Chapter 4
Human-Induced Building Vibrations: A Perspective on Their Role for Long-Term Health Monitoring

Jinsi Guo and Yiwen Dong

Abstract What if our buildings could play an active role in understanding our health? As cities grow and populations age, finding ways to monitor health within everyday living spaces becomes increasingly important for delivering personalized and preventative care. Since the average American spends more than 80% of their time indoors, making our buildings "health-aware" is essential. Today's health monitoring methods often rely on clinic visits, cameras, or wearable devices. While useful, these solutions can raise privacy concerns, feel intrusive, or disrupt daily routines, making them less practical for continuous use at home. This paper explores an alternative: using the natural vibrations people create as they move through buildings as a lens into their health. These vibrations can reveal physical and even mental health status, offering a low-cost, non-intrusive, and privacy-friendly way to support long-term monitoring in everyday environments. Most prior studies have been limited to short-term lab or field experiments, leaving open the question of how such systems perform over months or years in real-world homes. To address this, we introduce a framework that brings together the three key players in this process: humans, buildings, and AI systems. Through real-world examples, like gait analysis, monitoring heart and breathing patterns, assessing personal hygiene, and tracking sleep stages, we show how vibrations can become a meaningful health signal. Finally, we highlight the unique challenges of long-term monitoring and propose directions for future research. By integrating civil engineering, human biomechanics, and physics-informed AI, this perspective lays the groundwork for smarter buildings that can quietly and continuously support healthier lives.

Keywords Structural vibration · Health monitoring · Gait analysis · AI for health · Cyber-physics system

Introduction

With the growing urbanization and global aging population, health monitoring in daily living spaces has become a critical need [1]. Conditions such as diabetes, cardiovascular disease, and neurodegenerative disorders such as Alzheimer's and Parkinson's are often most manageable when detected early, yet traditional healthcare mainly relies on episodic clinic visits and often fails to identify precursors of these diseases [2]. Daily living environments, where individuals spend over 80% of their time [3], present an untapped opportunity for long-term, personalized health monitoring. By transforming homes, workplaces, and other everyday spaces into health-aware environments, we can reduce the pressure on healthcare systems and empower individuals to monitor and improve their well-being in their daily living spaces.

Existing health monitoring approaches in daily living spaces have practical issues with operations and privacy [4]. For example, wearables often require daily maintenance, such as charging and wearing, which can disrupt user's daily activities and discourage long-term usage. Camera-based systems, despite their accuracy, often raise privacy concerns and are impractical for spaces like bedrooms and bathrooms. Pressure/force-based systems require direct human-sensor contact, limiting their area of coverage. Radio frequency-based systems are sensitive to the change of layout in physical objects in the space

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and thus pose challenges for long-term monitoring. These limitations highlight the need for alternative approaches to achieve seamless, non-intrusive, and privacy-friendly health monitoring in daily living environments.

This perspective paper focuses on **Human-Induced Building Vibrations** and their potential for long-term health monitoring in daily living. Figure 1 illustrates how human-induced structural vibrations can be used for health monitoring. When people move through a building, their footsteps and activities excite the structures to produce vibrations. These vibrations, captured by sensors, can be analyzed from both time and frequency domains to extract gait-related features. Modeling and inference methods then map these features to health traits, enabling applications ranging from individual injury detection to community-level monitoring. Prior studies have leveraged vibrations generated from everyday activities like walking or resting to extract meaningful health insights. For example, studies have shown that footstep-induced vibrations can reveal gait abnormalities [5], which are critical indicators of fall risk and neuromuscular diseases. Similarly, vibration sensors embedded in furniture can monitor subtle physiological signals, such as heartbeats and respiration rates, with accuracy comparable to medical-grade equipment [6].

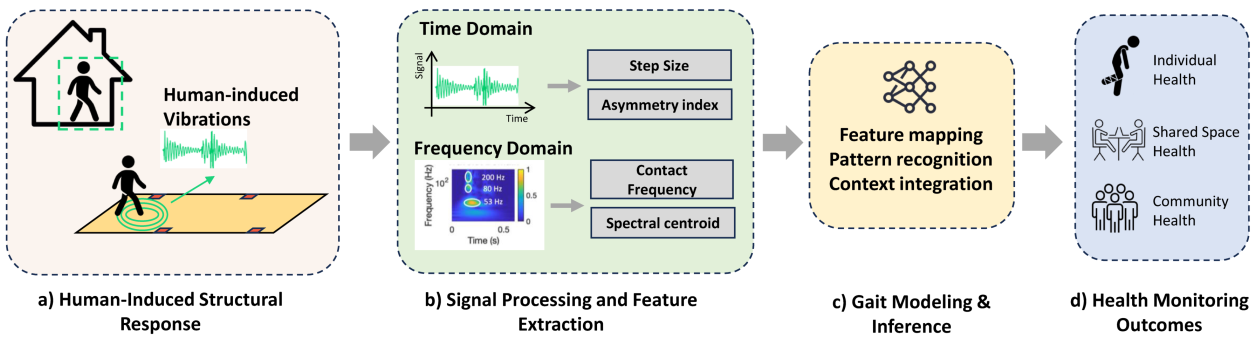

Fig. 1 Conceptual framework: a) Human-induced structural vibrations are captured by sensors. b) Transformed into features. c) modeled through inference. d) Mapped to health outcomes across individual, shared-space, and community levels

However, prior research has largely focused on assessing the feasibility of this approach through controlled laboratory settings and/or short-term field experiments on an hourly basis. Such studies often neglect the complex and unique challenges of deploying these systems in real-world, long-term monitoring scenarios. This paper introduces a conceptual framework that integrates human behavior, building structures, and AI-driven analytics, aiming to establish a foundation for long-term, non-intrusive health monitoring.

