Sustainable Health Design Based on Ecological Dynamics:Construction and Evaluation of a Dynamic Health Behavior Environment

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***Abstract*—Sedentary lifestyles and unhealthy behavioral patterns are placing an increasing strain on public health by accelerating the prevalence of chronic non-communicable diseases. Yet many health-oriented built-environment interventions remain largely static, offering fixed facilities that fail to adapt to people ' s changing needs, abilities, and motivations. Grounded in ecological dynamics, this study advances a sustainable health design approach that operationalizes person – environment coupling through a Dynamic Affordance Model, a multi-dimensional Health Behavior Environment Evaluation Framework, and five core design principles: Adaptability, Interactivity, Inclusivity, Motivation, and Ecological Integrity. To examine its real-world effectiveness, we implemented a dynamically adjustable health behavior environment in a community setting and conducted a six-month quasi-experimental study with 120 adult residents, randomly assigned to an intervention group (n = 60) or a control group (n = 60). A total of 112 participants completed the study. To enhance feasibility and reproducibility under typical community conditions, data collection relied primarily on low-cost, widely accessible tools, including participants ' own smartphones (built-in step and activity records), brief on-site health checks, mobile questionnaires, and semi-structured interviews, supplemented by simple facility-use logs and structured behavioral observations. Repeated-measures analyses revealed a significant time-by-group interaction for physical activity outcomes. Average daily steps in the intervention group increased from 6,250 to 8,960 (a 43.4% increase), while the control group showed no meaningful change; moderate-to-vigorous physical activity followed a similar pattern. Social interaction frequency rose from 3.5 to 6.8 times per week, accompanied by greater co-presence and longer dwell times in public spaces. Both physiological and psychological indicators improved, including reduced resting heart rate and higher self-efficacy scores (from 3.2 to 4.2). Further regression-based mediation analyses indicated that dynamic affordances influence health behavior not only directly but also indirectly by enhancing perceived environmental attractiveness and individual self-efficacy. Overall, the findings demonstrate that translating ecological dynamics into dynamically adjustable environmental affordances can generate measurable and sustainable improvements in community health behaviors and well-being, offering a practical and scalable pathway for health-oriented environmental design.**

Keywords—Ecological dynamics; Dynamic affordances; Built environment; Health behavior intervention; Sustainable health design

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I. INTRODUCTION

Chronic non-communicable diseases — including cardiovascular disease, diabetes, and cancer—have become a major global public health challenge, largely driven by sedentary lifestyles and unhealthy behavioral patterns [1]. The World Health Organization (WHO) has identified physical inactivity as the fourth leading risk factor for global mortality [2]. Within this context, a critical question has emerged at the intersection of public health, urban studies, and design research: how can environmental design interventions systematically promote everyday physical activity and healthier behavioral patterns among residents?

The built environment, as the spatial foundation of daily life, plays a decisive role in shaping health behaviors. Extensive evidence shows that spatial configuration, facility provision, and environmental quality influence residents ' physical activity levels, social interaction, and overall quality of life [3]. As a result, health-oriented environmental design has become a key focus in contemporary interdisciplinary research and practice.

Despite growing attention, prevailing approaches to health environment design remain constrained by notable limitations. Most interventions rely on static and standardized solutions, such as fixed walking paths or uniform outdoor fitness equipment. Although these " one-size-fits-all" strategies may improve physical infrastructure, they frequently overlook two fundamental challenges.

First, the lack of dynamic adaptability. Individuals ' health needs, behavioral motivations, and emotional states evolve over time. Static environments are poorly equipped to respond to these changes, limiting their capacity to provide sustained and context-sensitive behavioral incentives. Second, individual heterogeneity is insufficiently addressed. People differ widely in age, gender, cultural background, and physical ability, resulting in varying capacities to perceive and act upon environmental affordances—that is, differences in effectivities [4]. For example, an element that invites exploration and activity for a younger adult may function as an obstacle or deterrent for an older individual.

Consequently, a critical scientific and design challenge remains unresolved: how to create built environments that can dynamically adapt to diverse users, continuously invite health-promoting behaviors, and respond to changing individual capabilities over time. Addressing this challenge requires moving beyond static design paradigms toward more responsive, behavior-oriented, and ecologically grounded approaches.

II. Literature Review

The theoretical logic of this study is grounded in ecological dynamics and is further integrated with research on health behavior – environment design and sustainable design. This chapter reviews key concepts and advances in these three domains, establishing the theoretical basis for the proposed dynamic health behavior environment as well as its design and evaluation system.

A. Theoretical foundations of ecological dynamics

Ecological dynamics is an interdisciplinary framework rooted in ecological psychology and nonlinear dynamical systems. It provides a distinctive lens for understanding how complex behaviors — such as perception, action, and learning — emerge in real-world contexts [5]. Rather than treating behavior as a one-way output of internal cognition, ecological dynamics conceptualizes behavior as self-organized, arising through continuous interaction and information exchange within the integrated organism – environment system [6]. A foundational concept within this framework is affordance, introduced by James J. Gibson.

Gibson defined an affordance as what "the environment provides or furnishes the animal, for good or ill" [7]. Importantly, affordances are neither purely objective physical properties nor purely subjective perceptions; they are relational — formed through the functional fit between environmental features and an individual's capacities. For example, a flat surface (an environmental property) affords walking for a person who has the ability to walk. This ability is captured by the notion of effectivities, referring to the action capabilities an individual brings to a situation — shaped by body size, strength, skills, health status, and experience [4]. From this perspective, a rich landscape of affordances can offer multiple action possibilities to individuals with diverse effectivities, thereby supporting more varied and adaptive behavioral patterns [8].

Ecological dynamics further emphasizes that the human – environment relationship is inherently dynamic and continuous. Individuals change their relationship with the environment through action, perceive new affordances through that action, and adjust subsequent behaviors accordingly. This ongoing perception – action cycle is viewed as a core mechanism for adaptation and learning [9]. Translating this insight to health-oriented environmental design suggests a key implication: effective health environments should not be purely static. Instead, they should be capable of interacting with users and dynamically presenting or adjusting affordances as users' behaviors, states, and capabilities change — thereby continuously "inviting" and guiding healthy behavior.

B. Health behavior and environmental design

A large body of evidence confirms that the built environment has substantial influence on health behavior. Across urban planning, public health, and architectural research, multiple models have been developed to explain and guide the creation of healthier environments. The Social-Ecological Model, for instance, conceptualizes health behavior as shaped by interacting factors across multiple levels, including individual, interpersonal, organizational, community, and policy contexts [10]. Within this framework, the built environment functions as a key community-level determinant, influencing physical activity through mechanisms such as perceived safety, accessibility, comfort, and aesthetic quality [3].

Within built environment research, the widely used "5D" framework — Density, Diversity, Design, Destination Accessibility, and Distance to Transit — has been shown to relate strongly to walking and cycling behaviors [11]. Yet much of this literature relies on static assessments of environmental features. It typically treats built environments as fixed inputs rather than dynamic systems that can change over time or respond to real-time behavioral patterns.

In parallel, behavioral science has increasingly shaped health-oriented design approaches. The Nudge framework, for example, emphasizes "choice architecture" that steers individuals toward healthier decisions without eliminating freedom of choice [12]. Classic examples include making stairways more attractive and prominent than elevators to encourage incidental activity. However, nudge effects may weaken through habituation, suggesting that long-term effectiveness often requires continued novelty, contextual sensitivity, and, potentially, dynamic adjustment — an area where ecological dynamics may offer complementary theoretical grounding.

