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Integrating User-Centered Design and Biophilic Design to Improve Biophilia and Intelligentization in Office Environments

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Abstract: Intelligent technology has had a profound impact on working patterns and the needs of office workers. The corresponding office environments have also changed to some extent. As more and more intelligent functions are integrated, a question as to whether the intelligent office environment really meets needs of office workers needs to be considered. In this study, a methodology that is applicable to improve biophilic and intelligent designs simultaneously in office environments was developed according to the needs of office workers. The observations of office environments, interviews, and questionnaires of an office group were performed. The physical and psychological health needs of office workers, as well as the correlations between six office environmental factors and six intelligent functions were discussed using the data of 211 office workers. Then, 12 patterns of biophilic design were addressed from existing biophilic theory, and the results of a user study, as well as the corresponding design framework of intelligent office products, which are the carriers of intelligent functions, were described. The feasibility and the positive influence in the office have been illustrated through a design case and its evaluation in real office environments. This study mainly explores the design of office environments from the perspective of humans with the hope to provide helpful guidance for intelligent offices and related workspace design in the future.

Keywords: user-centered design; biophilic design; office workers; office environment

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1. Introduction

Information technology has fundamentally changed the daily life of the society. The multi-category environmental space and human–machine–environment systems have gradually shown the characteristics of informatization, autonomy, the combination of software interfaces and hardware systems, etc. [1–3]. The various manifestations of technologies have caused people to redefine environmental spaces [4]. Office environments are also gradually showing the trends of intelligence, visualization, and multi-dimensional collaboration. The scenarios, such as the interactions between human products and intelligent products, the collaborations between traditional office products and intelligent office products, and the information interactions between an intelligent product and another, etc., are increasing [5,6]. Meanwhile, with the development of working environments, from "human-physics" to "human-physics-intelligent machine-virtual information", unstructured and complicated scenarios now tend to occur much more than before. It makes the needs of the office group change, and it also compels researchers to think about how to meet the corresponding needs in the office, such as the requirements of the office environment, the proper improvements of intelligent functions, etc.

From the perspective of psychology, humans have a need to be close to nature, and nature also provides cultural and social values to humans [7]. The concept of biophilia,

which was first coined by Erich Fromm, is an empirical conclusion derived from humanity's love for nature [8]. The biophilia hypothesis is defined as the innate affinity of human beings to nature [9]. Biophilic design builds on this hypothesis to design for meeting the human needs positively and providing natural elements to different types of environments [10,11]. Incorporating natural elements in the design of building environments can help people recover from stress and mental fatigue [12]. Biophilic design has a robust evolutionary theoretical framework with different design patterns [13,14]. Browning et al. established the biophilic design framework from three categories—Nature in the Space, Natural Analogues, and Nature of the Space—to help improve the definition of biophilic buildings [15]. Ryan et al. developed 14 patterns of biophilic design, including visual and non-visual connections with nature, non-rhythmic sensory stimuli, the presence of water etc., to highlight the nature–health relationships in the environment [16]. The addition of biophilic elements promotes a human connection to nature and benefits health and well-being [17]. Currently, the theory of biophilic design has been used in a variety of environments and buildings, such as hotels [18–20], learning environments [21–23], and so on. For example, Mustafa et al. explored from the view of biophilic design patterns and found that 13 out of 14 patterns were available in the building of the Bilkent School; 8 patterns achieved an availability of more than 75% [22]. Song et al. examined how different biophilic designs affected guest emotion, quality perception, attitude, and behavior in a hotel environment; they concluded that the biophilic-designed environment could trigger stronger positive emotional and behavioral reactions in guests and make them think that the hotel had superior quality and good experience [19]. Khozaei et al. found that the perceived stress and the benefits of nature significantly affected tourists' preferences for hotels with biophilic attributes during the post-COVID-19 era [20]. In addition, the window view access in architecture [24], the application of virtual environments [25], and the green curtain of indoor environments [26] have been considered in some other studies about the use of biophilic design.

