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Is floor vibration serviceability problem solved for good by commercial active mass dampers?

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Abstract

Historically, structural engineers designing buildings dealt with many structural design uncertainties through the generous use of cheap construction materials, as no better approach existed. This paper identifies numerous uncertainties related to floor vibration serviceability, which has become a de facto governing design criterion for modern floors worldwide, influencing their size and shape.

With the need to stop wasting construction materials in the context of the climate emergency, and considering the uncertainties that can render floor vibration design predictions unreliable and useless, this paper also introduces CALMFLOOR®, a new active mass damping technology specifically designed to control the vertical vibrations of floors in buildings. Launched in the UK as recently as 2022, it is potentially a game-changer.

The mass-produced CALMFLOOR® mechatronics product enables structural engineers to minimize the weight while maximizing the span of floor structures in buildings without compromising the floor's vibration performance. It also allows for the quick and easy conversion of existing regular lightweight low-frequency floors into floors with much stricter vibration requirements, such as in laboratories, without any structural intervention.

CALMFLOOR® operates like noise-cancelling headphones, just on a large floor scale suppressing floor vertical accelerations with much lower frequencies compared with noise. It is a powerful tool that finally enables owners, architects, and engineers to approach the vibration serviceability design of floors rationally. Excessive floor vibrations perceptible by humans are normally caused by tiny levels of structural movement of only a few microns. Such small levels of vibration do not warrant significant structural intervention to control them, which has been common practice for the last 70 years around the world. Instead, CALMFLOOR® could and should be used.

CALMFLOOR® offers unprecedented levels of flexibility when managing floor vibrations, as it is an off-the-shelf mass-produced technology that can be deployed at short notice and only at floor vibration 'hotspots' after the building handover when the tenant and their needs are known.

CALMFLOOR® is rapidly gaining acceptance and is currently installed and operating successfully in Europe and North America.

CALMFLOOR
ACTIVE VIBRATION CONTROL

IS FLOOR VIBRATION SERVICEABILITY PROBLEM SOLVED FOR GOOD BY EMERGENCE OF COMMERCIAL ACTIVE MASS DAMPERS?

Aleksandar Pavić[1]

Summary:

Historically, structural engineers designing buildings have tended to address many structural design uncertainties through the generous use of inexpensive construction materials, as no better approach existed. This paper identifies numerous uncertainties related to floor vibration serviceability that have become a de facto governing design criterion for modern floors worldwide, influencing their size and shape.

With the need to stop wasting materials and the acknowledged uncertainties that can render floor vibration design predictions unreliable and useless, the new active mass damping technology recently launched in the UK is potentially a game-changer. The mass-produced CALMFLOOR® mechatronics product allows designers to avoid both the use of additional materials and the need for significant structural modifications, such as the reduction of precious spans, simply to control minor but highly perceptible floor resonant vibrations.

Key words: floor vibration serviceability, partitions, active mass damper, floor occupants

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1. INTRODUCTION

The present climate emergency necessitates a serious and rapid rethinking of how the construction sector operates worldwide. The construction and operation of buildings, along with the construction industry in general, currently generate 39% of the 42Gt CO2e of all annual carbon-equivalent emissions in the world. Of these emissions, 28% are attributable to buildings (construction and operation) and 11% to the rest of the construction industry. A good estimate [1] is that 10% of all worldwide annual emissions, i.e., a staggering 4.2Gt CO2e, result from structural engineering decision-making. This should be viewed in the context of the enormous size of the construction sector, which creates and maintains the human-built environment and provides millions of jobs, generating 13% of the world's Gross Domestic Product (GDP) [1]. However, in the process of doing this, construction very clearly also destroys the environment.

The UN Environment and International Energy Agency [2] estimates that the total building floor area on Earth will roughly double by 2060, adding 230 billion m² of new floors. This is equivalent to adding one Paris to the planet every week for the next 38 years! This fact emphasizes the importance of building floors in the generation of CO2e worldwide. On average, constructing one m² of a typical modern and very carbon-efficient building floor in a multi-storey building requires, at best, 250kg CO2e, often in practice - several times that. Therefore, to create 230 billion m² of floors in the next 38 years, a total of at least 57.5Gt CO2e is needed. This is more than what the entire world consumes in a single year. On average, this amounts to about 1.5Gt CO2e per year, just over a third of the aforementioned 4.2Gt CO2e for which structural engineers around the world are responsible annually. This represents about 3% of the total CO2e emissions generated annually by the entire world—just to build the floors needed for the growing human population demanding more quality space. For comparison, commercial aviation is responsible for about 2-3% of global carbon emissions, roughly the same amount as the construction of building floors. However, public perception is that commercial aviation is much more environmentally damaging than the construction of building floors. This may change very soon to a huge detriment to the reputation of the construction sector.

