution is also possible, therefore impacts are not included in the boundaries for this study. The comparison of solutions throughout the paper is made possible by accounting for equivalent fixed functional requirements and varying one parameter at the time. Functional requirements are defined based on SIA and ISO standards. These can vary depending on the national context and would affect the feasibility of the proposed solutions, but the function to carbon relationships are not affected.

2.2 Carbon impact and storage

Life Cycle Assessment is conducted following the standard SIA 2032. The assessment includes phases A1 to A3, B4, and C1 to C4 as per definition in EN15804. The impact category chosen is GWP100 and the unit is $kgCO_{2eq}$ per functional unit. The quantification of embodied emissions is reported in $kgCO_{2eq}$ per square meter of building element (BE) and year. Emission factors for construction materials are taken from the Swiss KBOB database 2022 version 4 (2023). EPDs or other databases can be used for the analysis to better reflect impact factors outside the Swiss context. The biogenic carbon content of materials, in kgC, is also extracted from the KBOB database and converted into an amount of CO_2 sequestered according to EN 16449:2014. The GWP_{bio} method [12] is also employed for the evaluation of the different systems. The method determines the benefits of delaying biogenic emissions through storage by defining indexes according to lifetime of components (SIA2032 – AnnexC) and rotation of the species utilized. The rotation periods are determined based on literature: 70 years for wood products [13] and 1 year-crop-rotations for fast growing materials.

2.3 Parametrization and analysed variations

The following four main functional parameters have been analysed:

- Structural layer
- Acoustic requirements
- Floor finishing materials
- Heating distribution.

For each parameter, variations in terms of materials and/or thickness have been implemented to grasp the potential opportunities of decreasing the carbon impact while fulfilling the functional requirements.

Thermal requirements are not accounted for as the focus is on intermediate slabs and no specific thermal requirement is specified. An insulation layer is still present but for acoustic performance.

Dimensioning of structural materials for equivalent spans are taken from the Lignum database. Acoustic requirements are evaluated based on ISO norm 12354-1/2 by combining the screed and the insulation layer and by varying thickness and materials. Alternative materials for floor finishings are examined based on commonly built systems. Finally, incorporation of the heating distribution in the screed layer is discussed through different screed materials and thicknesses.

3. RESULTS AND DISCUSSION

Results are presented first as a general overview of the systems commonly implemented in the market and then by comparing alternative materials and/or dimensions with regards to the main functional requirements: structural, acoustical, floor finishings, and heating distribution. Finally, analysed variations are compared with element-based carbon budgets.

3.1 Current practices - overview

Overall, the six slab systems depicted in *Figure 2* are considered as common current practices. The structure typically consists of a 25cm concrete slab or a wood-concrete composite. Alternatively, it can be entirely made of wood, employing a joist system that entails a main structure with robust beams supporting thinner planks to form a solid floor. The ceiling finishing is usually direct paint cover (in the case of a concrete slab) or a suspended gypsum ceiling. The floor finishing is mainly composed by either parquet or ceramics while the support tends to always use a 7cm cement screed with 2cm EPS acoustic insulation.

In new constructions in Switzerland, concrete slabs remain the most widely used system. This is usually due to cost of materials, easier integration of horizontal distribution of systems, and general culture.

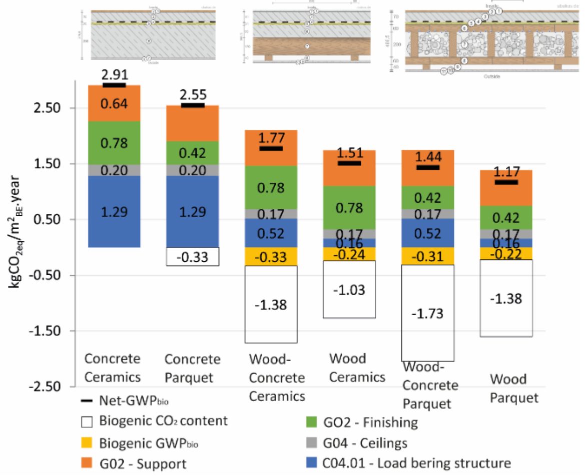

Figure 2: Main slab systems analysed – three structural materials; two types of ceiling; two types of finishing.