Biophilic design has also been applied to the field of offices to improve multiple aspects of work in recent years. It mainly considers the physical environments and the office workers' preferences. For example, from the view of physical environments, Sanchez et al. focused on a scheduled pilot experiment and found that introducing daylight and greenery into workplace design improved well-being, performance, creativity, and health [27]. Lei et al. examined the impacts of biophilic design attributes in offices on workers' health and wellbeing and provided designers with new weighted biophilic design guidelines [28]. Gray et al. found that incorporating biophilic design to promote workplace satisfaction, enhance well-being, and boost productivity contributed towards a high-performance workspace [29]. Candido et al. identified key drivers behind workers' satisfaction, perceived productivity, and health while identifying critical physical-environment-related features shared by high-performance, open-plan offices [30]. Meanwhile, from the view of office workers' preferences, Wallmann-Sperlich et al. conducted a pilot study and found that using biophilic design in offices could be a promising approach for increasing standing time [31]. Hähn et al. found that office workers had improved satisfaction with their overall workplace environment when they had physical and visual access to plants in their office environments [32]. The online surveys of Xie et al. indicated that a biophilic design with daylight and a view had the highest ratings on perceptual attributes [33]. All the mentioned studies have shown that biophilic design benefits office groups from different research approaches. However, as the interaction effects between environments and humans are enhanced by the improvement of the intelligence level, the applications of biophilic design need to generate much more corresponding extensions in the office.

The main purpose of this study is to develop an approach to improve biophilia and intelligentization simultaneously in office environments. User-centered design, which could date from the 1980s [34], was employed for making this study more suitable and practical for real-life office workers. The remaining structure of the paper is given as follows. Section 2 shows the user study process and results. Section 3 describes the patterns of biophilic design in the office and proposes the corresponding design framework of

intelligent office products to enhance biophilia and intelligentization in the office. Section 4 illustrates a case study to show the feasibility of the design. Section 5 concludes the outcomes of the research and the current limitations.

2. User Study

The user experience in the office environment and the diversified forms that are employed when working are important points of relevant research on office buildings and space. The office environmental factors and the intelligent functions, which are usually displayed by intelligent office products, have impacts on both the user experience and on office work. The office environments mainly considered here include the hardware such as surrounding equipment. Moreover, other items mentioned by office workers in the user study have also been considered. The needs of office workers were explored from the perspective of "office environment-products-users".

2.1. Methods

A progressive three-stage survey was conducted, and the results of each stage served as the guidance for the main points of investigation for the next stage. The office environments were observed, and the office workers were interviewed. Then, two online questionnaire surveys were performed. The office environments had the characteristics that each office worker had their own work desk and chair, as well as shared an office with several colleagues. Some office environments are shown in Figure 1. According to observations of office environments, the collaborative scenarios of using traditional and intelligent office products are common in the office. The products in the office were classified into electronics in office work, office appliances for the environment, office furniture, document supplies, record supplies, and other supplies. The common items are shown in Table 1.

Figure 1. Some office environments.

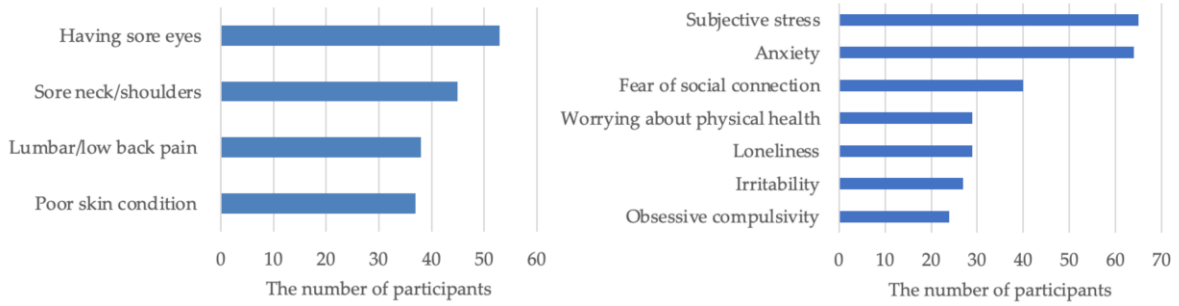
Table 1. Classification of products that are commonly used in the office.

Classification	Products in Office Environments
Electronics in office work	Computer, mouse, mobile phone, keyboard, headphones, plugboard, printer, etc.
Office appliances for environment	Humidifier, water dispenser, electric fan, vacuum cleaner, etc.
Office furniture	Desk, office chair, filing cabinet, etc.
Document supplies	Folder, report clip, bill clip, business card case, etc.
Record supplies	Stapler, scissors, pen holder/pen case, calendar, correction tape, pencil refill, etc.
Other supplies.	Cups, coasters, masks, disinfection supplies, etc.