C. Principles of sustainable design

The core objective of sustainable design is to meet present needs without undermining future generations' ability to meet theirs. In built environment practice, sustainability often focuses on energy efficiency, resource conservation, and ecological protection. However, sustainability also includes social sustainability and long-term human well-being [13]. A truly sustainable community is therefore not only low-carbon and resource-efficient, but also healthy, inclusive, and socially vibrant.

The Healthy Cities concept reflects this expanded understanding of sustainability by advocating that health should be embedded across urban policy domains and advanced through cross-sector collaboration [14]. Within this broad sustainability – health agenda, adaptive design becomes particularly relevant. Adaptive design highlights flexibility and responsiveness, enabling buildings and urban spaces to cope with uncertain future social, technological, and environmental shifts. Applied to health-oriented environments, this implies that spaces should be capable of adjusting their functions and configurations to meet the evolving needs of different populations over time. This sustainability principle aligns strongly with ecological dynamics, which similarly emphasizes continuous adaptation through person – environment coupling.

D. Research gap and positioning of this study

In summary, while these fields provide valuable foundations, significant integration gaps remain. Ecological dynamics offers a powerful theory of human – environment interaction, but it lacks widely adopted paradigms for large-scale application in built-environment health design. Health behavior – environment research has demonstrated the importance of physical context, yet it often relies on static indicators and gives limited attention to real-time interaction and behavioral adaptation. Sustainable design highlights adaptability and long-term value, but it lacks sufficiently operational methods for implementing dynamic adaptation specifically within the health dimension.

This study addresses the intersection of these gaps. By introducing a dynamic design orientation and translating ecological dynamics principles into actionable design logic, the study aims to bridge theory and practice. Its objective is to develop operable and evaluable strategies for building dynamic health behavior environments that are responsive to diverse effectivities and changing behavioral states, while remaining consistent with sustainability goals and real-world feasibility.

III. Related Work

To more clearly articulate the uniqueness and contribution of this study, this section reviews four cross-disciplinary research streams that directly inform the concept of dynamic health behavior environments: (1) affordances in health design, (2) dynamic environment design, (3) health behavior intervention research, and (4) smart health environment studies. This review also highlights how the present study extends and integrates these strands into a coherent theoretical and practical approach.

1) Affordances in health design: from conceptual grounding to early practice

Research applying affordance theory to health-related environments has gradually moved from conceptual discussion toward preliminary empirical exploration. For example, Brito et al. (2022) argued from an ecological dynamics perspective that urban natural environments support well-being and physical activity by offering rich and varied affordances—such as climbable rocks, uneven terrain, and exploratory pathways [15]. Similarly, Sando (2020) showed that physical features of kindergartens — especially varied ground textures and unstructured play materials — shape children ' s play behavior by influencing perceived affordances [16].

These studies provide important support for the underlying logic of the present work: environments shape behavior by structuring the landscape of action possibilities. However, most existing studies remain focused on describing and interpreting affordances in existing spaces, rather than systematically addressing how to proactively design environments that deliberately contain targeted, dynamic affordances, particularly for diverse users and changing states over time. This design-oriented gap is one of the main motivations for the current study.

2) Dynamic environment design: technological potential, limited health orientation

Research on dynamic environment design has been particularly active in human – computer interaction, interaction design, and interactive art. Work in this area has explored concepts such as transformable architectural surfaces, interactive installations, and responsive spatial systems that adapt to environmental data or user behavior [17]. These "responsive environments" demonstrate the feasibility and promise of dynamically changing form and function, opening new possibilities for making space adaptive rather than fixed.

Yet, in most cases, such work prioritizes technical implementation, experience design, or aesthetic expression, and it rarely integrates a clear goal of long-term health behavior promotion. There remains a methodological and theoretical gap regarding how dynamic design capabilities can be systematically aligned with evidence-based health objectives, and how responsive systems can be designed to sustain behavior change beyond novelty effects. This study directly addresses that gap by positioning dynamic design as a health-oriented affordance strategy rather than a purely technical or artistic exercise.

3) Health behavior intervention research: dynamic personalization, but mainly informational

Health behavior intervention research — especially in mobile health (mHealth) and wearable-based systems — has made important progress in dynamic, personalized strategies. For example, tailored message systems adjust the timing and content of motivational prompts based on recent behavior patterns such as step counts, activity intensity, or adherence history [18]. These studies demonstrate that personalization and immediate feedback can effectively support short-term behavior change and improve engagement.

However, most of these interventions occur primarily at the information layer (e.g., messaging, reminders, feedback dashboards), while the physical environment remains largely unchanged. This leaves an important opportunity underexplored: extending dynamic intervention logic beyond the virtual informational interface into the real, material built environment, where daily behavior is actually enacted. Translating dynamic and personalized principles into the spatial and environmental domain is therefore a key step toward deeper and potentially more sustainable behavioral effects—one that this study aims to operationalize.

4) Smart health environments: convergence of IoT/AI, but limited theory and long-term evaluation

Research on smart health environments represents the convergence of the above trends. With advances in the Internet of Things (IoT) and artificial intelligence (AI), scholars and practitioners have explored smart homes, smart communities, and smart cities capable of sensing residents' needs and responding through automated or adaptive environmental adjustments [19]. For example, smart homes may link sensors and wearables to adjust lighting and temperature to support sleep quality. At the community scale, pilot projects have experimented with smart trails, interactive fitness infrastructures, and digitally augmented public spaces to encourage activity [20].

While these efforts offer valuable technical pathways, many remain small-scale technical validations or conceptual demonstrations. They often lack a robust, unified design theory that explains why particular environmental interactions should work, for whom, and under what conditions. Moreover, long-term impacts and sustainability — especially beyond initial novelty — are still insufficiently evaluated. This is precisely where ecological dynamics can provide a stronger behavioral foundation, and where a systematic evaluation framework becomes essential.

5) Unique contribution of this study

The distinctive contribution of this study is its systematic use of ecological dynamics as a guiding theory to integrate dynamic environment design, health behavior intervention logic, and smart environment technologies into a sustainable, evaluable dynamic health behavior environment.

Compared with prior work, the study's innovation is reflected in three shifts:

- From "passive influence" to "active invitation." The environment is conceptualized not as a static backdrop, but as a dynamic participant in person–environment coupling — capable of continuously inviting and shaping behavior.
- From "information intervention" to "physical environment intervention." Instead of relying mainly on digital prompts, the study materializes dynamic adjustment mechanisms within the built environment itself, making behavioral support spatial, embodied, and contextually embedded.
- From "single behavior outcomes" to "comprehensive health." The study develops a multi-dimensional evaluation framework that assesses not only physical activity but also psychological well-being and social interaction, enabling a more complete understanding of long-term health and sustainability effects.

Together, these contributions position the present research as a theoretically grounded and practice-oriented step toward designing built environments that are not merely health-supportive, but dynamically health-generative over time.

IV. Methodology

This study adopted a mixed-methods research design that integrates theoretical development with empirical validation to systematically construct and evaluate a dynamic health behavior environment. By combining framework construction, a quasi-experimental field study, and multi-source data analysis, the research aims to both advance theory and demonstrate practical effectiveness. This chapter presents the overall research design, elaborates the core components of the theoretical framework, and describes the study setting, participants, data collection procedures, and data analysis strategies in detail.

A. Research Design

The core of this study is a six-month quasi-experimental investigation conducted in a real-world smart community setting. Two groups of residents were selected and assigned as the intervention group and the control group. The residential area of the intervention group was equipped with the dynamic health behavior environment system developed in this study, whereas the control group continued to live in a conventional, static community environment. Health behaviors, physiological indicators, and psychological perceptions of residents in both groups were continuously tracked and measured at baseline and throughout the intervention period.