A difference of 1.74 $kgCO_{2eq}/m^2_{BE}$.year can be observed in net-GWP_{bio} from the concrete slab with ceramic finishing to the wood slab with parquet, corresponding to a 60% reduction from the standard. The impact of the concrete slabs is dominated by the structural layer while the wood and wood-composite shift their impact to the finishing and the support.

3.2 Structural function

The primary function of the intermediate slab is structural. Designed to withstand vertical loads, slabs also play a crucial role in transferring horizontal forces, such as those induced by wind or seismic activity, to the walls. These walls, in turn, transmit these forces to the foundations. Several parameters come into play for the sizing and selection of a specific type of slab.

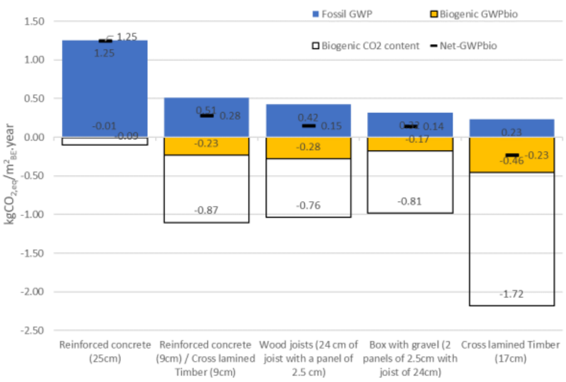

Figure 3: Example of structural layer based on Lignum database for a span of 6m [9].

For equivalent span capability (*Figure 3*), Cross Laminated Timber (CLT) holds five times lower carbon impact than a traditional reinforced concrete system. A wood-concrete composite structure, with a 50/50 ratio, presents an interesting middle option with less than half the impact compared to the base. This system could also be further optimized in its concrete-wood ratio to further decrease its environmental impact. Opting for a wooden structure instead of concrete can significantly reduce Global Warming Potential (GWP), decreasing from 1.25 to 0.23 $kgCO_{2eq}/m^2_{BE}$.year (See *Figure 3*). Additionally, when factoring in biogenic carbon, the environmental benefits become even more pronounced. The biogenic CO_2 content of the systems containing wood surpasses in all cases the fossil GWP and when applying the GWP_{bio} method, the CLT system reaches a negative net- GWP_{bio}, implying a positive impact on the climate.

However, mitigating the carbon footprint of the structural layer extends beyond material choice. Proper structural design is crucial. The thickness of the elements varies depending on the spans, the structural design, and the loads. Reducing the weight of functional layers above the structural layer also contributes to lighter support structures [14].

Furthermore, it must be noted that the dimensioning of the structural layer not always only relates to its structural function. More than half of the commonly implemented 25cm height of the reinforced concrete slab often serves as space for integration of technical horizontal distribution with ventilation ducts' diameters of up to 16cm. Therefore, the impact of the concrete slab depicted in *Figure 3* could be reduced if only the structural requirements were considered.

3.3 Acoustic function

Beyond its structural function, the slab must provide sound insulation. The purpose is to minimize the transmission of airborne noise, which includes sounds propagated through the air, as well as impact noises transmitted through the structure. This function is usually performed by the structure (C04.01) in homogeneous systems and by the support (G02.01) in "sandwich" systems.

For a moderate indoor sound emission, typical of residential and office spaces, with average sensitivity and considering a weighted evaluation level, the accepted values are L' <= 53 dB for impact noise and Di >= 52 dB for airborne noise [15]. For a homogeneous structure, the impact sound level ($L_{n,e,eq}$) and the weighted reduction index (R_w) can be calculated simply using the equation [16,17]:

$$L_{n,e,eq} = 164 - 35\log(m') \quad (1)$$

$$R_w = 37.5\, log(m') - 42 \quad (2)$$

Where m' is the mass per unit area of the structural slab (kg/m²). With the goal of maximising R_w and minimizing L, it is evident the important role that mass has on acoustic performance. Therefore, giving a net advantage to concrete structures (ca. 600kg/m²) in contrast to average wood structures (ca. 120kg/m²).