The one-to-one interviews mainly focused on experiences in office environments, the use of office products, desktop items, and health in office work. Experiences in office environments included experiences for time spent indoors, sound, light, air quality, indoor color, etc. The use of office products mainly considered the office worker's use frequency, duration, and scenarios of use with other products. Health in office work included physical health and mental health. A total of 11 office staff were interviewed. Two online questionnaires were implemented that respectively considered the office worker concerns and the psychological impacts. The numbers of recruited participants were 92 and 108, respectively. All respondents had long-term experiences in their own workspaces during working hours.

2.2. The Health Needs of Office Workers

Electronics in office work such as computers, mobile phones, and related accessories are the most commonly used products in workspaces. The majority of interviewees expressed that they were worried about health after using the computer for a long time. Most participants recruited for the questionnaire of the office worker concerns thought that having sore eyes was the most common item for physical discomfort caused by work, and the other three top items were sore neck/shoulders, lumbar/low back pain, and poor skin condition, respectively, as shown in Figure 2a. The results of run tests for the data in Figure 2a are given in Table 2. The values of significance, 0.819, 0.678, 0.763, and 0.625, were larger than 0.05. It means that the data were essentially random. The majority of the participants of this survey paid attention to their health through sports and regular health checkups, as well as by placing toys, pillows, and plants in the office to make the work space more comfortable. Participants also had certain preferences for desktop textures, including 59.78%, 17.39%, and 13.04% for wood grain, metal texture, and plastic texture, respectively. For mental health, as shown in Figure 2b, subjective stress and anxiety were the two items of highest concern, and the fear of social connection, worrying about physical health, loneliness, irritability, and obsessive compulsivity were also considered for participants recruited for the questionnaire of mental impacts. The data shown by Figure 2b were verified as random by the results of the run tests shown in Table 3. The above concerns of physical and mental health indicated the needs of office workers regarding health during long-term work.



(**a**) (**b**)

Figure 2. (**a**) Physical discomforts caused by work. (**b**) Mental discomforts caused by work.

Table 2. The run tests of the data that office workers feel regarding physical discomforts.

	Sore Eyes	Sore Neck/Shoulders	Lumbar/Low Back Pain	Poor Skin Condition
Mean	0.58	0.49	0.41	0.4
Sig.	0.819	0.678	0.763	0.625

Table 3. The run tests of the data that office workers feel regarding mental discomforts.

	Subjective Stress	Anxiety	Fear of Social Connection	Worrying about Physical Health	Loneliness	Irritability	Obsessive Compulsivity
Mean	0.6	0.59	0.37	0.27	0.27	0.25	0.22
Sig.	0.173	0.116	0.896	0.275	0.698	0.155	0.708

2.3. User Experiences of Office Environments

From the interviews, office environmental factors such as light, sound, and air quality were the biggest concerns of staff in office environments. Using humidifiers, air conditioning, and other related products or putting more plants indoors are common ways to improve the comfort level during working hours. Meanwhile, the majority of interviewees

also paid attention to the organization of their working spaces, e.g., the cleanliness of working desk, the distance from others, as so on. We defined the office environmental factor as E_i, where $i \in N*$, and $1 \leq i \leq 6$. N is the set of integers. According to the interviews, E_1~E_6 represent light, sound, air quality, color, the cleanliness of working spaces, and the spatial distance from another's working space, respectively. The corresponding attentions of the office workers to E_1~E_6 were investigated by the questionnaire for office worker concerns. The score was ranked from 0 to 4. The score of no attention was 0, and the score of great attention was 4. As shown in Figure 3a, air quality and sound had great impacts, with the scores of 3.09 and 2.84, respectively. Color had the least impact, with a score of 2.36. The other three factors resulted in similar scores. The psychological impacts of these factors on office workers were investigated by another questionnaire. The score was ranked from −3 to 3, where the absolute value of the score represents the level. The scores with minus sign, zero, and the positive scores mean negative impact, no impact, and positive impact on office workers, respectively, from the psychological view. As shown in Figure 3b, each environmental factor had a positive score. It means that the factors considered by office workers impacted them positively in their past experiences. The cleanliness of working spaces showed an average highest score, which indicates that it had the highest psychological impact on office workers. The scores of light, the spatial distance from another's working space, and color were around 1; additionally, air quality and sound showed the lowest impacts.