Therefore, as building floors are omnipresent and by far the most common type of civil engineering structure, the key question is: how are modern floors in buildings designed? Considering the vast floor area that needs to be built globally, any even small waste in the embodied carbon per m² of the floor should be identified, as it could lead to enormous waste on a global scale. Such identified waste should be addressed and eliminated through immediate changes in design or construction practices.

There are many types and classifications of building floors. Classifications exist based on construction materials (concrete, composite, timber, etc.), construction methods (in-situ cast, pre-cast, modular), ownership (private, commercial, mixed), and types of utilization (offices, assembly structures, condominiums, retail, laboratories, schools, hospitals, gyms, etc.).

Among these, commercial and assembly floors (offices, retail, airports, etc.) are particularly important as they typically require above-average embodied carbon (CO2e) while constituting a considerable proportion of all floors. For example, in the UK alone, over 1 million m² of new office floors are built each year. In the USA, an order of magnitude more space. The function and commercial viability of such floors dictate that they tend to be open-plan, long-span, and increasingly lightweight. Consequently, such floors have low stiffness, low natural frequencies, low damping, and low mass. This, in turn, means that they are increasingly prone to high vibrations caused by footfall dynamic forces due to the omnipresent walking of human occupants on such floors.

Vibration performance of building floors in response to human-induced footfall dynamic loading, typically walking, is by far the most widely considered vibration serviceability requirement worldwide. It has rightly become a governing design criterion due to the growing number of reported problems with excessive vibrations in floors that already meet safety requirements for strength and fire resistance as well as thermal and sound insulation comfort requirements. Not surprisingly, over the last 10 years, I have published dozens of technical and scientific papers with my researchers and collaborators dealing with the vibration serviceability of civil engineering structures, mostly focused on human-induced dynamic loading, such as walking on floors. The opening sentence of such papers typically reads:

> *"With the advent of stronger and lighter construction materials and advancements in construction technology, vibration serviceability has become a governing design criterion for lightweight and slender civil engineering structures occupied and dynamically excited by humans."*

This means that vibration, rather than strength considerations, determines the size and shape of office floor structures. This, in turn, dictates the carbon footprint of the floor structure, which typically accounts for 60% of the total weight of a multi-storey building.

So, how are low-frequency floors designed today to avoid excessive vibrations?

2. THE PROBLEM WITH DAMPING AND MASS

Design guidelines used worldwide [3, 4] invariably assume that human walking can cause a 'low (natural) frequency floor' structure to vibrate excessively in resonance. In resonance, the calculated floor acceleration response is inversely proportional to both the modal damping ratio and modal mass [3]. While modal mass can at least be estimated (modelled) directly via physical mass, damping can never be predicted; it can only be estimated from real-world measurements.

It is no surprise, then, that when checking floor vibration performance, there is often a scramble for evidence supporting the use of a high damping ratio to reduce the calculated response. Simply increasing the damping ratio from, say, 1.5% to 2.5%

reduces the calculated vibration response by a whopping 40%! A previously failing floor now passes with flying colours.

Interestingly, similar questions are not usually asked about modal mass. Because the modal mass values are generated by a formula or computer modelling, they are perceived to be more 'reliable' and less questionable and amendable. Modal mass comes from a calculation, whereas the modal damping ratio is assumed based on design guidelines and experience. Thus, there is a perception that the modal damping value is more 'flexible' to interpret and assume than its modal mass counterpart when it comes to calculating the resonant response.

However, those who—like me—have spent their professional lives not only modelling but also, whenever possible, dynamically testing full-scale floors (and comparing the two sets of data) know that modal damping ratio and modal mass are both highly unreliable floor vibration modelling parameters. Moreover, they are quite difficult to measure and correlate with their counterparts used in calculations. Hence, every time I use the assumed value of the modal damping ratio and the calculated value of modal mass to determine the floor's resonant response, I worry about how different they could be in reality after the floor is constructed. Yet, as nothing better is available, we all keep using them in a vertical acceleration response calculation procedure that is overly sensitive to their values.