The overall research process followed a clear technical route of "Theoretical Construction → System Design → Intervention Implementation → Data Evaluation" (see Figure 1). First, a design framework for the dynamic health behavior environment was constructed based on principles from ecological dynamics, emphasizing person–environment coupling and adaptive affordances. Second, guided by this framework, a set of dynamic intervention facilities was developed and deployed using low-cost, off-the-shelf interactive components and simple rule-based adjustment mechanisms—such as scheduled lighting cues, modular and updateable signage, and reconfigurable public furniture—ensuring feasibility, scalability, and replicability without reliance on specialized infrastructure. Third, the designed system was implemented in the intervention community and operated continuously over a six-month period. Finally, the comprehensive effects of the intervention were evaluated through statistical analysis of multi-source longitudinal data, enabling an integrated assessment of behavioral, physiological, and psychological outcomes.

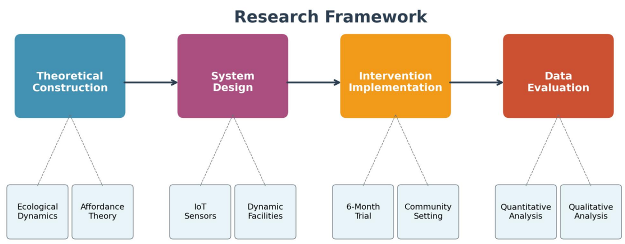

Fig. 1. Research Framework

B. Theoretical Framework Construction

The Dynamic Affordance Model constitutes the theoretical core of this study (see Figure 2). It conceptualizes how a dynamically adjustable built environment influences individuals' perception–action cycles by continuously shaping and reconfiguring environmental affordances. Drawing on ecological dynamics, the model explains health behavior as an emergent outcome of ongoing interactions between individuals and their environment rather than as a purely individual decision.

The model consists of four interrelated components:

1) Perception Layer:

Individuals perceive potential affordances in the environment through multisensory channels (e.g., visual, auditory, and tactile cues), filtered by their effectivities, such as physical ability, experience, and current psychological state. These perceptions determine which environmental action possibilities are salient at any given moment.

2) Action Layer:

Based on perceived affordances and personal intentions, individuals select and enact specific health-related behaviors, such as walking, jogging, stretching, resting, or social interaction. Behavior is thus understood as adaptive and context-dependent rather than pre-scripted.

3) Environment Layer:

The built environment provides a landscape of affordances that can support or constrain different behaviors. In contrast to static environments, the affordances in this layer are variable and can be reorganized over time through targeted environmental adjustments.

4) Dynamic Engine:

The Dynamic Engine functions as the system's coordinating mechanism. To ensure low-cost implementation, transparency, and reproducibility, it relies on lightweight and widely available inputs — such as time of day, weather conditions, aggregated smartphone-based activity data, optional brief user feedback, and periodic site inspections—rather than continuous high-resolution sensing. Using predefined rules and explicit decision logic, the engine adjusts environmental affordances in the Environment Layer.

For example, during evening hours, different ground-level lighting paths may be activated to offer walkers alternative routes and visual cues, while during periods of higher observed occupancy, simple prompts or manual reconfiguration of public seating can be introduced to encourage social interaction.

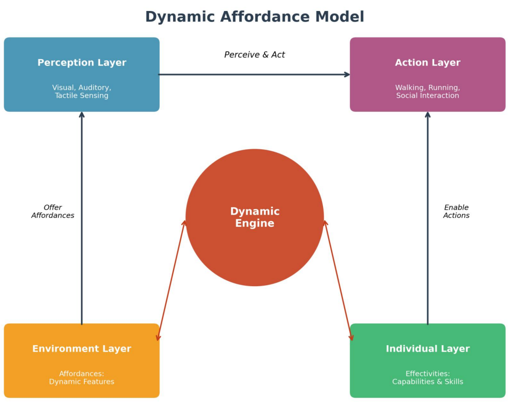

Fig. 2. Dynamic Affordance Model (conceptual person – environment coupling with low-cost, replicable inputs such as smartphone activity logs and facility check-ins)

5) Health Behavior Environment Evaluation Framework

To comprehensively assess the effectiveness and sustainability of the dynamic health behavior environment, this study constructed a multi-dimensional evaluation framework that captures changes at behavioral, physiological, psychological, and systemic levels. This framework enables an integrated assessment of both short-term behavioral responses and longer-term sustainability outcomes, ensuring consistency with the ecological dynamics perspective that health emerges from continuous person – environment interaction.

The framework consists of four main categories of indicators:

a) Behavioral Indicators:

These indicators directly reflect changes in residents' health-related actions and space use patterns. They include physical activity level (e.g., daily step count, activity duration, and moderate-to-vigorous physical activity time), activity diversity (number and variety of activity types observed), spatial utilization rate of public facilities, and frequency of social interactions in shared spaces.

b) Physiological Indicators:

Physiological indicators capture measurable changes in basic health status that are feasible to collect in community settings. These include resting heart rate, body mass index (BMI), and blood pressure, serving as proxy indicators for cardiovascular health and overall physical condition.

c) Psychological Indicators:

Psychological outcomes reflect residents' internal states and perceptions, which play a critical mediating role in sustained behavior change. Key indicators include self-efficacy related to physical activity, subjective well-being, sense of community, and environmental perceptions such as perceived safety, attractiveness, and comfort of public spaces.

d) Sustainability Indicators:

Sustainability indicators evaluate the long-term viability and scalability of the intervention. These include facility usage rates over time, maintenance and operational costs, and overall resident satisfaction with the environment. Together, these indicators assess whether the dynamic environment can maintain its effectiveness without excessive resource input.

By integrating these four dimensions, the evaluation framework moves beyond single-outcome assessments and provides a holistic understanding of how dynamic affordances influence health behaviors, well-being, and system sustainability.

6) Sustainable Health Design Principles

Guided by the Dynamic Affordance Model and the Health Behavior Environment Evaluation Framework, this study distilled five core Sustainable Health Design Principles that informed the design, implementation, and operation of all dynamic intervention facilities:

a) Adaptability

The environment should be capable of adjusting its affordances over time to accommodate changing user needs, behavioral patterns, and contextual conditions (e.g., time of day, weather, and seasonal variation). Adaptability ensures long-term relevance and prevents behavioral habituation.

b) Interactivity

The environment should actively engage users through perceptible cues and responsive elements, encouraging continuous perception – action coupling. Interactivity transforms the environment from a passive backdrop into an active participant in health behavior promotion.

c) Inclusivity

Design interventions should accommodate individuals with diverse physical abilities, ages, and cultural backgrounds by offering multiple, parallel affordances. This principle ensures equitable access to health opportunities and reduces exclusion based on individual effectivities.

d) Motivation

Environmental affordances should intrinsically motivate healthy behaviors by being enjoyable, meaningful, and socially rewarding, rather than relying on external enforcement or coercion. Motivation is strengthened through choice, novelty, and positive feedback embedded in the environment.

e) Ecological Integrity

Interventions should respect and enhance the ecological, social, and cultural context of the community. This principle emphasizes low resource consumption, environmental compatibility, and long-term social value, ensuring that health promotion aligns with broader sustainability goals.

Together, these five principles operationalize ecological dynamics into actionable design guidance, providing a transferable foundation for the development of sustainable, dynamic health behavior environments in diverse community contexts.

