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Understanding Sensory Spaces Through Evaluating the Impact of Vibrations

Mahima Ashish Vora[1]

[1] MSc Sustainable Architecture Studies, The University of Sheffield, Sheffield S3 7NA, mashishvora1@sheffield.ac.uk, mahimavora98@gmail.com

Abstract: This study explores how structural vibrations affect how people perceive and behave in sensory environments. The layout of these rooms has a big impact on people's mental, emotional, and physical health. In order to align the user needs in particular circumstances, it is necessary to update outdated standards and guidelines controlling vibration design. a method that combines behavioural observations that are both qualitative and quantitative. How people respond to vibrations in various contexts is studied through ethnography. Participants rate their level of irritation after experiencing various vibration levels in various scenarios while wearing virtual reality headsets. The inadequacy of current vibrations standards and its impact on conservative design are highlighted through a literature review, live case studies, and behavioural experiment analysis. Predictive models for how vibrations are perceived by people need to be revised immediately. By incorporating these ideas early in the design phase, vibration mitigation and its negative impacts can be avoided during construction.
Keywords: Vibrations, behaviour, perception, acceptability, user centric

1. Introduction

Architecture has always been about understanding the phenomena of a space be it interior or exterior, over the years it has become critical to focus on human experience rather than on other physically visual aspects and forms. Mood is impacted by the built environment. When it comes to modern architecture, the results aren't necessarily superior. (Leykam, 2018). A space is more than its appearance. Experiences of users are greatly influenced by textures, smells, and noises. These factors have the power to alter perceptions, encounters, and wellbeing. Notably, structural vibrations have a big impact on people's sensory experiences, which affects their mental and physical health. Individual impacts vary and call for thorough analysis to be understood by all. Among all the building components, the floor is the one that interacts with occupants most followed by walls. Each body part and organ in a human has a unique inherent frequency between 0 and 80 Hz. (Chúláin and Harte, 2018) Various human activities such as walking, running, and jumping can induce floors to vibrate. The building will also experience resonance effects simultaneously with its own structural vibrations, causing discomfort and health issues in humans. As a result, it is important to detect the cause and level of these vibrational discomfort to improve human life efficiency.

1.1 Human Acceptance Criteria

Vision is an important sensory function, accounting for 20% of sensory perception, and it interacts significantly with other senses (Acevedo et al., 2014). Vibrations have varying effects on human senses and are influenced by environmental factors. The comfort range for human vibrations, as per BS 6841, spans from 2Hz to 4Hz, but absolute comfort judgments are environment-dependent (Griffin, 1986). These variations in comfort levels underscore the importance of location and individual differences.

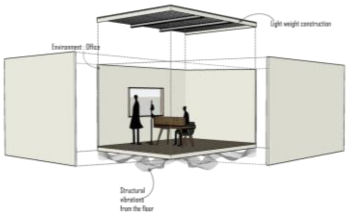

Figure 1. A structural space influenced by vibrations.

The research will employ the ratio of weighted RMS acceleration to frequency-related RMS acceleration to assess responses across different frequency ranges and establish acceptable and unacceptable vibration levels. The outdated ISO 10137 standards from 2007, which prescribe a lower threshold of 0.8 m/s2 rms and an upper threshold of 3.2 m/s2 rms, may no longer be relevant due to advancements in design and construction techniques (Standardisation, 2007). Understanding how vibrations affect people's comfort and responses in various situations and demographics is the central focus of this project. We will explore factors influencing this theme, identifying both commonalities and differences in settings where sensory stimulation varies. Embracing vibrations rather than relying on energy-intensive mitigation measures is crucial in the context of the energy crisis and environmental concerns.

2. Literature review

The intrinsic properties of building structures are governed by factors including mass, density, and stiffness. Identification of a structure's natural frequency, shape, structure, and materials is necessary to forecast how it will respond to external influences. Furthermore, certain characteristics or aspects can help us better understand how different vibrational intensities are perceived by different persons.

2.1 Defining Structural Vibrations: Direction, Position, Source, Threshold and Type

Buildings vibrate due to external or internal factors, including building materials. These vibrations can come from the ground or external sources. Understanding these vibrations and their impact on occupants is important. Human-structure interactions, as studied by Hashim et al. (2020), evaluate how people's dynamic characteristics relate to the building. Analysing vibrations in different directions and occupant positions is crucial due to limited knowledge in this field.

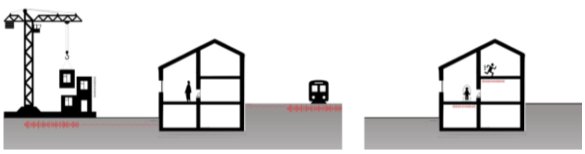
Figure 2. External and Internal Source of Vibrations.

