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Adaptive human bodies and adaptive built environments for enriching futures

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As humans, we spend most of our lives inside human-built environments, such as homes, offices, and schools. In these built environments, humans co-create and share a collective awareness, social practices, and knowledge while computing machinery is designed to maintain the built environment and support our interactions. The effects of these technologically enriched built environments on humans are how our bodies adapt to the practices they promote and how these practices, in return, affect the built environment and the natural environment. This perspective paper uses inbodied interaction to frame the constant adaption of our bodies to our surrounding environment as an opportunity to inform the design of technology and its practices and offer a vision where humans, the built environment, and the natural environment coexist in a mutually beneficial relationship.

KEYWORDS

inbodied interaction, bodily adaptation, adaptive built-environment, cybernetic process, human-computer interaction

Inbodied interaction

Inbodied interaction focuses on understanding how the body works internally to support human performance. Most of today's HCI work has investigated the interaction between the embodied and circumbodied design space. For example, previous works described our interactions with objects as a cognitive coupling between us, the object and the environment, highlighting the interdependence of the environment we are situated in as environmental embedding for our interactions (Clark, 1999; Wilson and Golonka, 2013). This environment also offers particular socio-cultural affordances to different people, directly influencing the interactions we see possible and consider adequate in a given environment (Dourish, 2001; Wilson and Golonka, 2013). The previous works on embodied and circumbodied recognize the link between the environment and our interactions and how they continuously influence inner bodily processes that, in turn, mediate how we perceive the world and our possibilities in it. So far, limited work has focused on understanding these inner bodily processes, often considering them as a black box. Inbodied interaction aims to open this black box to use the human body's inner workings to inform design. It relies on sciences that focus on the functioning of the human body, such as physiology, psychology, sociology, neurology, and nutrition. The goal of inbodied interaction is to bring concepts from these sciences to stimulate reflection and action about technology design and conceptual understanding of the interdependent, always adaptive relationship of the human body with the surrounding environment. This is vital to HCI because the inbodied processes respond to the embodied and circumbodied in a continuous dialogue that mediates our experience. Understanding this dialogue foregrounds the human body's innate quality of adaptation to its environment as a circular cybernetic process, offering an opportunity for designers to craft such environments and the technology and practices in them to promote human performance for learning, play, work, and resilience.

Bodily adaptation

Bodily adaptation is the process of physiological changes orchestrated *via* our metabolism to maintain homeostasis in the response to changes in the physical surroundings and our specific circumstances (Frisancho, 1993; Baar, 2014; Schraefel and Hekler, 2020). Adaptation is part of our bodily plasticity resulting in processes affecting every organ from cells in our brains to gut bacteria (Chen et al., 2013). Our bodies are efficient networks of multiple systems that adapt to context. For example, when learning to play an instrument, multiple systems adapt, from our motor function to muscular and nervous tissue resulting in increased coordination, speed, and endurance. When playing an instrument is no longer an activity we engage with, our bodies efficiently adapt to save energy resources by discarding the developed muscle tissue, and our neural pathways for playing the instrument become dormant and weaken until we practice again. Often, we experience this as being "rusty" while our bodies re-adapt to the demands of that activity.

The surrounding environment and our circumstances drive the underlining processes for adaptation to enable cognitive, social, and physical performance (Schraefel, 2020). Understanding that bodily adaptation is holistic, not fragmented, and involves the interplay of the various bodily systems working together is vital to depict our *adaptive context*: the changing surroundings and the specific circumstances that drive bodily adaptation. The built environments we live, work, play, and learn in, the technologies within them and the socially constructed practices they shape, are all part of our constructed *adaptive context* that shapes bodily adaptation. Today, the adaptive context we have constructed often promotes sedentarism, limiting engagement with nature and time to think deeply, affecting our performance in the moment and our adaptation over a longer time frame. All while offering limited visibility about the resources consumed and their effects on the natural environment.

