Synapse Flora: Design of an Adaptive Intelligent Biophilic Environmental Intervention System for Personalized Digital Well-Being

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Abstract*— The increasing dependence on digital technologies in educational and occupational environments has intensified prolonged screen exposure, contributing to digital stress, technostress, and reduced digital well-being. Although recent advances in wearable devices, artificial intelligence (AI), and digital health technologies enable continuous monitoring of physiological and behavioral indicators, existing approaches often address individual components of stress detection, digital intervention, or biophilic environmental support, with limited integration of adaptive environmental strategies based on biophilic principles. Therefore, this paper proposes Synapse Flora, an adaptive intelligent biophilic environmental intervention system designed to support personalized digital well-being during prolonged digital activities. The proposed conceptual architecture integrates wearable-based physiological monitoring, digital behavior analysis, environmental sensing, and AI to estimate the user's well-being state and dynamically select context-aware environmental interventions. To support this integration, an Adaptive Biophilic Decision Engine (ABDE) was defined to process multimodal information while considering user preferences and predefined safety constraints. The system was developed following an Evidence-Informed Engineering Design methodology that integrates evidence synthesis, user-centered requirements, engineering design, and sustainability principles. An exploratory survey of 36 participants found that 61.1% reported experiencing mental fatigue, difficulty concentrating, or mental saturation frequently or always after prolonged screen exposure, while the proposed concept received a mean attractiveness score of 4.69/5. These findings provide preliminary user-centered evidence regarding the perceived relevance of the problem and the attractiveness of the proposed concept, while experimental validation remains necessary to determine intervention effectiveness.

Keywords*— Artificial Intelligence; Digital Well-Being; Occupational Stress; Biophilic Design; Wearable Devices.

I. INTRODUCTION

The widespread adoption of digital technologies has transformed the way students and professionals study, communicate, and work. Although these technologies have improved productivity and accessibility, prolonged screen exposure, sustained cognitive demands, and continuous digital connectivity have contributed to digital stress, technostress, cognitive overload, and reduced digital well-being [1]-[2].

To mitigate these challenges, recent research has explored digital well-being interventions supported by artificial intelligence (AI), wearable technologies, physiological monitoring, and Internet of Things (IoT) devices. AI-based approaches can estimate stress from physiological and behavioral data, while wearable devices continuously monitor indicators such as heart rate (HR), heart rate variability (HRV), sleep quality, and physical activity [3]-[5].

At the same time, biophilic design has gained increasing attention as a strategy for improving psychological restoration and indoor environmental quality. Previous studies have shown that natural elements such as vegetation, natural lighting, and multisensory environmental experiences can reduce stress, improve cognitive performance, and enhance users' well-being in educational and occupational environments [6]-[7].

Despite these advances, the reviewed approaches largely address physiological monitoring, artificial intelligence, environmental sensing, and biophilic interventions as complementary but separately developed components. The literature reviewed in this study indicates limited integration of physiological state, digital behavior, environmental conditions, user preferences, and adaptive biophilic interventions within a unified engineering framework.

To address this research gap, this paper proposes Synapse Flora, which integrates physiological monitoring, behavioral analysis, environmental sensing, artificial intelligence, and sustainable engineering principles into a unified conceptual architecture. The proposed system extends digital well-being support toward the physical environment through adaptive biophilic strategies supported by an Adaptive Biophilic Decision Engine (ABDE).

The main contributions of this work are summarized as follows:

- A conceptual framework that combines physiological, behavioral, and environmental information to support personalized digital well-being.
- An adaptive biophilic decision engine (ABDE) that enables context-aware environmental interventions based on user and environmental conditions.
- A modular system architecture that incorporates sustainability, repairability, and design for sustainability (DfS) principles into the proposed solution.

- A design methodology for developing intelligent biophilic environments that integrates evidence from digital well-being, artificial intelligence, wearable sensing, and biophilic design.

II. RELATED WORK

A. Digital stress and digital well-being

The widespread adoption of digital technologies has increased dependence on computers, smartphones, and digital platforms across educational and occupational environments. Although these technologies have improved productivity and connectivity, prolonged digital exposure has also contributed to digital stress, technostress, and cognitive overload [1]-[2].

To mitigate these effects, various digital well-being interventions have been proposed, including mobile applications, web-based platforms, mindfulness techniques, and active break reminders. While these approaches have shown positive effects on stress reduction, their long-term effectiveness often depends on sustained user engagement. Furthermore, most existing solutions rely on notification-based interventions, making them susceptible to alert fatigue and decreasing user adherence over time [2], [8].