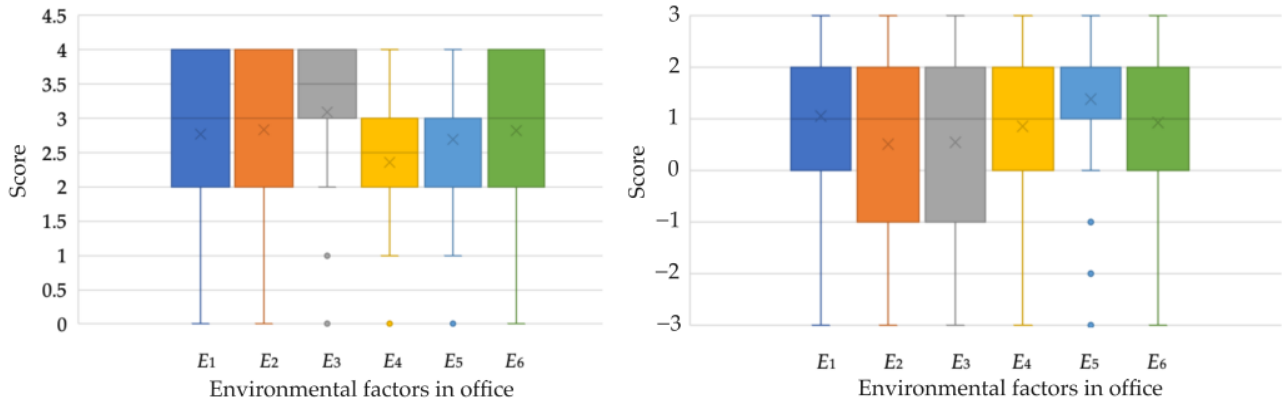


Figure 3. (**a**) The data of environmental factors from the view of user attentions. (**b**) The data of environmental factors from the view of psychological impacts.

The correlations of the six environmental factors were calculated using Spearman correlation coefficients. It was found that the six factors showed correlations, regardless of considering the attention levels of office workers or considering the psychological impacts on office workers. All correlation coefficients were larger than the critical value, and the p-values were smaller than 0.05. However, the degree of correlation varied. For example, from the view of the attention of office workers, E_1 had relatively strong correlations with E_4 (s = 0.587), E_6 (s = 0.519), and E_3 (s = 0.507). The value of s represents the Spearman correlation coefficient. The relative strong correlations could also be seen between E_3 and E_6 (s = 0. 569), as well as E_4 and E_5 (s = 0.503). E_2 showed relatively lower correlations with other factors. From the view of the psychological impacts on office workers, E_1 had relatively strong correlations with E_3 (s = 0.648), E_5 (s = 0.629), E_4 (s = 0.609), E_6 (s = 0.625), and E_2 (s = 0.535). Relatively strong correlations could also be seen between E_3 and E_6 (s = 0.575), as well as E_4 and E_5 (s = 0.571). However, the correlations between E_2 and E_4 (s = 0. 377), as well as E_2 and E_5 (s = 0.397), were relatively small. Hence, when designing from different perspectives of office environments, different environmental factors should be emphasized and weighted. For example, when light is the main design target in the

office, color, working spatial distance, and air quality become the main influencing factors. Additionally, when considering air quality, light and the cleanliness of working spaces become key factors.

2.4. Practicability of Intelligent Office Products' Functions

Remembering to drink water, air purification, lifting of the desktop, health detection, muscle massage, and sedentary reminders constituted key intelligent functions from the user-centered view according to the results of environmental observation and interviews. The six functions were defined as P_j, where $j \in N*$, and $1 \leq j \leq 6$. The affections to intelligent functions were investigated using a scale range from 5 to 0, which depicts from "like" to "don't like," respectively. The results are shown in Figure 4a. The affections to the functions of P_1~P_4 were basically similar and better than P_5 and P_6. The six functions had correlation properties. For example, P_1 had relatively strong correlations with P_2 (s = 0.732) and P_4 (s = 0.638). The psychological impacts on office workers were also asked on a scale of −3 to 3, where the absolute value of score represents the level. As shown in Figure 4b, the six intelligent functions showed positive psychological impacts on office workers, especially those of P_5 and P_3, which had average scores of 1.35 and 1.2, respectively. The scores of P_2, P_4, and P_6 were around 1. P_1 showed the lowest impact.