Designing for adaptation is complex as it demands a holistic understanding drawing on disciplines such as human physiology, psychology, sociology, neurology, and nutrition to view and inform the design of built environments, technology, and practices. One area integrating this thinking is inbodied interaction (Andres et al., 2019, 2020; Schraefel et al., 2021), which focuses on three interdependent systems that constantly adapt to one another; these systems are the functioning of the body (inbodied); the situational context relating to the actions and behaviors taken by individuals (embodied); and the environment around us with its qualities such as visuals, temperature, gravity, air quality, sounds, lights, shape, and microbiome (circumbodied) (see Figure 1). When we view the in-, em-, and circum-bodied as a large system, it reveals a holistic view to explore the design of our adaptive context.

Adaptive built environments

The term "built environments" refers to a human-made environment that provides space for human activity, from houses, buildings, parks, and cities, and often includes supporting infrastructure such as water supply, energy, and connectivity networks (Built Environment Health., 2022). Built environments, whether designed to support physical, hybrid, or virtual activities, are an output of human endeavor that support physiological and social needs relating to security and social practices.

The built environment significantly impacts bodily adaptation and the natural environment. For example, a lack of natural light affects our mood and motivation, and the spatial layout of built environments promotes or hinders incidental physical and social activity, which contributes to our overall performance and adaptation (Proulx et al., 2016; Arbib, 2021). The natural environment is also affected through the land in use, water, energy consumption, and the emission of greenhouse gases. Importantly, weather events are considered the major risks to build environments and the humans in them (Built Environment Health., 2022). However, in the long term, how we design, construct computational program, and utilize built environments is a larger risk for bodily adaptation when sedentary lifestyle and disconnection from nature are promoted, while our practices contribute to the natural environmental crisis.

In architecture and design literature, built environments that can use computation to adapt to the occupants' needs have been discussed (Furtado Cardoso Lopes, 2009). For example, built environments that could monitor space usage and rearrange walls, turn supporting systems ON and OFF to save resources, and use light to guide occupants and sound to communicate back with occupants in charge of maintaining the built environments. In these computationally adaptive built environments, the aim was to support work collaboration by facilitating a space where humans and technology coexist within the shared built environment. Often, grounded in cognitive psychology concepts to inform the technology and surrounding design to investigating our experiences with technology at arm's reach, or in the peripersonal space (Merleau-Ponty, 1962;