B. Artificial intelligence and wearable-based stress monitoring

Recent advances in AI and wearable technologies have enabled continuous monitoring of physiological and behavioral indicators associated with stress and well-being. Commercial wearable devices can acquire variables such as heart rate (HR), heart rate variability (HRV), sleep quality, blood oxygen saturation, and physical activity, while smartphones provide complementary behavioral information including screen time and application usage [3]-[4].

Machine learning techniques have demonstrated promising performance for estimating stress using multimodal physiological and behavioral data. However, most existing studies focus on stress detection and classification rather than using these data to support adaptive environmental interventions capable of improving users' well-being during prolonged digital activities [3], [9].

C. Biophilic environmental interventions

Biophilic design has emerged as an effective strategy for improving indoor environmental quality and promoting psychological restoration. The incorporation of natural elements, including vegetation, natural lighting, and multisensory environmental experiences, has been associated with reduced stress, enhanced cognitive performance, and improved user well-being in educational and occupational settings [6]-[7].

Despite these benefits, current biophilic interventions are generally implemented as static environmental resources that do not adapt to users' physiological conditions, behavioral patterns, or contextual information. Consequently, their ability to provide personalized support during prolonged digital activities remains limited [10]-[11].

D. Comparative analysis of existing approaches

The reviewed literature demonstrates significant advances in digital well-being, wearable technologies, AI, biophilic design, and Internet of Things (IoT)-based environmental monitoring. Nevertheless, these research areas have largely evolved independently, with limited integration among human-centric sensing, environmental control, and adaptive decision-making [3], [5], [6].

Table I summarizes representative studies according to the integration of AI, IoT, physiological monitoring, biophilic intervention, adaptive decision-making, and their reported limitations.

The comparative analysis reveals a clear research gap: although previous studies address individual aspects of digital well-being, the reviewed approaches show limited integration of physiological monitoring, contextual behavioral analysis, adaptive biophilic interventions, intelligent decision-making, and sustainable engineering within a unified conceptual architecture. This gap motivated the development of Synapse Flora.

TABLE I
COMPARATIVE ANALYSIS OF REPRESENTATIVE STUDIES

Ref.	AI	IoT	Physiol. Mon.	Biophilic Int.	Adaptive Dec.	Main Limitation
Lavender inhalation and stress	×	×	✓	✓	×	No intelligent monitoring
Intelligent adaptive environments	✓	✓	Partial	×	✓	No biophilic intervention
ML for stress detection	✓	×	✓	×	Partial	Limited personalization
Biophilic design and workplace stress	×	×	Partial	✓	×	No automatic adaptation
Personalized digital interventions	Partial	✓	Partial	×	✓	No biophilic integration
AI-based mental stress detection	✓	×	✓	×	Partial	Physiological stress focus
AI-based adaptive learning and personalization	✓	×	×	×	✓	Performance-based adaptation
Biophilic workplace design	×	×	Partial	✓	×	No intelligent adaptation
Digital and actual nature for stress reduction	×	×	✓	✓	×	No dynamic personalization
Real-time smart plant monitoring	×	✓	×	Partial	Partial	Plant-focused adaptation
IoT indoor monitoring and plant care	×	✓	×	Partial	Partial	Plant-needs-based adaptation
IoT wearable system for stress detection	✓	✓	✓	×	Partial	No biophilic intervention
Nature-integrated smart classrooms	×	✓	×	✓	Partial	No physiological adaptation
Acute stress classification + biophilic VR	✓	×	✓	✓	Partial	No automatic adaptation
Synapse Flora (Proposed)	✓	✓	✓	✓	✓	Unified adaptive intervention

Note: ✓ = Fully addressed; Partial = Partially addressed; ✗ = Not addressed.

III. SYNAPSE FLORA SYSTEM DESIGN

A. System overview

Synapse Flora is proposed as an adaptive intelligent biophilic environmental intervention system designed to promote digital well-being during prolonged digital activities. The proposed system integrates physiological monitoring, behavioral analysis, environmental sensing, artificial intelligence (AI), and adaptive biophilic interventions into a unified conceptual architecture.

Unlike conventional digital well-being solutions that primarily rely on software-based recommendations, Synapse Flora extends intervention toward the physical environment through an intelligent smart planter capable of monitoring environmental conditions and executing adaptive interventions according to the user's estimated well-being state. The proposed system is intended for university students, remote workers, and professionals who spend extended periods interacting with digital devices.