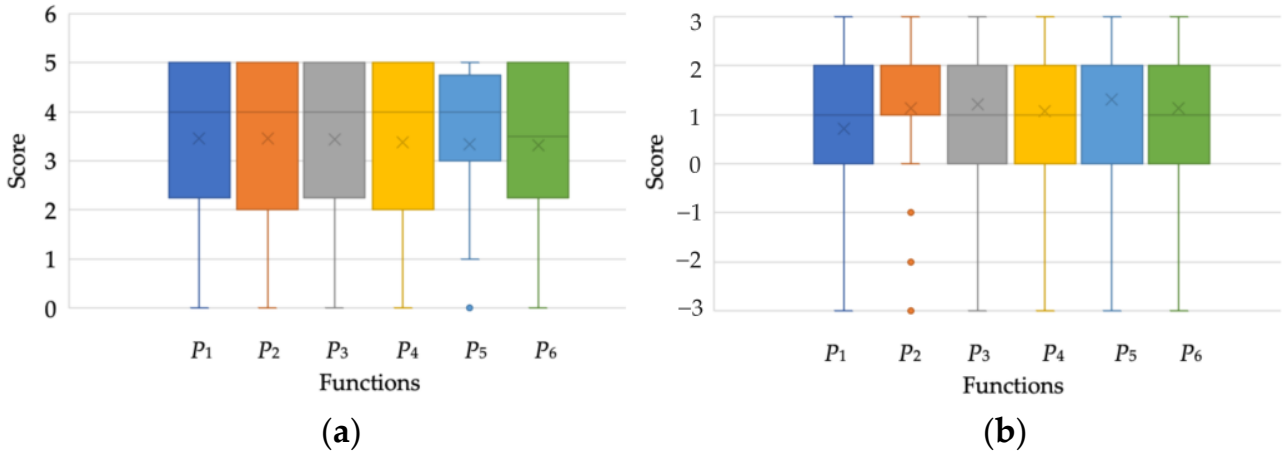
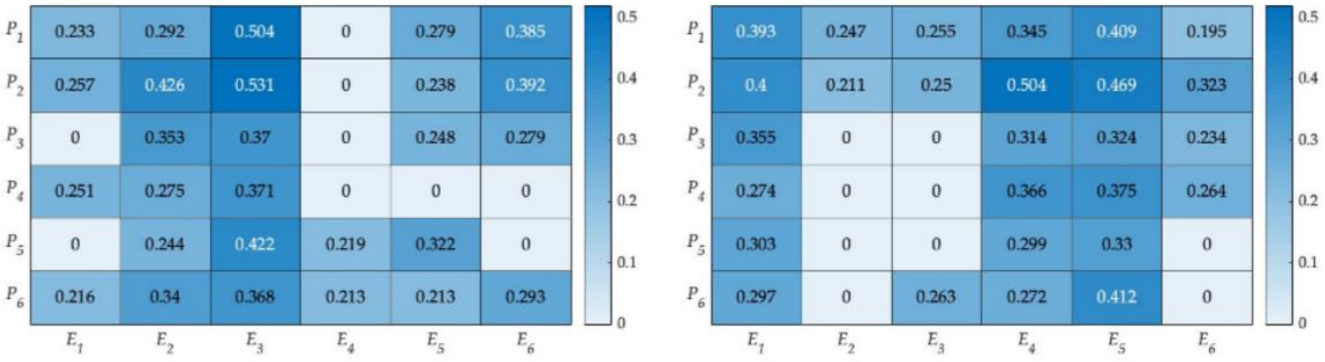


Figure 4. (**a**) The data for intelligent functions from the view of user affections. (**b**) The data for intelligent functions from the view of psychological impacts.

Both the office environment and the intelligent functions of office products have impacts on the user experience. The correlation analysis between office environmental factors E_1~E_6 and P_1~P_6 was calculated using Spearman correlation coefficients from two perspectives: the concerns of office workers and the psychological impacts on office workers. The results are shown by Figure 5. The zero values mean that the p-values did not meet the requirement of significance, and the others were the correlation coefficients, which were larger than the critical value. According to the data in Figure 5a,b, some intelligent functions had correlations with some office environmental factors in both perspectives, while others did not have correlations. For example, water-drinking P_1 and air purification P_2 both showed relatively strong correlations towards the air quality E_3 from the two points of view. However, the correlations between P_2 and the color E_4 were quite different from these two perspectives. These quantified correlations can help to build the relationship between office workers, office environments, and intelligent functions, as well as benefit the design of intelligent environments that are applicable to different needs in the office.



(**a**) (**b**)

Figure 5. (**a**) The correlations between the intelligent functions and the office environmental factors from the view of office works' concern. (**b**) The correlations between the intelligent functions and the office environmental factors from the view of psychological impacts on office workers.