Floor vibrations are the result of direct or indirect interactions between a given area, people, equipment, and the environment. From the main source, these vibrations travel through the ground or buildings. When analysing building and walkway vibrations, elements including the vibration source, transmission channel, and receiver characteristics are critical. The medium that connects the source and the receiver is the transmission path. According to experts (Standardisation, 2007), vibrations at the receiver must adhere to stated standards based on predefined serviceability limitations. There are two distinct sources: external and internal. When a building is subjected to vibrations, it may move as a whole or individual walls, floors, beams, columns, and materials may exhibit distinctive vibratory characteristics. Movement of the entire structure ranges from a few hertz to a fraction of a hertz. Even the smallest frequency can affect the building's residents and cause damage. High frequencies are frequently audible through the floor as a result of sources like adjacent train tracks. There are two types of vibration sources: External and internal.

The attention of the authors Haoyu, Junhui, et al. on how the environment affects the serviceability of CLT highlights the present vibration needs. They primarily research Chinese viewpoints on vibrations and motion amplitudes in a given setting. But this paper ignores other aspects by concentrating on one nationality and one environment. It’s crucial to evaluate vibration impacts on people from different countries in order to develop a thorough grasp of sensory surroundings. Building vibrations can include impulsive events like shocks and can be continuous, intermittent, or irregular (Standard, 2008). Comparing the rms value to the standards has been the approach used to determine these thresholds for sensing vibrations in both. (Hashim et al., 2020, Kowalska-Koczwara and Stypula, 2016). This method will be used in this study for evaluating the perception of vibrations in qualitative measures.

Table 1. Multiplying Factors used in several countries to specify satisfactory magnitudes of building vibrations with respect to human response.

Place	Time	Multiplying factors to base curve
Meditation centre	Day Night	1 1
Office	Day Night	4 4

2.2 Parallel Effects in an Environment: Impact of Light, Temperature and Humidity, Acoustics and Noise, Human Occupational Health

It's crucial to assess sequential vibration effects when evaluating human response. These effects, known as parallel effects, may be unrelated according to current research, but they still can influence the response. When analyzing these effects, it's essential to categorize them based on their contact with the environment or occupants.

The environment significantly affects occupants when exposed to vibrations, altering their responses. Variations exist between indoor and outdoor settings, as well as within individual spaces in a single building. Building design also plays a role in the response to vibrations. According to Zhang et al. (2013), occupants of multi-storey lightweight housing in European countries are greatly affected by vibrations from structural and acoustic sources, emphasizing the importance of vibration and response analysis for building structures.

Lighting, whether natural or artificial, plays a significant role in indoor spaces. A study by Gemelli et al. (2013) demonstrated that lighting can affect occupants' impressions, mood, cognition, and behaviors. When combined with external forces like vibrations, these lighting aspects can have a major impact. However, there is a lack of research on the influence of lighting on vibrational impressions, making it important to study and collect data to support future research. This study will consider both natural and artificial lighting scenarios under the influence of vibrations, serving as a starting point for further discussions.

Thermal comfort and occupant satisfaction are crucial factors when assessing how vibrations impact occupants. Discomfort due to temperature and humidity can impair decision-making and task performance. Considering temperature is essential when studying human perception of vibrations, as it can exacerbate existing discomfort and lead to annoyance in occupants.

Parallel effects, like acoustic elements, are interconnected. When vibrations occur, they often lead to bothersome radiated noise. Griffin (1986) suggests that there can be intricate interactions between how people respond to noise and their response to vibrations. Compared to strong vibrations, often a mix of noise and vibration, low-level vibrations are often overlooked. Therefore, it's crucial to differentiate between noise and vibrations when studying their perception.

People spend the majority of their time indoors, exposed to structural vibrations that can transmit from dynamic to sensitive spaces, affecting occupants. These vibrations can adversely impact health, with symptoms like motion sickness (nausea, sweating, vomiting, and elevated blood pressure) being common, as noted by Griffin.

Figure 3. Parallel effects in an Environment: Light, Temperature, Acoustics and Occupational health

3. Methodology

The research followed Saunders' research onion, using a mixed-method approach for comprehensive data collection, combining quantitative response measurements, qualitative interviews, and behavioral analysis to ensure unbiased results. The study examines human reactions to encountered stimuli, utilizing both quantitative measurements for response factors and qualitative methods for post-experiment interviews. Ethnographic observation and documentation complement the data.

3.1 Experiment: Design, Setup, Participants, Procedure, Measurement: Quantitative and Qualitative

To assess vibrations' impact on human perception, various factors are considered due to differing tolerance levels. This qualitative experiment examines intrinsic (e.g., sex, age, weight) and external factors (e.g., vibration duration, magnitude, literature review factors) with 30 participants from diverse backgrounds exposed to vibrations in VR simulations of meditation facilities and offices. Human interactions are recorded and evaluated based on disturbances.

A 25cm plywood floor, supported by timber underneath, induced vibrations with a shaker while participants sat on a chair wearing VR headsets, simulating a serene meditation center and a busy office. Thirty participants, including 10 Indians, 10 Chinese, and 10 from other countries, with prior consent, joined the human-vibration interaction study, representing diverse backgrounds and understanding of the environments. A questionnaire assessed their perception in the meditation center, with 70% expressing interest and 40% practicing meditation regularly. Basic knowledge sufficed for the office environment.