B. Overall architecture

The proposed architecture follows a modular engineering approach composed of five functional modules: (1) User Monitoring, (2) Environmental Monitoring, (3) Adaptive Biophilic Decision Engine (ABDE), (4) Environmental Intervention, and (5) Adaptive Learning.

Physiological information is collected through wearable devices, behavioral information is obtained from a companion mobile application, and environmental variables are acquired through the smart planter. These multimodal data are integrated and processed by the ABDE, which estimates the user's context and determines the most appropriate intervention while considering user preferences and predefined safety criteria. The overall architecture of Synapse Flora is illustrated in Figure 1.

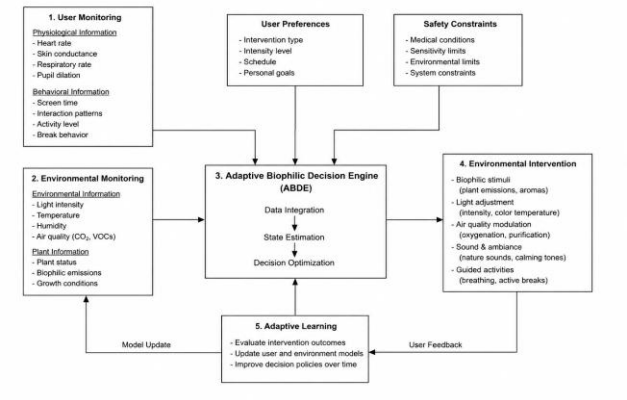


Fig 1. Overall Architecture of Synapse Flora.

C. Functional modules

C.1 User monitoring module

The user monitoring module is responsible for acquiring physiological and behavioral information associated with the user's digital well-being. Physiological indicators are obtained from commercially available wearable devices, while behavioral information is collected through the companion mobile application. Together, these data provide a comprehensive representation of the user's current physiological and behavioral state.

The module considers variables including heart rate (HR), heart rate variability (HRV), sleep quality, physical activity, screen time, and application usage patterns. These indicators constitute the primary input for estimating the user's current condition and are continuously transmitted to the ABDE [3]-[4].

C.2 Environmental monitoring module

The environmental monitoring module continuously acquires information regarding both the indoor environment and the condition of the plant. Environmental sensing allows the system to determine whether environmental interventions are feasible while simultaneously ensuring that the plant remains within its recommended growing conditions.

The monitored variables include ambient temperature, relative humidity, illumination level, soil moisture, and water reservoir level. Together, these parameters define the environmental context in which personalized interventions are performed [5], [12], [13].

C.3 Adaptive biophilic decision engine (ABDE)

The ABDE constitutes the core intelligence module of Synapse Flora. Its primary function is to integrate the physiological, behavioral, and environmental information provided by the monitoring modules in order to estimate the user's current well-being state and determine the most appropriate intervention strategy.

Rather than relying on predefined timers or static intervention schedules, the ABDE follows a context-aware decision process that considers physiological indicators, digital behavior, environmental conditions, user preferences, and predefined safety constraints [3], [6], [8].

The intervention strategy follows a hierarchical approach. Initially, the system prioritizes low-intrusion recommendations, including hydration reminders, breathing exercises, posture correction, or active breaks. If prolonged digital activity persists or physiological indicators suggest increasing stress levels, the engine progressively enables adaptive environmental interventions intended to improve comfort while preserving user productivity [6], [8].

C.4 Environmental intervention module

The environmental intervention module executes the actions selected by the adaptive biophilic decision engine. Unlike conventional digital well-being applications that depend primarily on notifications, this module modifies the surrounding environment through adaptive interventions designed to complement users' activities without disrupting their workflow.

The intervention platform is centered on the intelligent planter, which integrates automatic irrigation, environmental monitoring, and an optional hydrosol-based intervention

mechanism. During system initialization, users register the plant species incorporated into the device. Based on this information, the system loads species-specific environmental parameters that guide irrigation scheduling and environmental management according to the biological requirements of each plant.

Consequently, both plant care and environmental intervention are continuously adapted according to the estimated user condition, environmental context, and the selected plant species [5], [13].

C.5 Adaptive learning module

The adaptive learning module records user interactions, previous intervention outcomes, and behavioral patterns to progressively improve future decision-making. Although presented as a conceptual component within the proposed architecture, this module establishes the foundation for future implementations capable of refining intervention strategies through continuous user feedback.