C. Study Setting and Participants

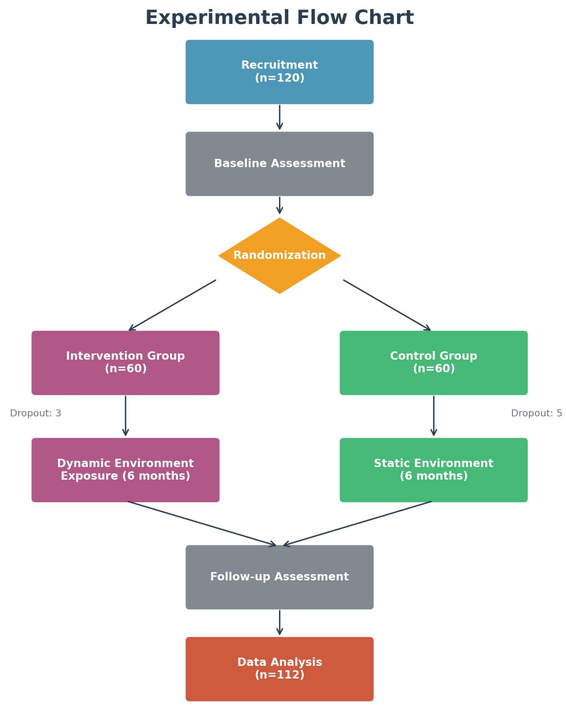

Fig. 3. Experimental Flowchart

The study was conducted in a newly built, large-scale smart community, characterized by well-developed infrastructure, integrated digital services, and a socio-demographically diverse resident population. These features provided an ideal real-world laboratory for examining the effects of a dynamic health behavior environment under typical living conditions. In close collaboration with the community management authority, two residential areas within the community were selected to serve as the intervention zone and the control zone. The two zones had comparable spatial layouts, facility configurations, and baseline service levels but were geographically separated to minimize cross-contamination of intervention effects (see Figure 3).

A total of 120 adult residents were recruited through community-wide announcements and online recruitment platforms. Participants were randomly assigned to either the intervention group (n = 60) or the control group (n = 60). All participants provided written informed consent prior to enrollment, and informed consent was obtained from all subjects involved in the study.

The inclusion criteria were as follows: (1) aged between 18 and 70 years; (2) residence in the community for at least six months prior to the study; and (3) absence of serious medical conditions that would substantially limit engagement in routine physical activity. Upon enrollment, participants completed a baseline survey to collect demographic information (including age, gender, and education level), and baseline health data were recorded to support subsequent longitudinal comparisons.

D. Data Collection Methods

To ensure the comprehensiveness, objectivity, and reproducibility of the empirical evidence, this study adopted a multi-source data collection strategy that integrates behavioral, physiological, psychological, spatial, and experiential data while deliberately avoiding high-cost or hard-to-replicate instrumentation.

1) Smartphone-Based Activity Records.

Participants used their own smartphones and built-in health or fitness applications to continuously record daily step counts and activity duration throughout the study period. When available, participants were also invited to optionally provide resting heart rate readings from commonly accessible personal or home devices (e.g., smartwatch summaries or automated home monitors). This approach ensured low participant burden and high ecological validity while maintaining a low-cost and easily replicable data collection protocol.

2) Facility Use and Space Utilization Records.

To assess patterns of public space use without deploying expensive sensing infrastructure, facility utilization and crowding levels were estimated using a set of lightweight, reproducible methods. These included time-stamped facility-use logs (such as voluntary QR-code check-ins or simple mechanical counters), periodic manual headcounts at predefined observation points, and structured observation sheets documenting coarse space-use patterns (e.g., presence, activity type, and approximate duration) without tracking individual trajectories. This approach balanced data richness with privacy protection and methodological feasibility.

3) Mobile Application – Based Surveys.

A companion mobile application was used to periodically distribute standardized questionnaires to participants. These surveys captured subjective psychological and perceptual data, including mood, perceived well-being, environmental satisfaction, and sense of community. In addition to data collection, the application also served as a basic communication channel for study-related information and reminders, enhancing participant engagement.

4) Brief On-Site Health Checks.

To capture essential physiological indicators in a standardized yet feasible manner, brief on-site health checks were conducted for all participants at three time points: baseline, mid-intervention, and post-intervention. Measurements were performed using widely available devices, including a digital scale and an automated blood pressure monitor. The checks focused on core indicators—body weight and BMI, blood pressure, and resting pulse or heart rate—following a consistent measurement protocol to enhance reliability while maintaining practical applicability in community settings.

5) Semi-Structured Interviews.

At the conclusion of the intervention, a purposive subsample of 20 participants from the intervention group was selected for semi-structured interviews. These interviews aimed to capture participants' lived experiences, perceived behavioral changes, and qualitative evaluations of the dynamic health behavior environment. The interview data provided contextual depth and explanatory insights to complement the quantitative findings.

E. Data Analysis Methods

This study employed a mixed-methods analytical strategy, integrating quantitative statistical analysis with qualitative thematic interpretation to comprehensively evaluate the effects and mechanisms of the dynamic health behavior environment.

1) Quantitative Analysis

All quantitative analyses were conducted using open-source software (R and Python) to enhance transparency, accessibility, and reproducibility across typical research settings.

a) Descriptive Statistics.

Descriptive analyses were performed to summarize participants' demographic characteristics and the distributions of all behavioral, physiological, psychological, and environmental variables at each measurement time point.

b) Baseline Comparability Tests.

Independent-samples t-tests (for continuous variables) and chi-square tests (for categorical variables) were used to assess baseline equivalence between the intervention and control groups, ensuring group comparability prior to intervention implementation.

c) Difference and Longitudinal Effect Tests.

Repeated-measures analysis of variance (RM-ANOVA) was employed to examine time effects, group effects, and time-by-group interaction effects on key outcome indicators, including physical activity, physiological measures, and psychological perceptions. Where assumptions were not met, appropriate robust or non-parametric alternatives were applied and reported.

d) Regression Analysis.

Regression models, including general linear models and reproducible mixed-effects models where appropriate, were used to examine how individual-level characteristics (e.g., age, gender, baseline activity level) and environment-level factors (e.g., exposure to dynamic affordances, facility use intensity) jointly influenced health behavior outcomes.

e) Pathway and Mediation Testing.

To test the hypothesized causal pathways proposed in the Dynamic Affordance Model, regression-based mediation analyses were conducted using bootstrapped confidence intervals. This approach allowed for transparent and widely reproducible pathway testing without reliance on specialized structural equation modeling (SEM) software.

All statistical tests were two-tailed, with a significance threshold of $p < 0.05$ unless otherwise specified.

2) Qualitative Analysis

Qualitative data from the semi-structured interviews were audio-recorded, transcribed verbatim, and analyzed using Thematic Analysis. A transparent, spreadsheet-based coding workflow was adopted to enhance reproducibility and accessibility.

Initial open coding was conducted to identify meaningful segments related to user experience, perceived behavioral change, environmental perception, and system usability. Codes were then iteratively grouped into higher-order themes. To ensure analytical rigor, double-coding was performed on a subset of transcripts by two researchers, and discrepancies were discussed until consensus was reached. The resulting themes were used to contextualize and explain the quantitative findings and to identify perceived strengths, limitations, and areas for future improvement.

V. DATA

This chapter presents the empirical data overview of the study. It first describes the demographic characteristics of the participant sample, followed by descriptive statistics of the key behavioral, physiological, psychological, and environmental variables. Finally, it outlines the data preprocessing and quality-control workflow, including data cleaning, screening, and preparation procedures undertaken prior to statistical analysis, to ensure the reliability, validity, and reproducibility of the results.