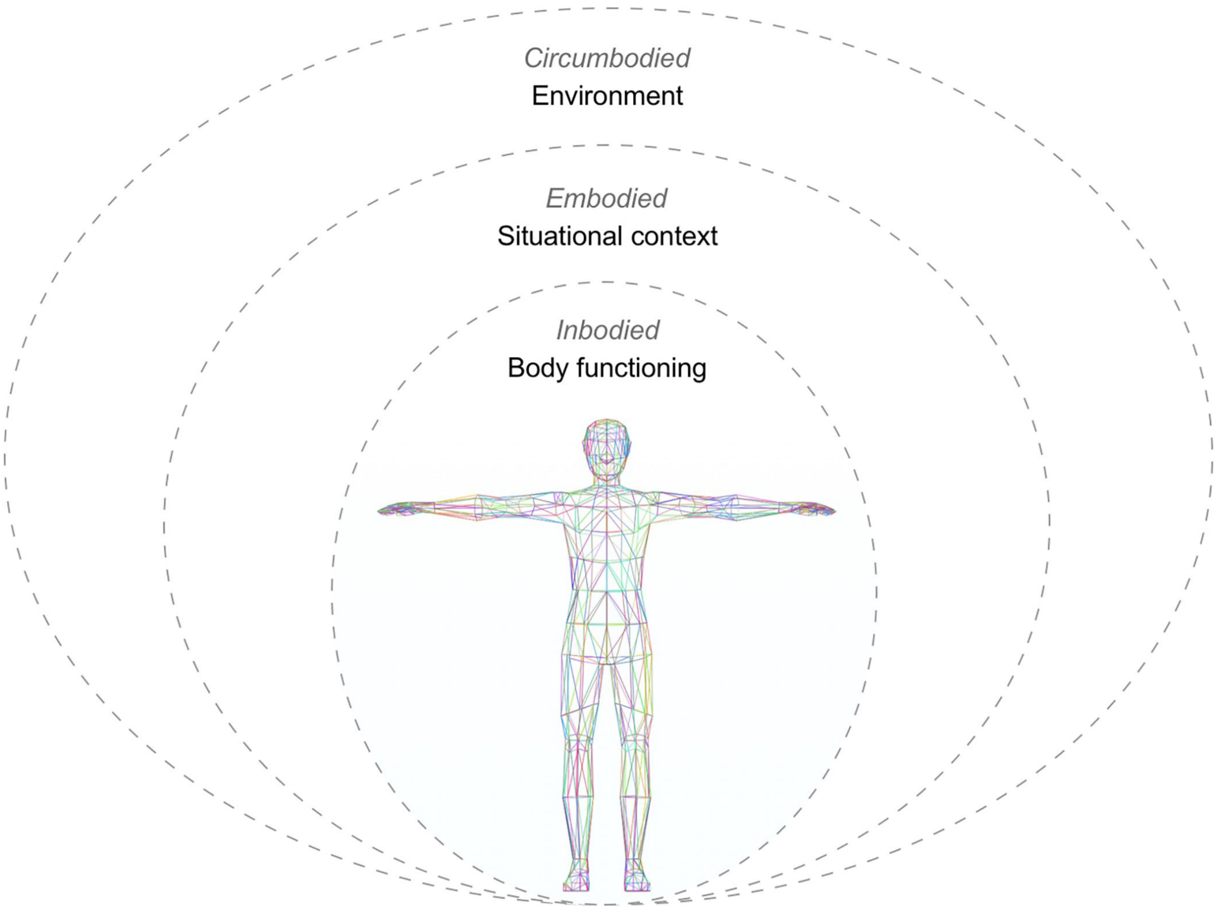

FIGURE 1
The in-, em-, and circum-bodied as interdependent systems to reflect on technology interventions and their effects on adaptation.

Pellegrino and Làdavas, 2015). This approach has been fruitful, and it could be extended with an inbodied approach to support human performance by understanding the inner workings of the human body.

Advances have been made to improve built environments toward promoting social enrichment and choices that positively support the human experience (Poldma, 2019), such as offering access to healthy food, community gardens, walkability, and bikeability AUS (Built Environment Health., 2022). While these additions are highly desirable for humans, advances in the computation are giving way to a new generation of built environments enriched with sensors, actuators, and running artificial intelligence to interpret and act on vast amounts of data in real-time and enable built environment adaptation. The adaptation can be oriented to save energy and water resources according to occupant consumption and in relation to a solar energy surplus and collection and treatment of rainwater. However, today the application of technology in built environments promotes disconnection from nature, for example, by equalizing weather year-round while sterilizing microbiome composition (Franklin, 1999). Instead of creating built environments as cocoons that divide us from nature, how can we let in the rhythms of the seasons, the natural climates, and microbiome compositions that connect us to life and nature to be part of our circumbodied, to benefit the inbodied, and support our performance?

As technology continues to enrich built environments, policies, and regulations that protect the occupants' privacy need to be rethought with the introduction of new technologies. To allow occupants to opt-in while explicitly and comprehensively explaining what data are being collected, is it user-identifiable, where is it stored, who has access to it, can it be deleted, and how such data may inform built environment adaptions for the occupants' benefit and the built environment performance. In this future, built environments could sense and fuse multimodal data to derive meaning and inform built environment adaptation across various applications (Caan, 2011; Simeone and Kalay, 2012; Thibault et al., 2020).

The trend for built environments is to support human needs and comply with emerging sustainability policy regulations, however, we see this new generation of built environments as an opportunity to use inbodied thinking to reveal a inbodied, embodied, and circumbodied space where humans and built environments adapt to one another to improve human performance while contributing to the natural environment, as we discuss next.