Over time, the accumulated interaction history enables the system to personalize intervention timing, prioritize preferred recommendations, and reduce unnecessary actions, contributing to a more individualized digital well-being experience.

D. Operational workflow

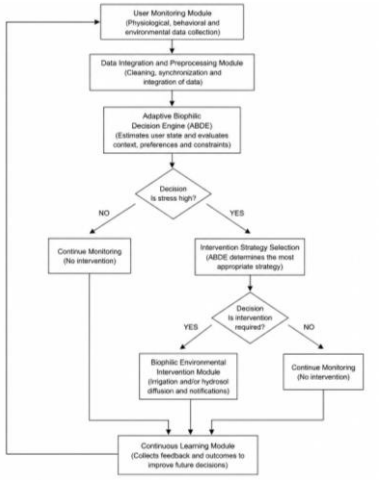


Fig 2. Operational Workflow of Synapse Flora.

IV. ENGINEERING DESIGN

A. Physical system design

The conceptual architecture proposed in Synapse Flora is physically implemented through a modular smart planter designed to integrate plant care, environmental sensing, and adaptive environmental intervention within a single platform. The engineering design emphasizes modularity and operational reliability while ensuring suitable conditions for plant growth and electronic protection.

Unlike conventional smart planters that mainly automate irrigation tasks, the proposed prototype incorporates multiple independent functional compartments that separate the biological, hydraulic, and electronic subsystems. This structural organization minimizes the risk of moisture-related failures, simplifies maintenance procedures, and enables individual component replacement without requiring complete system disassembly.

The prototype is conceived as a vertical modular structure in which each compartment performs a dedicated engineering function. Waterproof internal partitions isolate water reservoirs, electronic components, and the plant substrate, reducing interference among subsystems and improving long-term operational stability. This design philosophy facilitates future upgrades and supports scalable implementations based on the proposed conceptual architecture [14].

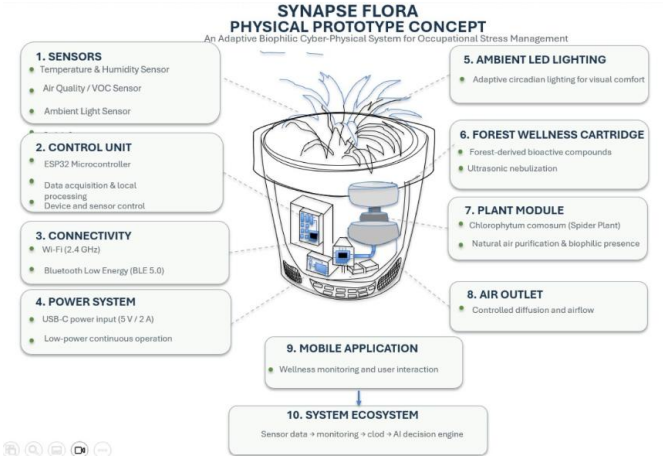


Fig 3. Conceptual Physical Architecture of Synapse Flora.

B. Modular physical architecture

The physical prototype is organized into five independent modules that collectively implement the proposed adaptive environmental intervention system. Each module performs a specific function while remaining mechanically isolated from adjacent compartments through waterproof barriers, thereby protecting sensitive electronic components and facilitating maintenance.

Plant compartment

The upper module accommodates the indoor plant and its organic substrate. This compartment provides adequate space for root development while incorporating a capacitive soil moisture sensor [5], [13] to continuously monitor substrate conditions. Water supplied by the irrigation system is distributed directly to this compartment through dedicated irrigation channels.

Drainage module

Immediately below the substrate compartment, a drainage layer prevents excessive water accumulation around the roots. A perforated support tray combined with a geotextile mesh allows surplus water to flow toward the irrigation reservoir

while preventing substrate particles from obstructing the pumping system.

Water reservoir module

The third compartment contains the irrigation reservoir together with the miniature water pump and the water-level monitoring mechanism [5], [13]. The reservoir supplies water automatically whenever soil moisture measurements indicate that irrigation is required. Additionally, the water-level sensor allows the mobile application to notify users when reservoir refilling becomes necessary.

Environmental intervention module

A dedicated compartment houses a replaceable hydrosol cartridge intended for optional environmental intervention. The cartridge stores plant-compatible hydrosol formulations that may be released through a controlled microfan-based diffusion mechanism whenever the Adaptive Biophilic Decision Engine determines that environmental intervention is appropriate and user preferences allow this functionality.