The decoupling of the screed from surrounding elements and the use of insulating material creates a "sandwich" effect that dampens noise. A poured floating screed, with a flexible intermediate layer, follows the mass-spring-mass principle to prevent the transmission of floor vibrations to the supporting structure and vice versa. These techniques are commonly employed to minimize noise propagation and enhance acoustic comfort within spaces. In this scenario, the level of impact sound is:

$$L_{n,d,w} = L_{n,e,eq} - \Delta L_w \quad (3)$$

To increase impact noise insulation, two crucial parameters are the dynamic stiffness of the insulation material (s’) and the mass of the floating screed (m’) [18] as depicted in the formula for the weighted reduction in sound impact (ΔL_w). Reinforcing, again, the importance of mass (of the screed in this case) to the acoustic performance. Explaining the wide use of thick cement-based screeds (ca. 130kg/m^2).

$$\Delta L_w = 13 log_{10}(m') - 14.2 log_{10}(s') + 20.8 \quad (4)$$

It must be noted that this analysis does not delve into different frequencies and indirect noise effects and the focus is given to direct impact noise attenuation. However, indirect effects, can be significantly mitigated with meticulous planning and well-thought-out connections.

3.3.1 Insulation material

The dynamic stiffness refers to the ability of a material to respond to sound vibrations within a specific frequency range. More specifically, it measures the resistance of the material to deform in response to sound waves. A lower dynamic stiffness indicates an increased ability of the material to attenuate vibrations and, consequently, to provide better sound insulation.

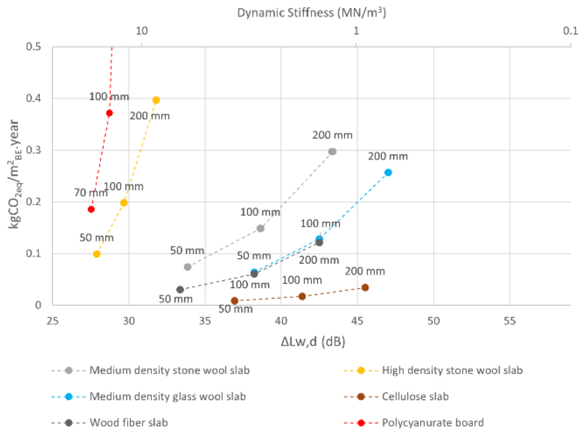

Figure 4: Direct impact sound reduction versus carbon impact for different insulation materials with a concrete slab and a floating screed [19].

The dynamic stiffness involves considering the Young's modulus, the thickness of the insulating material, the airflow resistivity, and the density. Generally, the greater the material thickness and density, the higher the dynamic stiffness, consequently resulting in higher carbon impacts.

Using wood-based materials, such as cellulose, proves beneficial. In addition to a favourable carbon footprint, cellulose offers good acoustic insulation with a low thickness. For instance, choosing a cellulose insulation of 50mm thickness instead of the commonly used stone wool reduces carbon emissions by 0.07 kgCO_{2eq}/m$^2_{BE}$.year and increases acoustic insulation by 3dB. This not only ensures lower environmental impact but also enhanced acoustic performance (see Figure 4). Finally, it is worth noting that not all materials present the same slope and that the thickness is not linearly correlated to the acoustic reduction.

3.3.2 Screed thickness

It has been observed that increasing the thickness of the screed has only a minimal impact on acoustics beyond a certain thickness [7].

30 MN/m^3 represents the maximum dynamic stiffness limit for insulation materials according to the standard. Dynamic stiffness between 6 MN/m^3 and 9 MN/m^3 are typical values for glass wool of 30mm, with different densities. However, specific values from suppliers are often challenging to obtain.