3. HOW MUCH DOES GOOD FLOOR VIBRATION COST?

As previously mentioned, and quite surprisingly, in the case of omnipresent open-plan and long-span floors, it is not the *strength* (i.e., the threat of structural failure) but vibration (i.e., the threat of excessive dynamic motion) that dictates the size and shape of such structures nowadays. When I discuss this with laypeople, they are often perplexed that anything other than serious structural failure and threat to life can dictate the use of literally millions of tonnes of additional construction materials and associated embodied carbon to control structurally non-lethal vibrations. Frequently, in such discussions, I am asked a simple question: how much more material and embodied carbon is needed just to achieve satisfactory floor vibrations?

Here is an example illustrating the answer to this important question.

3.1. DOUBLING FLOOR WEIGHT TO CONTROL ONLY TINY FLOOR VIBRATIONS

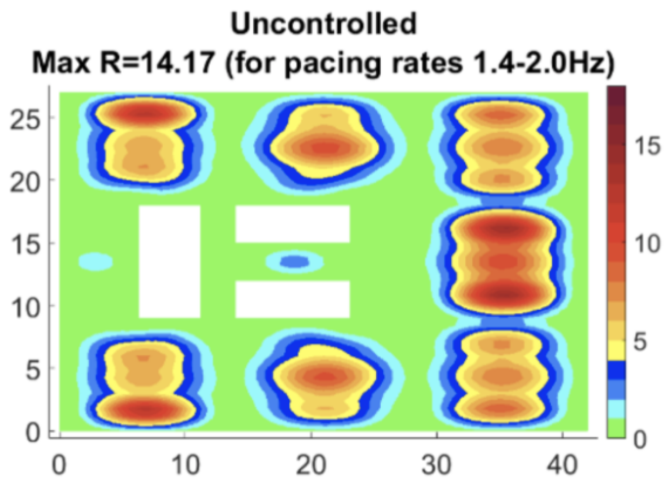

Figure 1: Uncontrolled floor designed for minimum weight satisfying all design criteria apart from vibration serviceability.

Figure 1 shows the contour plot of the so-called response factors

[3] due to walking over a 42m long and 27m wide (1,134m^2) floor plate consisting of nine floor panels, each spanning 14m and being 9m wide. This represents a typical long-span composite steel-concrete floor commonly found in many modern commercial buildings in the UK and internationally. The floor, featuring the usual 14m long secondary beams to minimize the number of beam-to-beam connections, was optimised to have minimum weight and structural depth while satisfying all design criteria (strength, deflection, fire resistance, thermal comfort, and sound insulation) apart from vertical floor vibrations.

The maximum vertical vibrations allowed were set to a response factor R<4, as appropriate for an office in accordance with the relevant, respected, and widely used international standard ISO 10137 [5]. In the UK, R<4 would be a criterion required for a 'quiet office'. The floor's 130mm deep lightweight concrete deck, beams, and columns had an admirably low mass of 231kg/m^2 and an equally very reasonable embodied energy of only 201 kgCO2e. However, as Figure 1 shows, about 25% of the floor area (warm-coloured) had R>4 with the maximum R>14. The structurally very efficient and lightweight floor clearly failed the vibration serviceability check.

The usual structural modifications followed to improve the floor's vibration performance by increasing the sizes of the structural elements of the floor while keeping the spans intact. After many iterations, a floor structure with minimum weight and depth emerged once again, but this time satisfying the R<4 criterion over 99% of its area. However, the mass of that structurally modified floor almost doubled to 452kg/m^2, with the total floor depth being 260mm greater and embodied carbon 30% higher just for the floor structure. This is before considering the increased costs of larger vertical support elements, foundations, construction, and decommissioning due to the significantly greater mass of concrete in particular needed. Additionally, a typical multi-storey commercial building featuring floors like this would lose one entire usable floor level every dozen or so levels. The colossal consequential costs of structural modifications to meet the R<4 floor vibration serviceability requirements, which equate to a peak dynamic displacement of only around 20µm (micron, i.e., 0.02mm) for a 6Hz floor, are hardly acceptable.

So, is there a better way?