Electronics module

The lower compartment contains the electronic subsystem responsible for coordinating all sensing, communication, and control functions. This compartment includes the ESP32 [5], [13] microcontroller, wireless communication interfaces, actuator controllers, battery, and power management circuitry. The electronics are enclosed within a sealed housing to minimize exposure to humidity generated by the irrigation system.

C. Hardware components

The proposed prototype employs commercially available electronic components selected according to criteria including reliability, compatibility, low energy consumption, ease of programming, and widespread availability. Table II summarizes the principal hardware components considered for the conceptual implementation.

TABLE II
PROPOSED HARDWARE COMPONENTS FOR SYNAPSE FLORA

Component	Proposed Hardware	Function
Microcontroller	ESP32	Coordinates sensors, actuators, processing and communication.
Soil Moisture Sensor	Capacitive soil moisture sensor	Monitors soil moisture for automatic irrigation.
Temperature and Humidity Sensor	Digital temperature and humidity sensor	Measures ambient temperature and relative humidity.
Light Sensor	Ambient light sensor	Measures illumination conditions.
Water-Level Sensor	Water-level sensor	Monitors irrigation reservoir and enables refill notifications.
Water Pump	Miniature water pump	Supplies water to the plant when needed.
Diffusion Actuator	Microfan	Controls diffusion of plant-compatible hydrosol.
Hydrosol Cartridge	Replaceable hydrosol reservoir	Stores the formulation for environmental interventions.
Wireless Communication	Wi-Fi / Bluetooth (ESP32 integrated)	Enables communication with mobile app and connected devices.
Power System	Battery and power-management circuitry	Provides and regulates electrical power.

D. Sustainable engineering design

Sustainability constitutes one of the fundamental engineering principles considered during the conceptual development of Synapse Flora. The proposed design follows the Design for Sustainability [14] (DfS) approach by incorporating environmentally responsible materials, modular construction, and maintenance strategies intended to extend product lifespan while reducing electronic waste.

The external housing is proposed to be manufactured using post-consumer recycled polyethylene terephthalate (rPET). This material was selected because of its favorable mechanical properties, moisture resistance, low weight, and compatibility with additive manufacturing and injection molding processes. Additionally, using recycled PET [14] contributes to reducing virgin plastic consumption and supports circular economy initiatives through material reuse.

The modular architecture enables independent replacement of sensors, electronic components, batteries, irrigation modules, and environmental intervention cartridges without requiring disposal of the entire product. Consequently, maintenance becomes simpler, repair costs decrease, and the operational lifetime of the prototype can be extended significantly.

Finally, the proposed product life cycle incorporates recycled material utilization, modular maintenance, component replacement, and end-of-life material recovery. These considerations position sustainability as an integral engineering criterion throughout the conceptual design process rather than as a secondary product characteristic.

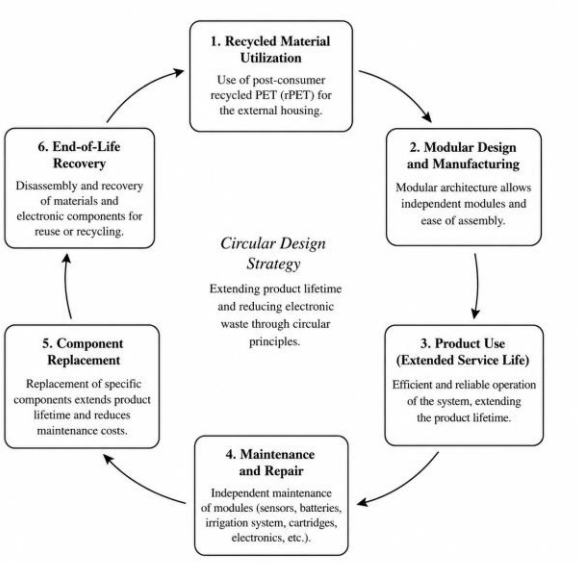


Fig 4. Circular Design Strategy of Synapse Flora

V. DESIGN METHODOLOGY

This research adopts an evidence-informed engineering design methodology to develop Synapse Flora, an adaptive biophilic environmental intervention system aimed at promoting digital well-being among university students and remote knowledge workers during prolonged digital activities. These populations were selected because they are consistently exposed to extended periods of screen-based work and study,

making them particularly vulnerable to digital stress, cognitive fatigue, and technostress [1].