A. Sample Description

A total of 120 community residents were enrolled in the study and randomly allocated to either the intervention group (n = 60) or the control group (n = 60). Over the six-month study period, 8 participants withdrew due to circumstances such as relocation or extended business travel (3 from the intervention group and 5 from the control group). As a result, the final analytical sample consisted of 112 participants, including 57 in the intervention group and 55 in the control group (see Figure 4).

Baseline comparisons showed no statistically significant differences between the two groups in key demographic and health-related characteristics, including age, gender, education level, marital status, and baseline BMI (all $p > 0.05$). These results indicate that the randomization procedure was effective and that the intervention and control groups were well balanced and comparable at the start of the study (see Table I).

TABLE I. BASELINE DEMOGRAPHIC AND HEALTH CHARACTERISTICS OF PARTICIPANTS

Variable	Intervention Group (n=57)	Control Group (n=55)	p-value
Age (years), mean ± SD	48.3 ± 14.2	47.8 ± 15.1	0.856
Female, n (%)	29 (50.9%)	28 (50.9%)	0.998
BMI (kg/m²), mean ± SD	24.8 ± 3.6	25.1 ± 3.8	0.672
Education - High School, n (%)	14 (24.6%)	16 (29.1%)	0.582
Education - Bachelor, n (%)	29 (50.9%)	27 (49.1%)	0.852
Education - Master & Above, n (%)	14 (24.6%)	12 (21.8%)	0.724
Married, n (%)	42 (73.7%)	40 (72.7%)	0.908

Employed, n (%)	38 (66.7%)	35 (63.6%)	0.738
Baseline Daily Steps, mean ± SD	6250 ± 1520	6180 ± 1480	0.805
Baseline MVPA (min/week), mean ± SD	85 ± 35	88 ± 38	0.652
Baseline Self-Efficacy (1-5), mean ± SD	3.2 ± 0.8	3.1 ± 0.9	0.528

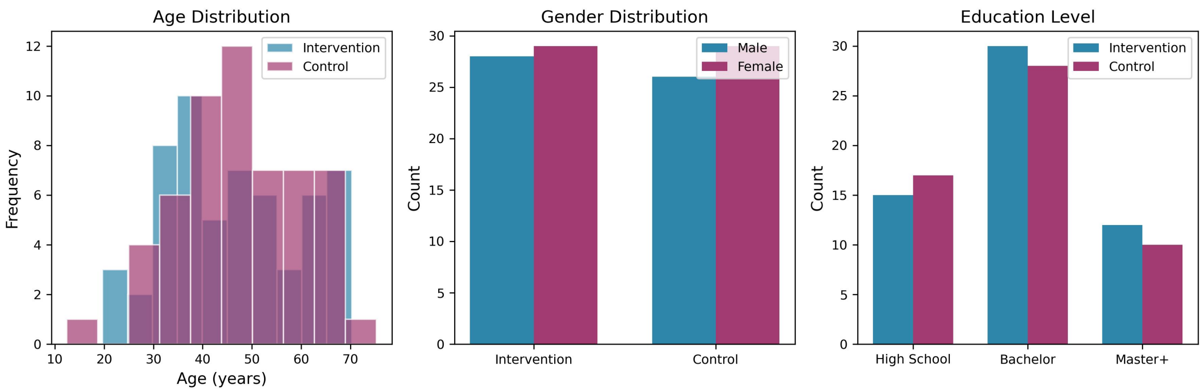

Fig. 4. Distribution of Sample Demographic Characteristics

B. *Descriptive Statistics*

Descriptive statistical analyses were performed on all key baseline measurement indicators (see Table II). The results indicate that, prior to the intervention, participants in the intervention and control groups exhibited comparable levels of average daily step counts, moderate-to-vigorous physical activity (MVPA) duration, resting heart rate, and self-efficacy scores. No statistically significant differences were observed between the two groups across these indicators ($p > 0.05$), suggesting a well-balanced baseline. This comparability provides a robust and reliable foundation for assessing the effects of the intervention in the subsequent analyses.

TABLE II. DESCRIPTIVE STATISTICS OF KEY OUTCOME VARIABLES (DERIVED FROM ROUTINE SMARTPHONE ACTIVITY LOGS AND LOW-COST FACILITY CHECK-INS)

Variable	**Time Point**	**Intervention Mean**	**Intervention SD**	**Control Mean**	**Control SD**
Daily Steps	Baseline	6250	1520	6180	1480
Daily Steps	Month 3	7890	1680	6280	1520
Daily Steps	Month 6	8960	1850	6310	1550
MVPA (min/week)	Baseline	85	35	88	38
MVPA (min/week)	Month 3	125	42	92	40
MVPA (min/week)	Month 6	155	50	90	42
Resting Heart Rate (bpm)	Baseline	72.5	8.2	73.1	8.5
Resting Heart Rate (bpm)	Month 3	70.8	7.8	72.8	8.3
Resting Heart Rate (bpm)	Month 6	69.2	7.5	72.5	8.2
Self-Efficacy (1-5)	Baseline	3.2	0.8	3.1	0.9
Self-Efficacy (1-5)	Month 3	3.8	0.7	3.2	0.9
Self-Efficacy (1-5)	Month 6	4.2	0.6	3.2	0.8

Social Interaction (times/week)	Baseline	3.5	1.8	3.4	1.7
Social Interaction (times/week)	Month 3	5.2	2.1	3.6	1.8
Social Interaction (times/week)	Month 6	6.8	2.4	3.5	1.9

C. Data Preprocessing

Prior to formal analysis, all raw data underwent a rigorous and transparent preprocessing procedure to ensure data quality and analytical reliability.

- Data Cleaning: For smartphone-derived activity records, days with clearly implausible values were excluded, as were days explicitly flagged by participants as non-carry or abnormal routine days (e.g., travel or illness). A valid observation day was defined as one with a complete daily step record and no abnormality flag, following a simple and easily reproducible rule.
- Missing Value Handling: Because the overall proportion of missing data was low (less than 5%), straightforward and transparent strategies were adopted. The primary analyses were conducted using complete-case data, while sensitivity analyses applied simple single-imputation methods for questionnaire items (e.g., participant-level mean or median within the same scale) to verify the robustness of the results.
- Data Aggregation: Daily activity records were aggregated into analytically meaningful indicators, including average daily step counts, average weekly moderate-to-vigorous physical activity (MVPA) duration (when available from smartphone summaries), and periodic resting heart rate or pulse values obtained from the brief on-site health checks.
- Data Integration: Multi-source data — including smartphone-based activity records, mobile app questionnaires, brief on-site health measurements, and facility-use or structured observation logs—were temporally aligned by measurement wave to construct a unified longitudinal dataset for each participant.

VI. Results

This chapter presents the core findings derived from both quantitative and qualitative analyses in an objective and systematic manner, with the aim of evaluating and validating the effectiveness of the dynamic health behavior environment. Quantitative results focus on changes in residents' health-related behaviors, physiological indicators, and psychological perceptions over time, as well as differences between the intervention and control groups. Qualitative findings complement these results by providing in-depth insights into participants' experiences, perceptions, and interpretations of the dynamic environment, helping to explain the underlying mechanisms through which the intervention influenced behavior. Together, these results offer a comprehensive assessment of the effectiveness and practical value of the proposed dynamic health behavior environment.