3.2. 4<R<8 CAN AND DID CREATE EXCESSIVELY LIVELY FLOORS

A common approach is to relax the floor vibration serviceability requirement from R<4 to R<6 or R<8. However, over the years, I have encountered many problematic floors with vibration levels falling within the range of 4<R<8, resulting in unhappy tenants. Similar issues have been reported by others as well. I have found little peer-reviewed scientific evidence justifying vibration levels above R>4 for offices. Therefore, the decision to use R<8 for offices appears to be driven primarily by the prohibitively high environmental and financial costs associated with achieving R<4.

Nevertheless, the range of 4<R<8 has somehow become a de facto norm, with an expectation that floors within this range will perform adequately. However, there is a risk of complaints under certain conditions, indicating the need for further scientific research to provide clarity.

In a 2015 survey, the Institution of Structural Engineers (IStructE) gathered evidence suggesting that building floors designed to be compliant with guidelines, yet falling within the range of 4<R<8, may exhibit disappointing vibration behaviour.

Having all this in mind, what is then the way forward when: a) meeting R<4 criterion is prohibitively expensive, and b) not meeting R<4 can easily create an unduly lively floor attracting complaints and which is difficult to let and eventually fix?

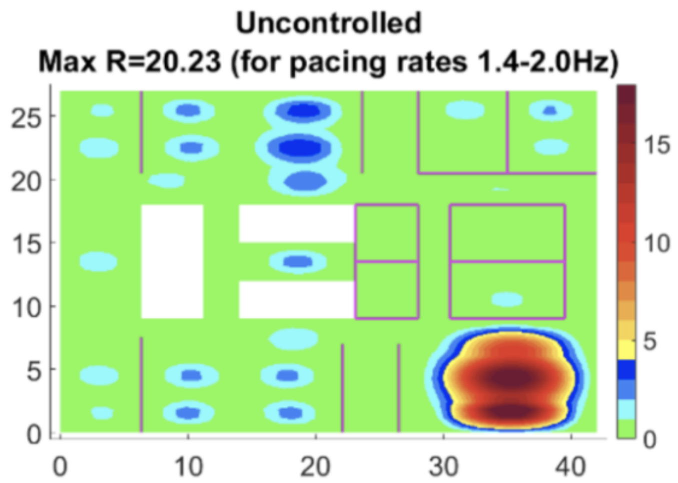

Figure 2: The original lightweight composite floor not satisfying vibration serviceability, but with floor partitions modelled.

Figure 2 depicts the same floor as shown in Figure 1, now featuring full-height non-structural partitions outlined in pink. While these partitions are typically present in every office, their stiffness is often overlooked in calculations, despite a growing body of peer-reviewed evidence indicating that their effects can invalidate assumptions made for bare, unpartitioned floors. This is a common experience for those who have witnessed a lively composite floor transform into a well-behaved floor in partitioned areas as soon as the partitions are erected.

In our example, we modelled the vertical stiffness of the outlined partitions using simple vertical springs, based on recommendations found in peer-reviewed publications [1, 7]. As expected, the partitions effectively suppressed vibrations in the partitioned areas. However, they also *unexpectedly amplified* vibrations in the unpartitioned, open-plan section of the floor, resulting in a maximum R-factor increasing from about 14 to exceeding 20! While it is known that unpartitioned areas of the floor tend to be lively, such a significant amplification of the vertical floor vibration is a surprising result.

Upon comparing the contour plots in Figures 1 and 2, it becomes evident that the response factors in the unpartitioned area of the floor (bottom right corner) are almost 50% greater when considering the presence of partitions. This challenges the common belief that neglecting partitions is a 'safe' assumption. This finding may raise concerns among many colleagues, as it certainly does for me.

3.3. OTHER PROBLEMS

There are additional sources of uncertainty in response predictions. For instance, I conducted tests on an open-plan floor occupied by as many as 120 people, where conventional calculation formulas typically assume only a single person walking and causing resonance. However, it is common for occupants in such offices to walk simultaneously and closely together, potentially resulting in greater responses than those caused by an individual walker. While this observation is anecdotal, there is currently no peer-reviewed evidence supporting it.

Footbridge design guidelines have been addressing multi-person loading for over a decade, taking into account the likelihood of pacing frequencies aligning with the natural frequency. However, floor design guides often retain outdated assumptions from 30 to 40 years ago, including the assumption of a single person walking. The rationale behind this has been that the conservative assumption of perfectly achieving resonance would offset the unconservative assumption of a single pedestrian, resulting in an acceptable outcome. However, pass-fail criteria suitable for ultimate limit state calculations still dominate floor vibration serviceability assessment, despite the preference for a more nuanced and informed probability-based approach that considers likely day-to-day operations.