Rather than proposing an isolated technological solution, the system architecture was derived from scientific evidence on digital well-being, physiological stress detection, Internet of Things (IoT), intelligent plant monitoring, biophilic design, and sustainable product engineering [1], [3], [5], [6], [13], [14]. The methodological process consisted of four stages: (A) Problem Identification and Target Population, (B) Evidence-Based Literature Review, (C) Engineering Design of the Proposed System, and (D) Design Constraints.

A. Problem identification and target population

The first stage focused on identifying the research problem and defining the target population. Synapse Flora is intended for users engaged in study and/or work activities involving prolonged interaction with digital devices. Previous research identifies prolonged digital exposure as a relevant factor associated with cognitive fatigue, mental overload, reduced concentration, and stress [1]-[2].

To assess the perceived relevance of the identified problem, an exploratory anonymous online survey was conducted with 36 participants. Participants were contacted directly and were informed about the academic purpose of the survey before responding. The questionnaire addressed participants' demographic profile, work and study modality, perceived fatigue after prolonged screen exposure, digital well-being habits, and perceptions of the proposed Synapse Flora concept. Among respondents, 44.4% reported experiencing mental fatigue, difficulty concentrating, or mental saturation frequently, 16.7% always, and 27.8% sometimes. Thus, 61.1% reported these symptoms frequently or always, while 88.9% reported experiencing them at least sometimes. Reported consequences included mental exhaustion, visual fatigue, headaches, and difficulty maintaining concentration.

Regarding the proposed concept, Synapse Flora obtained a mean attractiveness score of 4.69/5, with 91.7% of participants rating it 4 or 5. Open-ended responses identified scientific evidence, verifiable results, system operation, sensor information, data privacy and security, ease of use, maintenance, and cost as relevant factors for trusting the proposed solution. Participants also suggested personalized recommendations, different intervention intensities, improved usability, and adaptation to different study or work environments.

These findings provide preliminary user-centered evidence regarding the perceived relevance of the problem and the attractiveness of the proposed concept. However, the survey was exploratory and does not demonstrate the effectiveness of Synapse Flora in reducing mental fatigue.

The survey findings were considered alongside previous research on digital well-being and technostress. Existing solutions include mobile applications, timers, and notification-based recommendations, while previous research suggests that excessive notifications may contribute to alert fatigue and reduce long-term user adherence [8]. This context informed the design of Synapse Flora as an adaptive environmental intervention system that extends support beyond exclusively digital notifications.

B. Evidence-based literature review

The engineering decisions adopted during the development of Synapse Flora were supported by three complementary research domains identified through the literature review.

The first research domain concerns physiological stress detection using wearable technologies. Recent review studies identify heart Rate (HR), heart Rate Variability (HRV), Electrocardiography (ECG), Photoplethysmography (PPG), Electroencephalography (EEG), and Galvanic Skin Response (GSR) as reliable physiological indicators for stress estimation when combined with artificial intelligence and machine learning techniques. These investigations also highlight the importance of continuous physiological monitoring to enable personalized well-being systems [3].

The second research domain focuses on IoT-based monitoring systems for indoor plants and smart environments. Previous studies consistently employ environmental variables such as soil moisture, ambient temperature, relative humidity, light intensity, and water reservoir level to monitor plant health and automate irrigation processes. These works demonstrate the feasibility of integrating low-cost sensors, embedded controllers, and wireless communication technologies into intelligent environmental monitoring systems [5], [12], [13].

The third research domain corresponds to biophilic design and intelligent environmental interventions. Recent research consistently demonstrates that incorporating biophilic elements into workspaces contributes not only to psychological well-being but also to increased productivity, job satisfaction, and cognitive performance. Studies conducted in corporate environments report that natural elements such as vegetation, daylight, and organic materials improve users' perception of comfort while reducing stress during prolonged working activities [6], [7], [11].

More recent research extends these principles toward intelligent environments through the Positive Computing paradigm. Rather than introducing static natural elements, adaptive biophilic interventions supported by AI can personalize environmental conditions according to users' physiological and contextual information, promoting well-being without compromising task performance [6], [10].

Furthermore, experimental studies combining physiological sensing with biophilic virtual environments demonstrate that artificial intelligence can successfully classify stress levels using multimodal physiological data while simultaneously evaluating the effectiveness of biophilic interventions. These findings provide evidence supporting the feasibility of combining physiological monitoring with the evaluation of biophilic environmental interventions [9].

Together, these three research domains established the conceptual foundation of Synapse Flora by integrating

physiological monitoring, environmental sensing, artificial intelligence, and adaptive biophilic interventions into a unified engineering architecture [3], [5], [6].