In this study, we explored human acceptance of vibrations and annoyance levels. Participants sat on a chair at the center of a plywood floor with a shaker underneath, transmitting vibrations that influenced their experience, even though the actual floor remained still. Using VR headsets, participants immersed themselves in the meditation center, focusing on their surroundings while listening to calming sounds to minimize distractions. Following the experiment, interviews and surveys were conducted to assess the impact of induced vibrations. Participants rated their experiences on a Likert Scale from 1-7, providing valuable insights into the discussed annoyance levels and indicating their preferred environment.

4. Results

This study compared vibrations in Meditation Centers and Office environments, following ISO 10137:2007 standards. These standards suggest that vibrations are acceptable when the response factor is below 1 for Meditation Centers and below 4 for Offices. However, recorded annoyance rates deviated significantly from these standards.

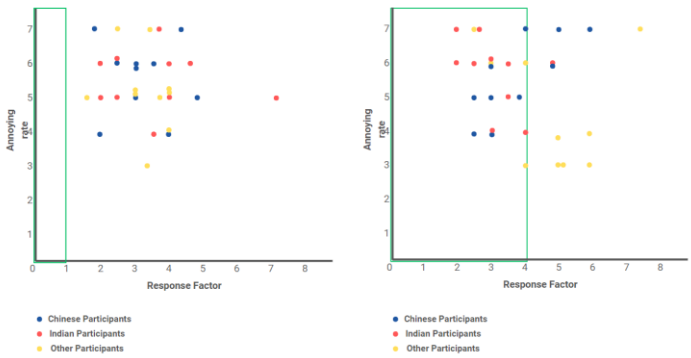

Figure 4. Relationship between the annoyance rate and the response factor in Meditation Centre and Office Environment

Participants found Office vibrations more discomforting, especially with lower response factors, indicating lower tolerance for vibrations in financially important public spaces compared to serene Meditation Centers. Further analysis revealed that when the response factor limit was 3.5, 30% of participants rated discomfort between 6 and 7, compared to 13% when it exceeded this limit. For the office environment, with a response factor limit of 4, 36% of participants reported extreme discomfort when the response factor was less than or equal to this limit, while 16% did so when it exceeded it. The annoyance scale categorized levels 4 and 5 as moderate discomfort and levels 6 and 7 as extremely uncomfortable.

Table 2. Calculated Median value of the annoyance rating in terms of response factor in both the environments.

Annoying rates	Response factor			
	0 - 4		4.1 - 8	
	E1	E2	E1	E2
Median	5	6	5.5	4

ISO 10137:2007's low response factors suggest conservative designs, but the results indicate higher human tolerance levels. Further research across different environments and countries is warranted. The study also highlighted that the environment significantly influences perceptions of vibrations. VR headsets depicting Meditation Centers and Offices were used. Participants from various nationalities and floor conditions experienced more than just VR simulations. A majority lived in concrete structures, affecting their perceptions.

Table 3. Classification of the participants of Median value of the annoyance rating in terms of response factor in both the environments

Annoying rates	Response factors					
	E1			E2		
	Chinese	Indian	Others	Chinese	Indian	Others
Median	6	5.5	5	5	6	5

Distinctions between environments were evident through statistical analysis, revealing that participants felt more discomfort in Offices compared to Meditation Centers. Chinese and Indian participants found Meditation Center vibrations more uncomfortable in environment one, while participants from other countries were least uncomfortable in environment 1. Median rates varied slightly between nationalities for E1. In E2, Indian participants had the highest median annoyance rate at 6, while Chinese and other nationalities reported similar discomfort levels of 5.

5. Discussion and Conclusion

This study evaluated vibrations in meditation and office spaces, highlighting the need for future research to encompass a wider range of environments. Suggestions for improvement include exploring different flooring materials, structural elements, and real spaces instead of VR simulations. Involving participants from timber or lightweight structures and increasing the sample size would yield more statistically significant results. Additionally, incorporating physiological measurements like heart rate and blood pressure would enhance understanding of the health effects of vibrations. This comprehensive approach can expand the assessment of human annoyance and the impact of vibrations.

Key findings from the study include:

1. Different reactions to vibrations in office and meditation environments, emphasizing the influence of sensory aspects on occupants' responses.
2. Human acceptance of vibrations exceeding ISO standards, suggesting a need for updated guidelines favoring low-impact and sustainable design.
3. Limited applicability of existing vibration response factors to various space types, with this study contributing to acceptability in meditation centers.
4. Variability in occupants' perception of vibrations based on patterns, with a preference for continuous vibrations and higher frequencies leading to increased annoyance.

In conclusion, this research calls for revising outdated vibration standards and codes, as it reveals a higher tolerance for vibrations among humans than currently accepted, potentially shaping more sustainable and flexible designs in the future.

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