Most importantly, the climate emergency necessitates a departure from business as usual in the structural engineering profession. Simply increasing the mass and/or stiffness of the floor to control minute footfall-induced vibrations in low-frequency floors is no longer a sustainable design option, considering the vast amounts of construction materials and embodied energy involved.

4. THE BIG QUESTION

So, given all this, the fundamental question arises: why do we persist in designing ubiquitous low-frequency floor structures relying on uncertain structural parameters and unreliable loading models? The mounting evidence suggests that this approach often falls short and is woefully inadequate for addressing the challenges posed by the climate emergency.

In partitioned areas of the floor, responses frequently turn out to be significantly lower than calculated, while in unpartitioned areas, they can easily exceed expectations. Attempting to control low-frequency floor resonance by simply adding mass and stiffness is fundamentally flawed for such small dynamic displacements, especially when damping offers a far more effective solution. Every textbook on structural dynamics underscores the importance of increasing damping rather than mass and/or stiffness to mitigate resonant vibrations.

So, why not veer away from this conventional path and instead start designing floor structures without prioritising vibration serviceability?

In this paradigm shift, we optimize floor structures for minimal embodied energy while ensuring compliance with strength, deflection, concrete cracking, fire safety, sound insulation, thermal comfort, and any other relevant criteria—except footfall-induced vibration. We disregard footfall vibrations entirely when determining spans and sizing structural elements.

After all, what's the point of designing low-frequency floor structures for vibration serviceability when we're well aware of the following:

- Significantly more materials, possibly up to 100%, would be required to achieve a code-compliant design for vibration serviceability. This would severely impact material utilization and compromise the environmental sustainability of the building. This is so considering that approximately 60% of the total mass of multi-storey buildings is above ground level and is attributed to floors, as previously mentioned.
- Even when a floor structure is designed for acceptable vibration serviceability, uncertainties in damping, inappropriate footfall loading models, and the influence of partitions can render the design calculations meaningless compared to the actual behaviour of the floor post-construction.

Admittedly, neglecting vibration serviceability in structural design would result in a slender floor that might exhibit some bounce under footfall dynamic loading, as illustrated in Figure 1. While such a floor would be safe and sustainable, it may not entirely serve its intended purpose.

So, what's the alternative?

Figure 3: The alternative – the 67kg CALMFLOOR AMD attached to a steel I-beam supporting a composite steel-concrete deck. Courtesy of FSD Active Ltd.

The constructed lightweight and lively floor would subsequently be fitted with partitions and other non-structural elements (installations, facades, furniture, etc.). These additions often significantly improve the floor's vibration performance in partitioned areas, albeit unpredictably upfront. This transformation is familiar to anyone who has observed the fitting out of an initially lively floor, which then becomes solid in partitioned areas. While large non-partitioned areas may remain lively and necessitate vibration control, this typically represents only a fraction of the total floor area. This approach minimizes the need for structural modifications throughout, thus reducing the annual wastage of millions of tonnes of steel and concrete worldwide.

5. A SOLUTION FOR THE 21ST CENTURY: SOPHISTICATED VIBRATION ANALYSIS COUPLED WITH THE NEW CALMFLOOR® PRODUCT

Pouring excessive amounts of steel and concrete into floor design contradicts the principles of lean design, especially in today's climate emergency. The current approach to floor design is often wasteful and unsustainable.

There is a pressing need for innovative solutions to address resonant vibrations in floors more effectively. As mentioned earlier, increasing damping is the most efficient method to reduce resonant vibrations, achievable through passive or active technologies.

Following multi-million-pound investments in years of research and development, UK-based start-up FSD Active Ltd has introduced CALMFLOOR®, a groundbreaking Active Mass Damper (AMD) mechatronics device, as the first solution of its kind to permanently resolve the issue of lively low-frequency floors (see Figure 3). This technology represents a significant advancement in floor vibration control, offering a promising avenue towards more sustainable and efficient building practices.