C. Engineering design of the proposed system

The architecture of Synapse Flora was designed following principles of modularity, interoperability, scalability, maintainability, and user-centered adaptation. Every hardware component was selected based on evidence reported in previous research rather than solely on implementation convenience.

Environmental monitoring is performed through sensors measuring soil moisture, ambient temperature, relative humidity, illumination, and water reservoir level. These variables were selected because previous IoT-based smart plant systems identify them as the primary environmental parameters required to maintain healthy indoor vegetation while enabling autonomous irrigation and environmental management [5], [12], [13].

Data acquisition and wireless communication are managed through an ESP32 microcontroller, selected due to its integrated Wi-Fi and Bluetooth connectivity, low power consumption, processing capability, and compatibility with multiple sensing modules. Similar architectures have been successfully implemented in embedded IoT systems for environmental monitoring and intelligent irrigation [5], [13].

Physiological information is obtained from wearable devices capable of monitoring heart Rate (HR), heart Rate Variability (HRV), sleep quality, and physical activity. The selection of these variables is supported by systematic reviews that recognize HR and HRV as among the most reliable physiological biomarkers for stress detection using artificial intelligence, while sleep quality and physical activity provide complementary information regarding user recovery and behavioral patterns [3]-[4].

In addition to physiological monitoring, the proposed architecture incorporates behavioral indicators collected through a companion mobile application, including screen time, study duration, work sessions, user interaction patterns, and adherence to previous recommendations. Combining physiological, behavioral, and environmental information provides a broader contextual representation of user status, enabling more informed adaptive interventions.

A distinctive characteristic of Synapse Flora is its species-aware adaptive configuration. During the initial setup, users select the plant integrated into the system, allowing the platform to automatically load species-specific environmental requirements, including irrigation frequency, soil moisture thresholds, optimal temperature ranges, humidity conditions, and illumination levels. Instead of applying identical maintenance strategies to every plant, the system dynamically adjusts environmental management according to the biological requirements of each species while simultaneously adapting user-oriented interventions.

This decision was inspired by intelligent plant monitoring systems demonstrating that different plant species require distinct environmental conditions and that personalized environmental control improves automation performance and plant health [5], [12].

D. Design constraints

Privacy, safety, and sustainability were considered throughout the engineering design process.

From a privacy perspective, Synapse Flora follows a Privacy by Design approach by collecting only the information required to personalize environmental interventions. Wearable integration is optional, and physiological information is intended exclusively to support well-being rather than medical diagnosis.

Regarding safety, environmental interventions are designed as complementary well-being strategies rather than therapeutic treatments. The proposed low-intensity diffusion module employs natural formulations and can be completely disabled for users with respiratory conditions, allergies, or personal preferences against aromatic interventions.

Finally, sustainability principles were incorporated from the earliest design stages. The proposed physical structure employs recycled PET, while sensors, electronic modules, and refillable cartridges follow a modular architecture that facilitates maintenance, repair, component replacement, and future upgrades. These engineering decisions are aligned with circular economy principles by extending product lifetime, reducing electronic waste, and promoting responsible material utilization [14].

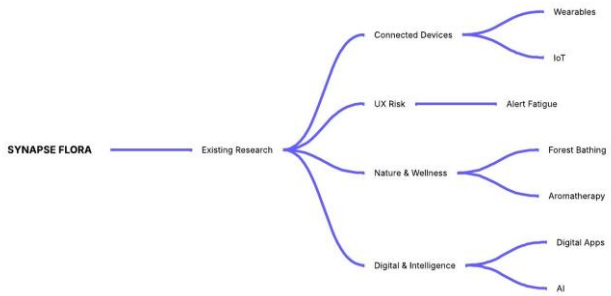


Fig 5. Evidence-Informed Engineering Design Methodology

VI. DISCUSSION

A. Engineering contributions

The exploratory survey provides preliminary user-centered evidence supporting the relevance of the problem addressed by Synapse Flora. Among the 36 participants, 61.1% reported experiencing mental fatigue, difficulty concentrating, or mental saturation frequently or always after prolonged screen exposure, while 88.9% reported experiencing these symptoms at least sometimes. The proposed concept also obtained a mean attractiveness score of 4.69/5, with 91.7% of participants rating it 4 or 5. These findings indicate perceived relevance of the problem and initial attractiveness of the proposed concept, but they should not be interpreted as evidence of intervention effectiveness.