Thus, it can be observed that for the same weighted reduction in sound impact of ΔL_w=35 dB, with s’=6 MN/m^3 the screed has a thickness of 46 mm compared to 73.1 mm with s’=9 MN/m^3. This result decreases the carbon emissions from 0.26 to 0.17 kgCO_{2eq}/m$^2_{BE}$.year, translating to a 0.09 kgCO_{2eq}/m$^2_{BE}$.year reduction for the same level of insulation depending on the insulation material and reducing the screed thickness (*Figure 5*).

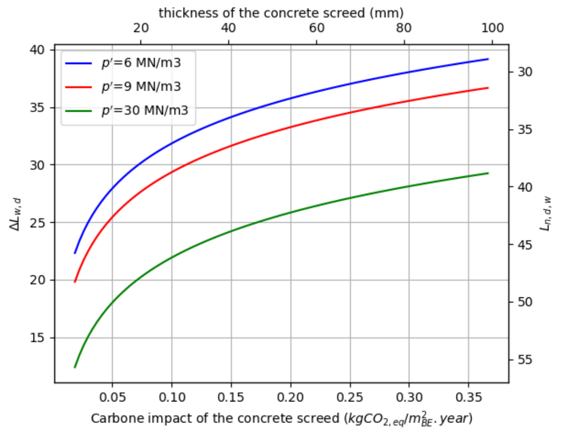

Figure 5: Direct impact sound reduction level comparison for a concrete screed in a floating floor for different dynamic stiffness of the insulation.

It's also interesting to note that the choice of finishing can significantly impact the total load exerted on the structure. Minimizing thickness of the screed is advantageous. A lighter screed allows for a smaller structure as it needs to support less weight. Reducing the weight of the screed contributes to lowering both the carbon footprint of the screed and that of the overall structure. Although accepted values for direct impact noise are below 53 dB, indicating that the thickness could potentially be drastically reduced, it must be noted that a minimal thickness of 40mm for cement-based screed is defined in the SIA 251 to avoid the risk of cracks.

Screed's materials are not compared in terms of acoustic performance in this article, but acoustic insulation depends on mass. Anhydrite screeds have a better volumetric mass. Thus, at equal weight, potentially similar acoustic insulation can be achieved, leading to a better carbon footprint with a lower thickness (kg/kgCO_{2eq}: 0.12 for concrete vs. 0.09 for anhydrite).

Other initiatives in the market are currently being proposed and evaluated such as earth-based materials which is promising in providing the necessary mass and low carbon impact, but a lack of acoustic studies has been observed to confidently assess its implementation.

3.4 Finishings

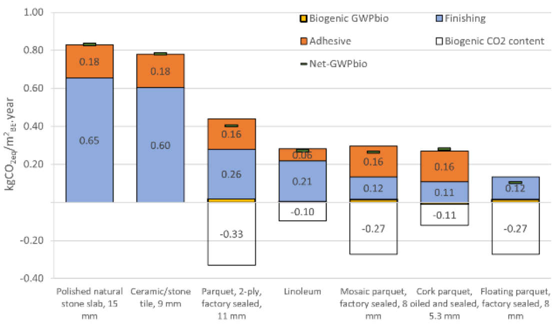

Figure 6: Variations of the finishing layer.

In terms of fossil carbon emissions, linoleum has less impact than certain types of parquet. Choosing parquet over ceramic saves approximately 0.5 kgCO_{2eq}/m^2_{BE}.year (see *Figure 6*), a noteworthy reduction. Homes often incorporate a mix of both materials to leverage the benefits of ceramics in bathrooms or kitchens, but minimizing the use of ceramic is worthwhile to decrease the overall carbon footprint.

Adhesives significantly contribute to the carbon footprint. With a floating floor, the carbon impact of the finishing decreases over 0.16 kgCO_{2eq}/m^2_{BE}.year. However, it is not compatible with floor heating systems.

3.5 Heating distribution

In addition to providing floor levelling, a screed can incorporate the heating distribution. For this purpose, various types of screeds are possible.