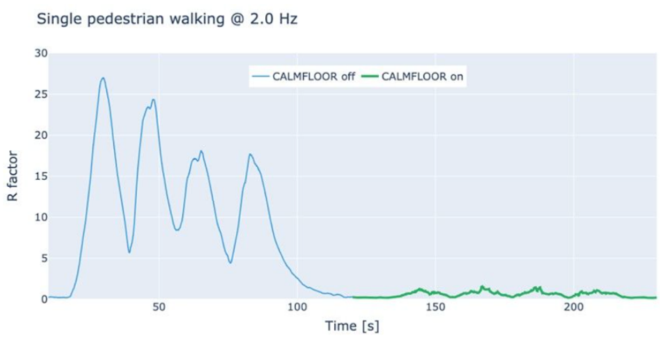

Figure 4: CALMFLOOR performance on a real-life open plan office floor achieving vibration reduction of over 90%.

5.1. ACTIVE VS. PASSIVE COMMERCIALLY AVAILABLE TECHNOLOGY FOR REDUCING FLOOR VIBRATIONS

In essence, any type of AMD device has the potential to revolutionize floor design by allowing for the creation of exceptionally slender structures that maximize the efficient use of construction materials. This innovation eliminates the need to excessively shorten spans to meet stringent vibration criteria, ensuring exceptional vibration performance for long-span, open-plan, low-frequency commercial floors (refer to Figure 4). This level of performance is virtually unattainable with existing commercially available passive methods like constrained layer damping materials and tuned mass dampers (TMDs).

How is this possible?

The CALMFLOOR® device achieves its remarkable performance (see Figure 4) by employing an innovative active control mechanism. By generating an active force proportional to the velocity of the floor structure it is attached to, CALMFLOOR® effectively increases damping simultaneously in all modes of floor vibration it controls. This results in a substantial damping ratio of typically more than 10%, a level far surpassing anything currently available commercially on the market.

When integrated into the design of a new building, this autonomous mechatronics device has the potential to replace tens to hundreds of tonnes of traditional construction materials like steel and concrete. This is primarily due to its ability to increase damping by five or more times, which would traditionally require an equivalent increase in floor modal mass—something practically impossible with conventional methods. The breakthrough CALMFLOOR® technology makes this level of damping enhancement achievable for the first time, offering a transformative solution for floor vibration control in commercial structures.

5.2. CALMFLOOR® TECHNOLOGY EXPLOITS SPECIFICS OF FLOOR VIBRATION PROBLEM

The CALMFLOOR® AMD leverages a fundamental yet often overlooked principle: the very small oscillatory displacements of floors caused by individual walking dynamic forces, typically around only 100-200 N. This mechatronics device continuously detects floor vibrations and applies similar force levels to counteract them. In essence, it functions as a large-scale equivalent of noise-cancelling headphones.

Additionally, the CALMFLOOR® technology addresses several key challenges that have limited the wider adoption of passive floor vibration control technologies:

1. **Simultaneous Control of Multiple Modes**: CALMFLOOR® can effectively control multiple modes of floor vibration simultaneously, which is essential for floors that typically have closely spaced modes due to structural symmetry and repetitive geometry. In contrast, TMDs can only control a single mode, potentially requiring multiple TMDs for different modes, which may lead to performance issues due to interactions between TMDs.
2. **Mass-Produced Uniformity**: CALMFLOOR® devices are identical and mass-manufactured, whereas TMDs are custom-built for each floor and mode.
3. **Consistency in Performance**: Unlike TMDs, CALMFLOOR® devices cannot be detuned if the floor's usage changes, ensuring consistent performance over time.
4. **Engagement at Ultra-Low Vibration Levels**: CALMFLOOR® can engage even at extremely low levels of real floor vibration, down to just a few microns. Passive technologies may struggle to engage effectively at such low levels.
5. **Lightweight Design**: CALMFLOOR® devices totalling 67kg each are significantly lighter than TMDs, reducing structural load and simplifying installation.
6. **Ease and flexibility of deployment**: CALMFLOOR® devices can be easily installed after the floor tenant moves in, offering flexibility and convenience. In contrast, passive solutions may require complex installation processes that are not feasible post-occupancy.

Overall, the CALMFLOOR® technology represents a groundbreaking advancement in floor vibration control, offering superior performance, versatility, and ease of installation compared to traditional passive solutions like floor TMDs.