A. Environmental Affordance Evaluation Results

At the conclusion of the six-month intervention, participants' environmental perceptions were assessed using the Perceived Affordance Scale. As shown in Figure 5, the intervention group reported significantly higher scores than the control group on the dimensions of interactivity, adaptability, and attractiveness ($p < 0.01$). In contrast, no statistically significant differences were observed between the two groups with respect to safety and comfort. These results suggest that the dynamic health behavior environment effectively enhanced residents' perceptions of the environment as engaging and responsive, without compromising their sense of safety or comfort.

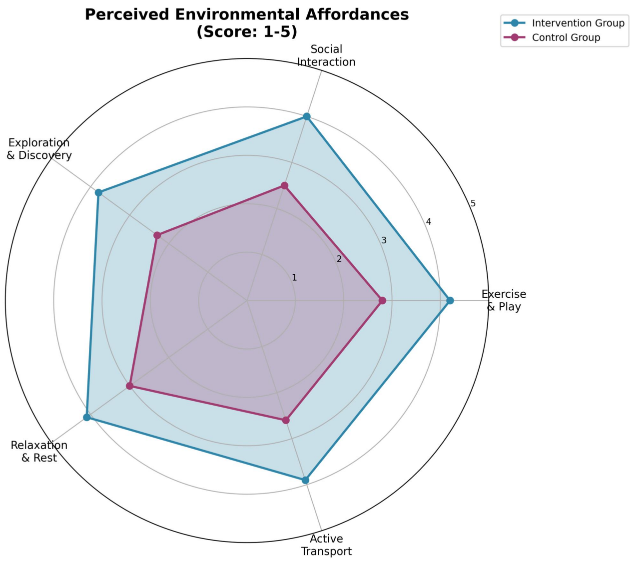

Fig. 5. Radar Chart of Perceived Environmental Affordances for Intervention and Control Groups

B. Impact on Health Behaviors

1) Changes in Physical Activity Level

The repeated-measures ANOVA revealed a significant time × group interaction for average daily step count ($F(2, 220) = 15.8$, $p < 0.001$), indicating that changes in physical activity over time differed markedly between the intervention and control groups (see Figure 6). As illustrated in Figure 7, participants in the intervention group exhibited a steady and substantial increase in daily steps across the six-month period, rising from a baseline average of 6,250 steps to 8,960 steps, corresponding to a 43.4% increase. In contrast, the control group showed no statistically meaningful change in daily step count over the same period.

A comparable pattern was observed for moderate-to-vigorous physical activity (MVPA) duration, further corroborating the positive effect of the dynamic health behavior environment on residents' physical activity levels.

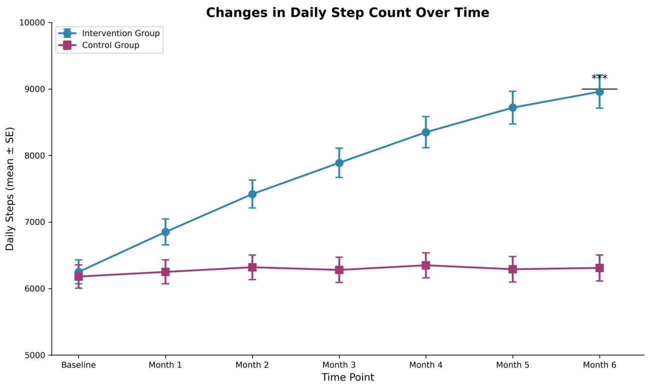

Fig. 6. Trend of Changes in Average Daily Steps for Both Groups

2) Impact on Social Interaction

The intervention also exerted a significant positive effect on social interaction. In the intervention group, the average weekly frequency of social interactions increased from 3.5 times at baseline to 6.8 times by the end of the study period, whereas the control group exhibited no statistically significant change.

These self-reported improvements were corroborated by facility-use logs and structured observational data, which showed a higher degree of co-occurrence in public spaces within the intervention area, as well as longer observed dwell times during peak usage periods. Together, these findings indicate that the dynamic health behavior environment not only promoted physical activity but also effectively fostered social engagement and use of shared community spaces.

C. Impact on Physiological and Psychological Indicators

After six months of intervention, participants in the intervention group exhibited measurable improvements in physiological and psychological health indicators. Specifically, resting heart rate decreased significantly ($p < 0.05$), indicating a potential enhancement in cardiovascular fitness. Body Mass Index (BMI) showed a modest improvement, although this change did not reach statistical significance, suggesting that longer intervention periods or complementary dietary strategies may be required to produce detectable anthropometric changes.

In terms of psychological outcomes, the intervention group demonstrated a substantial increase in self-efficacy, with mean scores rising from 3.2 to 4.2 ($p < 0.001$). In addition, subjective well-being and sense of community scores were both significantly higher in the intervention group compared with the control group at follow-up. These findings suggest that the dynamic health behavior environment not only supported healthier behaviors but also strengthened residents' confidence, emotional well-being, and social connectedness.

D. Analysis of Individual Differences

To examine whether the dynamic health behavior environment exerted differential effects across population subgroups, a subgroup analysis by age was conducted. The results indicate that, although the intervention produced positive effects on physical activity outcomes across all age groups, the increase in moderate-to-vigorous physical activity (MVPA) was most pronounced among middle-aged participants (45 – 59 years).

Insights from the in-depth interviews help explain this pattern. Participants in this age group frequently emphasized that the dynamic environment offered a balanced combination of challenge and safety. On the one hand, adaptable and engaging affordances provided sufficient stimulation to support health improvement goals; on the other hand, the perceived safety and controllability of the environment reduced concerns about injury or excessive physical strain. This alignment with the middle-aged group's dual priorities — enhancing physical health while minimizing risk—appears to have amplified the intervention's effectiveness for this population.

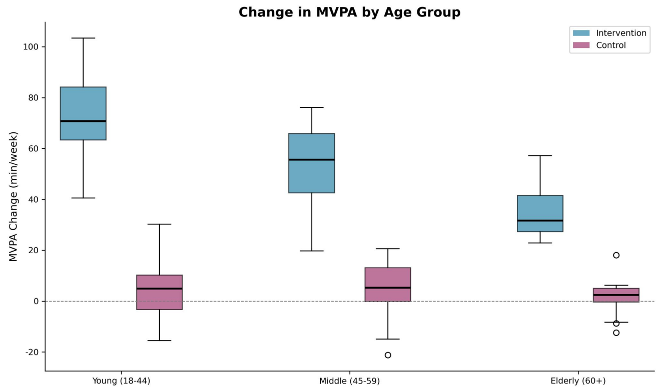

Fig. 7. Boxplot of Intervention Effects (Change in MVPA) by Age Group

E. Spatiotemporal Analysis of Facility Use

The heatmap derived from routine facility usage records (see Figure 8)—based on aggregated QR-code check-ins and anonymized Bluetooth/Wi-Fi counts — illustrates the spatiotemporal intensity of use across the main dynamic facilities. The results reveal clear temporal differentiation in facility utilization.

Specifically, the interactive light-up plaza was most frequently used during the evening hours, functioning as a focal point for family-oriented and social activities. In contrast, the smart fitness trail exhibited distinct usage peaks in the morning and early evening, aligning with residents' daily exercise routines.

These patterns suggest that the dynamic facilities successfully generated time-specific affordances, attracting different user groups at different periods of the day. By doing so, the intervention effectively distributed resident activities across space and time, reduced crowding at single locations, and enriched the diversity and rhythm of daily activity patterns within the community.