Bodily adaptation and built environment

Taken together, advances in built environments present an alternative framing from the current deteriorating cycle for humans and the natural environment to one focusing on "inbodied" opportunities to positively drive bodily adaptation while increasing awareness about our interdependent adaptive relationship with the natural environment. Notably, thinking about adaptation offers a longer time span than designing technology for sequential interaction because adaptation is non-linear and ongoing. This ongoing property invites examination of the effects at scale that our choices and the adaptive context they form to lead us and the environment to.

Acknowledging the interdependence of bodily adaptation and built environments provides us with a number of opportunities for reimagining their relationship.

First, we begin by questioning how we may shift from a comfort-oriented mindset where we consider that the role of technology is to serve our comfort-oriented desires, or in other words, we see technology as a servant (Franklin, 1999). This illustrates a hierarchical order where human needs are at the top of the ecological realm at the cost of all else (Coulton and Lindley, 2019). A shift to humans as equal participants in the ecological realm can be helpful to open opportunities for technology design that assists with reframing social practices about what is acceptable, *that's how we do things around here*, and how these practices present choices about our interdependence with the natural environment mediated through the built environment adaptability, space, and context.

Second, we draw inspiration from the human body's interconnected systems. Where whole-body equilibrium benefits the functioning of the entire body while offering its systems suitable working conditions within their functioning parameters. For example, the respiratory system breathing cycle facilitates gas exchanges to support motor functions, such as running, going over the breathing rate limits motor functions, and serves as a mechanism to slow down and preserve the respiratory system and the integrity of the entire network. This mutually beneficial relationship between systems working toward whole-body equilibrium is what we consider lacking when we study the human—the built environment—and the natural environment relationship.

Third, it is helpful to understand how the practices enacted through built environments shape our experiences, promote or hinder human performance, and drive adaptation for humans and the natural environment in order to experiment with alternative configurations. For example, the "biological" as humans and living organisms, the "technological" as computational machines and automations, the "material" as non-living objects, and the encompassing "social," and "cultural" context across time and space. These elements shape our experiences and our adaptations. Can we fine-tune their configurations to drive a mutually beneficial human and natural environment adaptation over time?

The future of bodily adaptation and built environment

We reflect on the presented trajectory and intersection of inbodied interaction and the advances in adaptive built environments to illustrate a vision where a mutually beneficial relationship between humans, the built environment, and the natural environment is possible.

Technology design has mainly used a human-centered approach to understand, collect, and rank user needs and inform technology design. Alternative design paradigms are becoming more common today, such as country-centered design that looks at informing technology design and the practices around it for the benefit of the natural environment (Abdilla, 2020). Advances in adaptive architecture study the effects of the surrounding environment on the brain, showing the benefits of connection to nature, natural light, and plants for human performance (Arbib, 2021; Schraefel et al., 2021). This intersection could open a future where technology challenges our human-centered perspective on how the environment and technology should function to serve us. Instead, could technology design be framed to contribute to the natural environment and human performance, even if this means occasional discomfort for humans by design? Discomfort ignites the body's innate quality of adaptation to its surroundings.

This, for example, could translate to interaction opportunities that are culturally and contextually framed as a dual opportunity to support responsible use of resources while creating inbodied micro-challenges for resilient adaptation.

The built environments sensors, AI's and cyber-physical systems and its operational strategy for energy harnessing, allocation, and usage support sustainable practices today; we believe a shift in perception is needed to not only take inspiration from nature to inform the design and function of the built environment but one where the built environment and the technological practices in it exert connection to the natural environment for human performance while through our interactions serve as an extension that endows the built environment with recycling properties. This alternative-centric view is critical to reducing sedentary lifestyles that can result in atrophy of human performance through negative adaptation, while supporting lifestyles where over-consumption of resources is acceptable.

At large, our technosphere is made from all the human-created infrastructures (Herrmann-Pillath, 2018; UNESCO., 2018), and this lacks the recycling properties of the other spheres that have supported life over millennia—a transition can begin by designing our adaptive context, such as the technologies, practices, and built environments from an inbodied perspective for human performance and connection and care for the natural environment.

Conclusion

This perspective paper presented computationally adaptive built environments that use inbodied interaction to offer a vision where humans, the built environment, and the natural environment coexist in a mutually beneficial relationship.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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