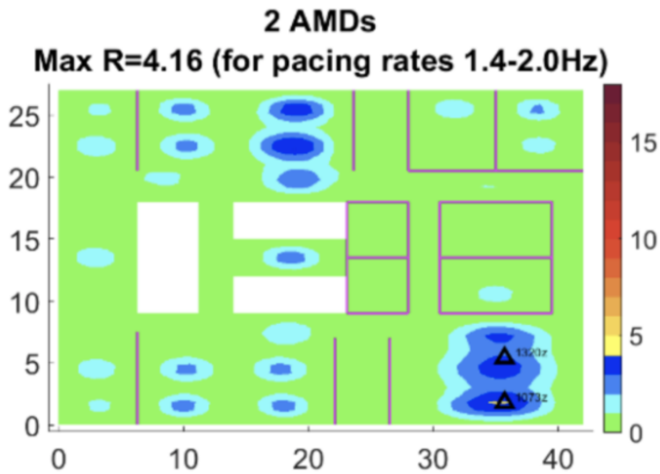

Figure 5: The original long-span composite floor featuring full-height partitions and two CALMFLOOR® units reducing the maximum R-factor from highly problematic 20.2 to satisfactory 4.2 in the problematic unpartitioned area of the floor.

The contour plot depicted in Figure 5 illustrates the R-factors for the structurally unmodified, original lightweight floor, which includes partitions and the effects of only two CALMFLOOR® active mass dampers in the problematic unpartitioned area previously highlighted and depicted as two back triangles in Figure 5. Remarkably, the floor plate demonstrates satisfactory performance with R-factors consistently below 4 across its entire area. This achievement is attained without any structural modifications or the risky relaxation of vibration criteria.

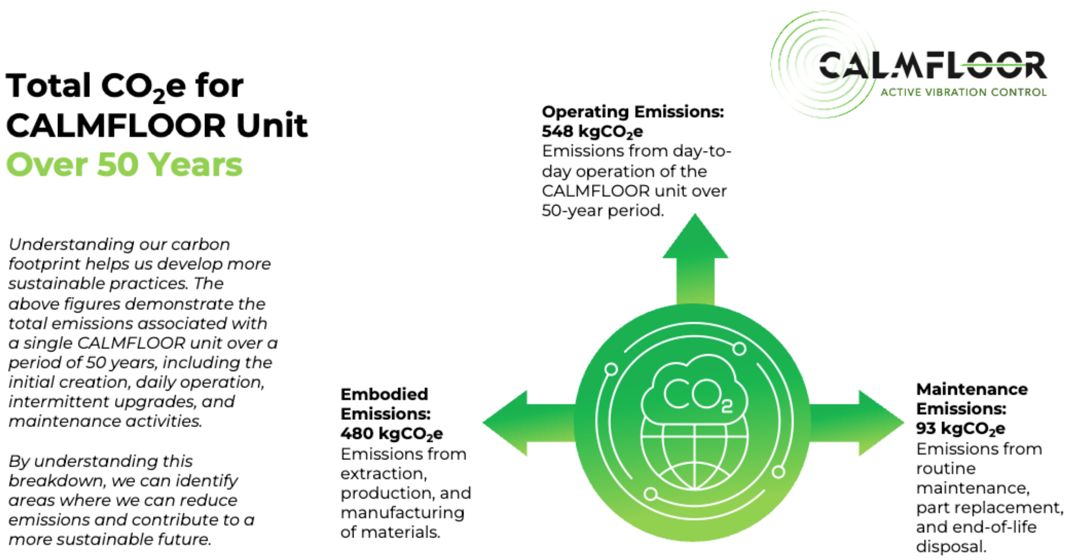

Figure 6: The carbon footprint of a CALMFLOOR® unit over 50 years.

The small carbon footprint (as depicted in Figure 6) of the two CALMFLOOR® AMDs, relative to the structural modification mentioned earlier, along with their competitive costs makes CALMFLOOR® a solid value proposition for all stakeholders: investors, owners, engineers, tenants and other commercial floor users. The whole-life cost of floor vibration control solution based on the CALMFLOOR® technology is many times lower than the costs associated with structural modifications required to achieve the coveted R<4 criteria.

However, one common argument against the explicit modelling of partitions is the uncertainty regarding their placement until the tenant moves in. However, it is crucial to note that once the partitions are erected, the typically lively unpartitioned areas become evident. At this stage, the 67kg CALMFLOOR® units can be effortlessly installed to control these unpartitioned locations, with the full cooperation of the tenant post-move-in.