From an engineering perspective, Synapse Flora addresses the identified gap by proposing an integrated conceptual architecture that combines multimodal sensing, adaptive decision-making, and environmental intervention within a single system. The Adaptive Biophilic Decision Engine (ABDE) coordinates physiological, behavioral, and environmental information while considering user preferences and predefined safety constraints.

Additionally, the integration of sustainability principles through modular design and recycled materials broadens the contribution beyond digital health by incorporating environmentally responsible engineering practices.

B. Comparison with existing approaches

Compared with existing digital well-being solutions, Synapse Flora adopts a broader systems engineering perspective. Most current approaches focus primarily on monitoring physiological variables or encouraging behavioral changes through reminders, mobile applications, or wearable devices [3], [8]. Similarly, biophilic interventions are commonly implemented as static environmental resources [6], [7], [11] that remain unchanged regardless of users' physiological or behavioral conditions.

The proposed architecture differs by integrating physiological sensing, behavioral monitoring, environmental information, and adaptive environmental intervention within a unified decision-making framework. Rather than considering plants solely as decorative elements, Synapse Flora incorporates living vegetation as an active component of an intelligent cyber-physical environment capable of dynamically supporting personalized digital well-being.

Furthermore, the proposed modular architecture facilitates scalability, maintainability, and future technological upgrades, characteristics that are not typically addressed simultaneously in existing digital well-being systems.

C. Limitations

Despite the proposed contributions, several limitations should be acknowledged. First, Synapse Flora is currently presented as a conceptual engineering architecture and has not yet been implemented as a fully functional prototype. Consequently, the effectiveness of the Adaptive Biophilic Decision Engine and the proposed intervention strategies has not been experimentally validated.

Second, the accuracy of future implementations will depend on the reliability of wearable devices, environmental sensors, and physiological signal quality. Variability among commercial sensing devices may influence system performance and intervention accuracy.

Finally, user acceptance, long-term adherence, perceived usefulness, and the effectiveness of adaptive environmental interventions remain open research questions that require controlled experimental studies involving representative user populations.

D. Future work

Future research will focus on the physical implementation and experimental validation of Synapse Flora. A functional prototype will be developed to evaluate the performance of the proposed architecture under real operating conditions involving university students and remote workers.

Subsequent studies should evaluate adaptive biophilic interventions using physiological, behavioral, environmental, and user-centered measures. Physiological measures may include HR, HRV, and electrodermal activity; behavioral measures may include screen exposure, session duration, and break adherence; environmental measures may include temperature, humidity, illumination, and soil moisture; and user-centered measures may include perceived stress, perceived well-being, task completion time, and error rate. These measures would enable the evaluation of intervention effectiveness while assessing whether the system can support digital well-being without compromising task performance.

Finally, future developments may incorporate additional physiological sensors, cloud-based data processing, energy optimization strategies, and expanded environmental intervention capabilities, supporting the evolution of Synapse Flora toward a more adaptive and scalable intelligent biophilic environment.

VII. CONCLUSIONS

This study provided preliminary user-centered evidence regarding prolonged screen-related fatigue and the perceived attractiveness of Synapse Flora. In the exploratory survey of 36 participants, 61.1% reported experiencing mental fatigue, difficulty concentrating, or mental saturation frequently or always after prolonged screen exposure, while 88.9% reported these symptoms at least sometimes. The proposed concept obtained a mean attractiveness score of 4.69/5, with 91.7% of participants rating it 4 or 5. These findings support the relevance of the problem and the initial perception of the proposed concept, but do not demonstrate its effectiveness.

A key contribution of this work is the introduction of the Adaptive Biophilic Decision Engine (ABDE), which conceptually coordinates multimodal information to recommend context-aware interventions while considering user preferences and predefined safety constraints. Additionally, the proposed Evidence-Informed Engineering Design methodology demonstrates how scientific evidence from digital well-being, wearable technologies, artificial intelligence, biophilic design, IoT, and sustainability can be systematically integrated into the conceptual development of intelligent health-support systems. The incorporation of modular architecture and circular economy principles further reinforces the feasibility of designing adaptive systems that are not only intelligent but also sustainable and scalable.

Although Synapse Flora has been presented as a conceptual architecture, it establishes a robust engineering foundation for future implementation and experimental validation. Future work will focus on developing a functional prototype,

implementing the proposed decision-making algorithms, evaluating physiological and environmental sensing performance, validating user acceptance and intervention effectiveness through controlled studies, and exploring advanced personalization strategies to support healthier and more sustainable digital environments in educational and occupational contexts.

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