Anhydrite screeds are increasingly being employed as alternatives to cement screeds. However, their installation can be more challenging due to a longer drying time and precise condition requirements. Nevertheless, thanks to their increased strength, they provide the advantage of being able to achieve reduced thickness.

A dry screed, despite its thin thickness, can still have a significant carbon impact (*Figure 7*). But it avoids the need for a drying period, as the entire construction process is dry.

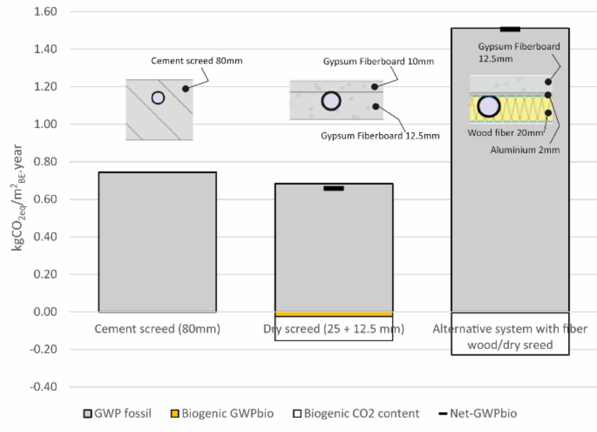

Figure 7: Systems to integrate heat distribution in screed.

3.6 Carbon Budgets

Looking at the next decades and considering carbon budgets until 2050 reveals the precarious position of concrete slabs, becoming obsolete towards the 2040 budget. More importantly, common finishings already face obsolescence now, necessitating a focused examination of these materials and designs (*Figure 8*).

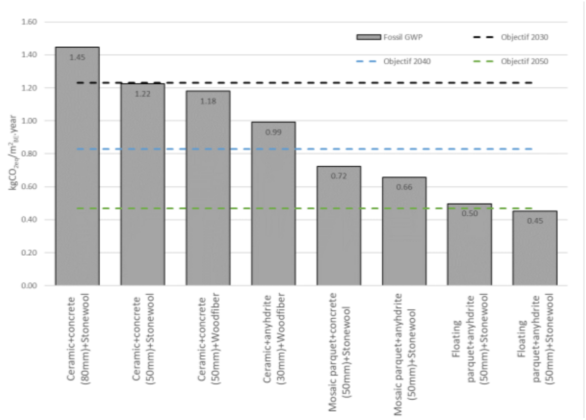

Figure 8: Comparison of finishing systems impact with finishing layer carbon budgets for 2030, 2040, and 2050.

4. CONCLUSION

In conclusion, the identified hotspots in a multi-family house intermediate slab underscore the critical role of this element. The structural layer being on the forefront of the overall impact in case of commonly used reinforced concrete slabs but being surpassed by floor finishing in case of wood-based structures with the screed layer resulting in a determining layer in the slab both for its function and its carbon impact.

Considering these hotspots, the main challenge lies on the fact that heavier structures (ex: concrete structure with cement-based screed) tend to have improved acoustic insulation, making the definition of alternatives a considerable hurdle. The complexity of functional requirements (acoustic insulation, heat distribution) for the screed, a lack of comprehensive data from the suppliers, and limitations on the assessment methods impede the implementation of alternative materials and reduced thicknesses for the finishing layer. The highest challenge, in terms of carbon budget lies in the other functional layers (finishings) with current systems surpassing the budget by circa 20%.

Nevertheless, this study highlighted some preliminary opportunities to decrease the carbon impact of slabs by up to two thirds compared to traditional systems. Notably, the 7cm cement-based screed is usually used for its acoustic insulation ability but the study reveals that reducing the thickness has minimal impact on acoustic performance but a high reduction on carbon impact (logarithmic relationship).

In light of these findings, a call for a more integrated and holistic approach to address all functional requirements of slab elements in multi-family houses becomes imperative. This shift is crucial to recognizing the challenges, fully understanding and implementing the opportunities available, and ensuring a smooth transition to a net-zero built environment.

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