This level of flexibility is a key transformative feature of CALMFLOOR®: it represents new, off-the-shelf technology, with all CALMFLOOR® units being identical and suitable for mass production. Installation is straightforward, in stark contrast to other post-occupancy solutions for controlling floor vibrations, such as structural modification and TMDs.

Combining the sophisticated modelling of partitions with CALMFLOOR® units in the remaining unpartitioned floor areas is an innovative design approach that permits the retention of long and very lightweight spans while achieving excellent vibration performance impossible by other means.

CALMFLOOR® represents a groundbreaking tool that unlocks the potential hugely beneficial effects of non-structural partitions in a manner that minimizes floor mass and stiffness - a capability not previously utilised by the sector. By effectively controlling floor vibrations while optimizing the use of partitions, CALMFLOOR® revolutionises floor design, offering unprecedented levels of efficiency and performance. This innovative technology marks a significant advancement in the field, enabling more sustainable and cost-effective solutions for building construction and design.

All these benefits have been noticed by individuals and organisations who pioneered the use of the technology since its launch in July 2022. The interest in CALMFLOOR® technology is rapidly increasing on an international scale. As of the time of writing this article in late May of 2024, Figure 7 illustrates that CALMFLOOR® technology has been deployed in the UK, USA, and Continental Europe.

Figure 5: Commissioned buildings using CALMFLOOR® around the world.

6. CONCLUSIONS

Historically, structural engineers often addressed uncertainties in building design by overusing low-cost construction materials, lacking a better alternative. However, the urgency of the climate emergency demands an immediate end to such practices, necessitating a radically innovative approach to meeting increasingly stringent floor vibration requirements.

This paper identifies numerous uncertainties related to floor vibration serviceability, including the location and effects of partitions, walking corridors, the number and activity of office occupants, and future tenant needs. Contrary to common belief, the perception that floor partitions generally improve vibration response is debunked; in fact, partitions can unexpectedly increase vibration in unpartitioned areas. Therefore, the common practice of not modelling partitions is generally not conservative regarding floor resonant vibrations.

Given the imperative to cease material wastage in the current climate emergency and the considerable uncertainty surrounding floor vibration performance, which can render design predictions unreliable, the recent launch of CALMFLOOR® active mass damping technology in the UK holds significant promise. CALMFLOOR® has the potential to obviate the need for additional materials or substantial structural modifications, including the shortening of valuable spans, solely to mitigate minute floor resonant displacements that may still be bothersome to occupants. Offering unprecedented flexibility, CALMFLOOR® is a mass-produced, off-the-shelf technology that can be swiftly deployed at identified floor vibration 'hotspots' after tenant handover, addressing specific needs as they arise.

REFERENCES

[1]. Orr, J. J., Cooke, M., Ibell, T. J., Smith, C., Watson N., Algaard, W., Arnold, W., Butterfield, T. J., Darby, A. P, Gardner, H., Hawkins, W., Mandoki R., Marsh, E., Nuh, M., Oval, R., Peters, A. and Roynon, J. (2021). "Design for Zero". London, United Kingdom: The Institution of Structural Engineers.

[2]. UN Environment and International Energy Agency (2021). "Towards a zero-emission, efficient, and resilient buildings and construction sector". UN Global Status Report for Buildings and Construction.

[3]. Willford, M. R. and Young, P. (2006). "A Design Guide for Footfall Induced Vibration of Structures", CCIP-016, The Concrete Centre.

[4]. Murray, T. M., Allen, D. E., Ungar, E. E. and Davis, D. B. (2016). "Vibrations of steel Framed Structural Systems Due to Human Activity". Second Edition. American Institute for Steel Construction.

[5]. International Standardisation Organisation. (2007). "Bases for design of structures – Serviceability of buildings and walkways against vibrations". ISO 10137, Second Edition.

[6]. Pavic, A. (2019). "Results of IStructE 2015 Survey of Practitioners on Vibration Serviceability". SECED Conference. 9-10 September. Greenwich, London.

[7]. Devin, A., Fanning, P. and Pavic, A. (2015). Modelling the Effect of Non-Structural Elements on Floor Modal Properties. Engineering Structures. Vol. 91, 58-69 (doi:10.1016/j.engstruct.2015.02.021).