Review of Human-Induced Building Vibrations for Health Monitoring

Structural vibrations offer a unique window into human health, enabling monitoring that spans from the individual to entire communities. Since it operates non-intrusively through everyday structures, vibration sensing enables continuous and privacy-preserving health monitoring. Figure 2 illustrates this layered applications landscape, individuals, shared-space and community health. For individual health, vibrations reveal important health traits such as vital signs, sleep and daily activities, allowing continuous health monitoring for a single person [5], [6]. With the addition of identification and localization, it becomes possible to know who generated a vibration and where it occurred, enabling multi-person monitoring and the tracking of interactions [7], [8]. Finally, the scope expands to community health, where collective vibrations reflect crowd behavior, public safety, and even animal welfare [9], [10]. The following section reviews the recent progress in human-induced vibrations for health monitoring across these levels, providing an understanding of how vibrations sensing advances from personal monitoring in the home to population-scale.

A Conceptual Framework

To unify these advances, we propose a Human–Structure–Health framework that links behavior, structural response, and AI-driven inference. Everyday actions such as walking or sitting excite the structure, generating vibrations that encode health-relevant signals. AI models can infer metrics such as gait asymmetry, cadence, or respiration rate from these vibrations,

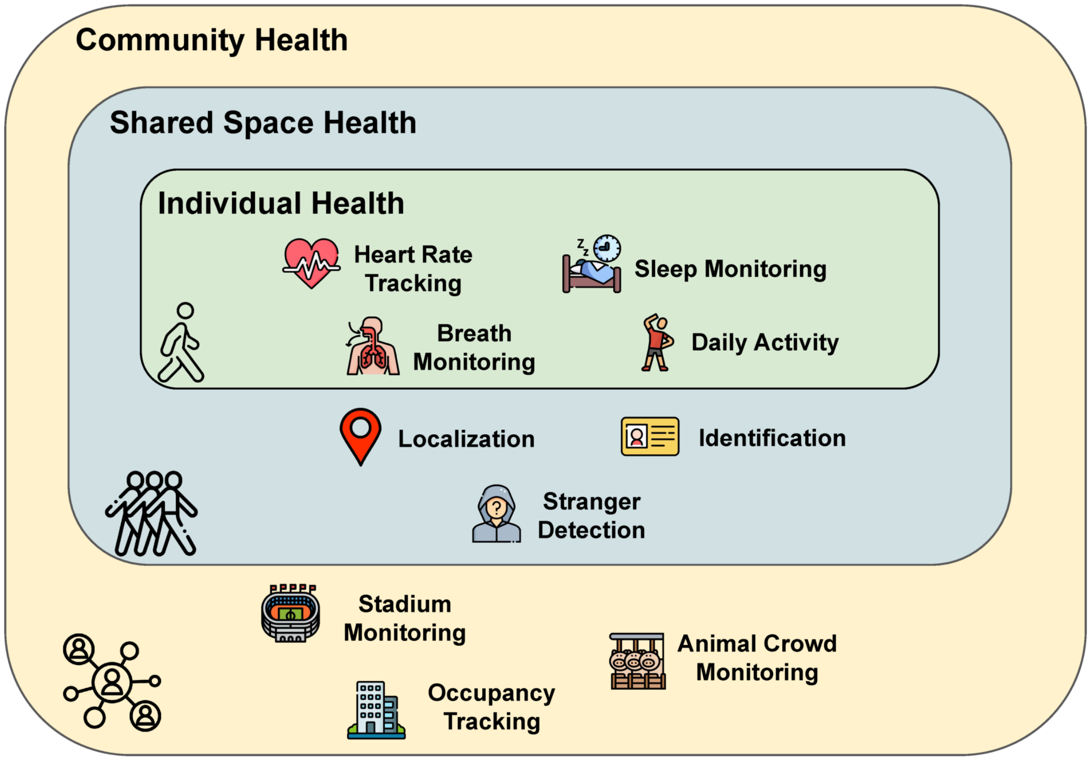

Fig. 2 Application landscape of vibration-based sensing for health: from individual-level monitoring to shared-space functions and community-scale applications

which in turn inform feedback and interventions for individuals. This framework positions buildings as active participants in health monitoring, creating a closed loop where human health both shapes and is reflected in the built environment.

Future Perspectives

Looking ahead, future research must address the unique challenges of long-term and real-world monitoring. This includes developing drift-aware methods that can adapt to daily contextual changes, attribution pipelines that preserve personalization in multi-occupant settings, and integration strategies that fuse in-home vibration data with wearable or outdoor signals. Achieving this will allow vibration sensing to move beyond feasibility demonstrations toward systems that support continuous, clinically meaningful evaluation in everyday environments.

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