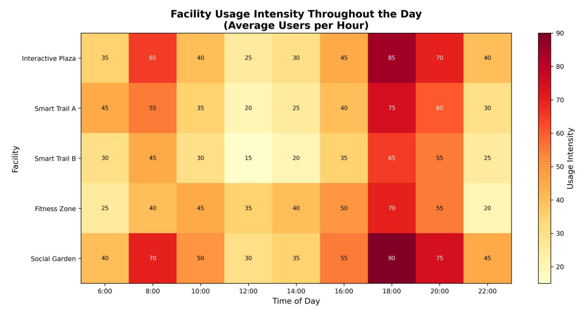

Fig. 8. Spatiotemporal Heatmap of Main Dynamic Facility Usage Intensity (derived from aggregated facility QR check-ins and anonymized Bluetooth/Wi-Fi counts)

F. Validation of the Theoretical Model

We evaluated the proposed theoretical model using regression-based mediation analyses (see Figure 9). The results provide strong support for the hypothesized pathways. Specifically, dynamic affordances exert a significant direct positive effect on health behavior (standardized $\beta = 0.28$, $p < 0.01$), indicating that dynamically adjustable environmental features can directly encourage residents' engagement in healthy activities.

More importantly, dynamic affordances also demonstrate substantial indirect effects on health behavior through two key mediators. First, perceived attractiveness significantly mediates this relationship (indirect effect $\approx 0.58 \times 0.45 = 0.26$, $p < 0.001$), suggesting that environments perceived as more engaging and appealing are more likely to stimulate active use. Second, self-efficacy also serves as a significant mediator (indirect effect $\approx 0.62 \times 0.52 = 0.32$, $p < 0.001$), indicating that dynamic environments enhance individuals' confidence in their ability to engage in health-promoting behaviors.

Taken together, these findings confirm the core mechanism proposed in this study: dynamic health behavior environments promote healthy behaviors not only through direct environmental influence, but also indirectly by increasing perceived environmental attractiveness and strengthening individual self-efficacy, thereby reinforcing the person – environment coupling emphasized in the dynamic affordance model.

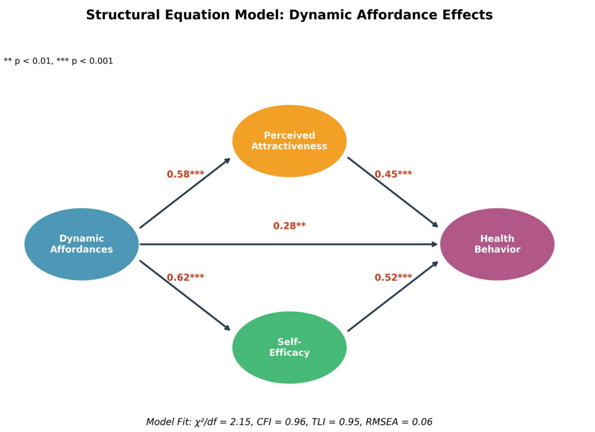

Fig. 9. Path Diagram of the Mediation Model for the Dynamic Affordance Theory (regression-based path analysis with bootstrapped indirect effects)

G. Qualitative Analysis Results

The thematic analysis of the semi-structured interviews identified three interrelated themes that help explain the quantitative findings and illuminate the experiential mechanisms underlying the intervention's effects:

1) From "Forced Exercise" to "Invited Play."
Many participants reported that the dynamic and playful qualities of the environment fundamentally changed their perception of physical activity. Rather than viewing exercise as a compulsory or monotonous task, they experienced it as an engaging, exploratory activity that they were naturally drawn into. This shift aligns with the concept of affordances as "invitations to act," emphasizing voluntary engagement rather than obligation.

2) A Sense of Control and Accomplishment.
Participants frequently highlighted the importance of being able to interact with the environment and receive immediate, visible feedback (e.g., changing lights, responsive cues). This interaction fostered a sense of agency, control, and accomplishment, which in turn strengthened their confidence and intrinsic motivation to remain active over time.

3) Social Catalyst.
The dynamic facilities—particularly the large interactive plaza—were widely described as a "social catalyst." They created more opportunities for spontaneous encounters, shared activities, and conversations among neighbors, thereby enhancing social connectedness and reinforcing community cohesion.

Together, these themes illustrate how dynamic affordances operate not only at the physical level but also at the psychological and social levels, supporting sustained health behaviors through enjoyment, empowerment, and social engagement.

VII. Discussion

This study systematically designed and evaluated a dynamic health behavior environment grounded in the ecological dynamics framework. The findings offer strong empirical evidence that this emerging design approach is effective in promoting residents' health. This chapter interprets the key results, situates them within existing research, discusses theoretical and practical implications, and acknowledges the study's limitations.

A. Interpretation of Key Findings

The most notable outcome of this study is that, compared with a traditional static environment, the dynamic health behavior environment significantly increased residents' physical activity levels and frequency of social interaction. This finding supports the core hypothesis that environments capable of dynamically adjusting their affordances are more effective at continuously encouraging and guiding healthy behaviors. The consistent rise in daily step counts in the intervention group over a six-month period — without evidence of a fading novelty effect—suggests that dynamic design promotes sustained behavior change rather than short-term compliance.

Another key contribution is the empirical validation of the Dynamic Affordance Model through mediation analysis. The results clarify the psychological pathways through which the dynamic environment influences behavior. Beyond its direct effects, the environment enhances health behaviors by increasing residents' perceived environmental attractiveness and strengthening their self-efficacy. This underscores the importance of designing environments that go beyond functional provision to deliver positive emotional experiences — such as enjoyment, novelty, and aesthetic appeal — while also fostering a sense of autonomy and competence. Qualitative data reinforce this conclusion, with participants describing a shift from experiencing exercise as an obligation to perceiving it as an engaging and playful activity.

The study also demonstrates that dynamic environments are better suited to accommodating individual differences.

Positive effects were observed across all age groups, with the strongest benefits seen among middle-aged residents. This suggests that environments offering diverse and flexible affordances can provide appealing activity options for a broad population, reflecting an inclusive design philosophy.

B. Comparison with Existing Research

This research advances the literature on the built environment and health in several important ways. While previous studies based on the "5D" framework have established links between static environmental characteristics and physical activity, this study highlights the critical role of environmental dynamism in sustaining long-term engagement. Similarly, although nudge-based interventions have proven effective within informational choice architectures, this research extends the nudge concept into the physical realm, creating embodied and immersive "physical nudges."

In comparison with mHealth interventions that rely on dynamically tailored digital messaging, the present approach targets the physical environment itself, potentially yielding more durable and community-wide impacts. By reshaping the context in which behaviors occur, rather than focusing solely on individual persuasion, this approach aligns closely with ecological and public health principles. The study also builds upon smart health environment research by offering a solid theoretical foundation based on ecological dynamics and by providing a comprehensive, long-term, multi-dimensional evaluation that moves beyond technological demonstrations.

C. Theoretical and Practical Implications

Theoretically, this study is among the first to empirically test the ecological dynamics framework within a large-scale, real-world built environment. It extends affordance theory by introducing and operationalizing the concept of dynamic affordances, illustrating how environmental design can actively shape the perception–action cycle. The validated Dynamic Affordance Model provides a valuable foundation for future research in this domain.

From a practical standpoint, the findings suggest a new paradigm for urban planners, architects, and public health policymakers. The proposed sustainable health design principles—adaptability, interactivity, inclusivity, motivation, and ecological integrity—offer actionable guidance for creating healthier communities. The success of the intervention indicates that investments in smart, interactive public spaces can deliver meaningful public health benefits. For instance, urban renewal projects and new residential developments could integrate dynamic lighting, modular public furniture, and interactive installations to foster more active and socially engaging environments.

D. Limitations and Future Research

Several limitations should be acknowledged. First, although a control group was included, the quasi-experimental design does not provide the same level of causal inference as a randomized controlled trial. Second, the study was conducted in a single newly developed smart community, which may limit generalizability to older or less technologically advanced neighborhoods. Third, while physical activity was the primary outcome, further research is needed to explore deeper impacts on mental health and social capital. Finally, the long-term sustainability of such interventions—particularly in terms of maintenance costs and technological obsolescence—requires continued monitoring.

Future research should address these limitations by conducting randomized controlled trials across diverse community contexts. Longer-term longitudinal studies are needed to assess sustained behavioral and health outcomes. Cost-effectiveness analyses would further inform policy decisions. Additionally, future work could explore applying this framework to other health behaviors, such as healthy eating, and to specific populations, including children and individuals with disabilities.

VIII. CONCLUSION

This study demonstrates that a sustainable health design framework grounded in ecological dynamics can effectively enhance residents' physical activity, social interaction, and overall well-being. By shaping a dynamic health behavior environment that continuously responds to and accommodates individual needs, this approach moves beyond the constraints of static, one-size-fits-all design strategies.

The central contribution of this research lies in bridging the gap between the theoretical depth of ecological dynamics and the real-world demands of public health promotion. The findings show that, when combined with modern technologies, built environments can evolve from passive settings into active and engaging partners in supporting healthier lifestyles. Overall, the results suggest that the future of healthy cities may depend on the creation of intelligent, responsive, and playful environments—spaces that naturally encourage healthy behaviors by making them both easy and enjoyable for everyone.

REFERENCES

[1] GBD 2019 Mental Disorders Collaborators. (2022). Global, regional, and national burden of 12 mental disorders in 204 countries and territories, 1990–2019: A systematic analysis for the Global Burden of Disease Study 2019. The Lancet Psychiatry, 9(2), 137-150. https://doi.org/10.1016/S2215-0366(21)00395-3

[2] World Health Organization. (2010). Global recommendations on physical activity for health. World Health Organization. https://www.who.int/publications/i/item/9789241599979

[3] Sallis, J. F., Cerin, E., Conway, T. L., Adams, M. A., Frank, L. D., Pratt, M., Salvo, D., Schipperijn, J., Smith, G., Cain, K. L., Davey, R., Kerr, J., Lai, P.-C., Mitáš, J., Reis, R., Sarmiento, O. L., Schofield, G., Troelsen, J., Van Dyck, D., & Owen, N. (2016). Physical activity in relation to urban environments in 14 cities worldwide: A cross-sectional study. The Lancet, 387(10034), 2207-2217. https://doi.org/10.1016/S0140-6736(15)01284-2

[4] Turvey, M. T. (1992). Affordances and prospective control: An outline of the ontology. Ecological Psychology, 4(3), 173-187. https://doi.org/10.1207/s15326969eco0403_3

[5] Warren, W. H. (2006). The dynamics of perception and action. Psychological Review, 113(2), 358-389. https://doi.org/10.1037/0033-295X.113.2.358

[6] Gibson, J. J. (2014). The ecological approach to visual perception (Classic ed.). Psychology Press. https://doi.org/10.4324/9781315740218

[7] Brito, H., Brymer, E., & Araújo, D. (2022). An ecological dynamics perspective on designing urban nature environments for wellbeing and health-enhancing physical activity. Frontiers in Public Health, 10, 877208. https://doi.org/10.3389/fpubh.2022.877208

[8] Richardson, M. J., Shockley, K., Fajen, B. R., Riley, M. A., & Turvey, M. T. (2008). Ecological psychology: Six principles for an embodied–

embedded approach to behavior. In P. Calvo & T. Gomila (Eds.), Handbook of cognitive science: An embodied approach (pp. 159-187). Elsevier. https://www.sciencedirect.com/science/article/pii/B9780080466163000098

[9] Chemero, A. (2013). Radical embodied cognitive science. Review of General Psychology, 17(2), 145-150. https://doi.org/10.1037/a0032923

[10] Warren, W., Fajen, B., & Belcher, D. (2001). Behavioral dynamics of steering, obstacle avoidance, and route selection. Journal of Vision, 1(3), 184. https://doi.org/10.1167/1.3.184

[11] Stokols, D. (1996). Translating social ecological theory into guidelines for community health promotion. American Journal of Health Promotion, 10(4), 282-298. https://doi.org/10.4278/0890-1171-10.4.282

[12] Ewing, R., & Cervero, R. (2010). Travel and the built environment: A meta-analysis. Journal of the American Planning Association, 76(3), 265-294. https://doi.org/10.1080/01944361003766766

[13] Thaler, R. H., & Sunstein, C. R. (2009). Nudge: Improving decisions about health, wealth, and happiness. Penguin. https://books.google.com/books/about/Nudge.html?id=dSJQn8egXvUC

[14] Barton, H. (Ed.). (2000). Sustainable communities: The potential for eco-neighbourhoods. Earthscan. https://doi.org/10.4324/9781315870649

[15] World Health Organization. (2022). Implementing health in all policies: A pilot toolkit. World Health Organization. https://iris.who.int/handle/10665/366435

[16] Morgenthaler, T., Lynch, H., Loebach, J., Pentland, D., & Schulze, C. (2024). Using the theory of affordances to understand environment–play transactions: Environmental taxonomy of outdoor play space features—A scoping review. The American Journal of Occupational Therapy, 78(4), 7804185120. https://doi.org/10.5014/ajot.2024.050606

[17] van den Hoven, E., Mazalek, A., & Margetis, G. (2024). Tangible and embodied interaction. In C. Stephanidis & G. Salvendy (Eds.), Interaction techniques and technologies in human-computer interaction (pp. 290-324). CRC Press. https://doi.org/10.1201/9781003490678-11

[18] Hekler, E. B., Michie, S., Pavel, M., Rivera, D. E., Collins, L. M., Jimison, H. B., Garnett, C., Parral, S., & Spruijt-Metz, D. (2016). Advancing models and theories for digital behavior change interventions. American Journal of Preventive Medicine, 51(5), 825-832. https://doi.org/10.1016/j.amepre.2016.06.013

[19] Acampora, G., Cook, D. J., Rashidi, P., & Vasilakos, A. V. (2013). A survey on ambient intelligence in health care. Proceedings of the IEEE, 101(12), 2470-2494. https://doi.org/10.1109/JPROC.2013.2262913

[20] Autio, P. (2021). Passive sensing data sources on citizen opinions, emotions and experiences to benefit urban planning in Malmi, Helsinki (Master ' s thesis). Aalto University. https://aaltodoc.aalto.fi/items/46d4e206-a469-4838-bcee-f59013e6f848

ACKNOWLEDGEMENTS

The authors would like to thank all community residents who participated in the six-month study for their time, sustained engagement, and valuable feedback. We also gratefully acknowledge the support of community management and on-site staff for facilitating the implementation and coordination of the intervention activities and data collection. In addition, we appreciate the assistance of colleagues and volunteers who contributed to study organization, field operations, and data handling. Finally, we thank the anonymous reviewers for their constructive comments that helped improve the manuscript.

FUNDING

None.

AVAILABILITY OF DATA

Not applicable.

AUTHOR CONTRIBUTIONS

Yingyan He contributed to conceptualization, theoretical framework development, methodology design, formal analysis, and drafted the original manuscript. Wanfen Lin contributed to practical implementation support, field coordination, investigation and data collection, data curation, and critically reviewed and edited the manuscript. Both authors contributed to the interpretation of results and approved the final version of the manuscript.

COMPETING INTERESTS

The authors declare no competing interests.

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