3. Methodology

3.1. The Patterns of Biophilic Design in Office

Biophilic design contains three categories, including "Nature in the Space", "Natural Analogues" and "Nature of the Space", and each category has different numbers of patterns [15,16]. When biophilic design is used in different areas, there should be different refinements to make the patterns much more realistic and feasible. When applying it to intelligent offices, both the office environments and the office workers' needs must be considered. According to the results of the user study and the existing biophilic design theory, the three categories were redefined, namely, "Direct experience of nature in office space", "natural analogues of office product," and "natural human-product experience in office".

3.1.1. Direct Experience of Nature in Office Space

The category, "direct experience of nature in office space" addresses the physical, direct experience of nature integrating the office environmental factors and officer's health and functional needs based on the category "Nature of the Space" of biophilic design. This category encompasses six biophilic design patterns, as shown in Table 4.

Table 4. Patterns and corresponding details for "direct experience of nature in office space".

Patterns	Details
Thermal and Airflow Variability	Air quality that mimics natural environments, including air temperature, relative humidity, etc.
Dynamic and Diffuse Light	Light and shadow that are helpful to user's health, especially for the eyes.
Sound	Auditory stimuli that engender positive references to office workers.
Presence of Water	A condition that reminds one of drinking water.
Visual Connection with Nature	The visualization of natural elements with office workers' health-centered practices.
Connection with Natural Systems	Awareness of natural psychological and physiological reactions of office workers to decrease the physical and physiological discomforts during working hours.

3.1.2. Natural Analogues of Office Product

The elements, such as objects, materials, textures, colors, shapes, etc., found in nature are widely used in the design of different environments [35,36]. Following the user surveys, color in the office had some impacts on office workers, and the wood texture tended to be more acceptable to them. Considering that traditional office products and intelligent office products are often used in same scenario, the ensuing complexity cannot be ignored in office. The surveys found that, among the six environmental factors, the cleanliness of

the working space had the highest psychological impact on office workers. It is a kind of manifestation of order for complexity in workspace. Complexity is verified as a relative property affected by a user's prior knowledge [37]. Following an order similar to nature is a helpful way to understand the complexity. Focusing on the category of "natural analogues of office product", three biophilic design patterns are described in Table 5.

Table 5. Patterns and corresponding details for "natural analogues of office product".

Patterns	Details
Biomorphic Shapes and Patterns	Symbolic references to contoured, patterned, or numerical arrangements that persist in nature.
Color and Texture Connection with Nature	Color and texture derived from nature or capable of giving a natural association.
Complexity and Order (Naturally Integrated into the Office Space)	Rich sensory information used to create an effective cooperation for traditional and intelligent office products that adheres to a spatial hierarchy similar to that encountered in nature.

3.1.3. Natural Human–Product Experience in Office

This category addresses the natural experience in human–product processes, including the experiences from physical and information dimensions. It is also a representation of users and a spatial system of office environments, which consists of the tangible and intangible configurations. Both the tangible office products and the intangible information in human–product processes create a space configuration that appeals to the office workers. In physical dimensions, flexibility, convenience, and harmonious levels when integrating intelligent products into office environments are considered. The information dimension mainly focuses on multiple types of information generated by intelligent products in the office, the privacy of personal information, and the openness of office collaboration. The multi-dimensional interfaces of the office intelligent products are the core connecting the information dimension and the physical dimension and are also one of the most important parts for multi-sensory information interaction and human–product cooperation [38,39]. The details of this category are illustrated in Table 6.

Table 6. Patterns and corresponding details for "natural human-product experience in office".

Patterns	Details
Multiple Information Channel	Multi-dimensional, multi-sensory, and immersive perception for office workers through visual, hearing, touch, etc.
Privacy Space	Physical space, such as desktop lifting, spatial distance, etc., and personal information space for protecting the privacy rights of individuals.
Information Coordination	The promise of effective information transmission between multiple individuals to decrease subjective stress, anxiety, loneliness etc.

3.2. The Corresponding Design Framework for Intelligent Products in the Office

Intelligence in office environments is displayed by intelligent office products to a large extent. In order to make office environments feature intelligent functions that meet the needs of the office group, a design framework was proposed that integrates the patterns of biophilic design in the office. Based on Tables 4–6 and considering the complexity and the order of the information interaction, the corresponding design framework for intelligent products in the office contained three layers, i.e., the perception layer, the computing and communication layer, and the feedback layer, as shown in Figure 6.

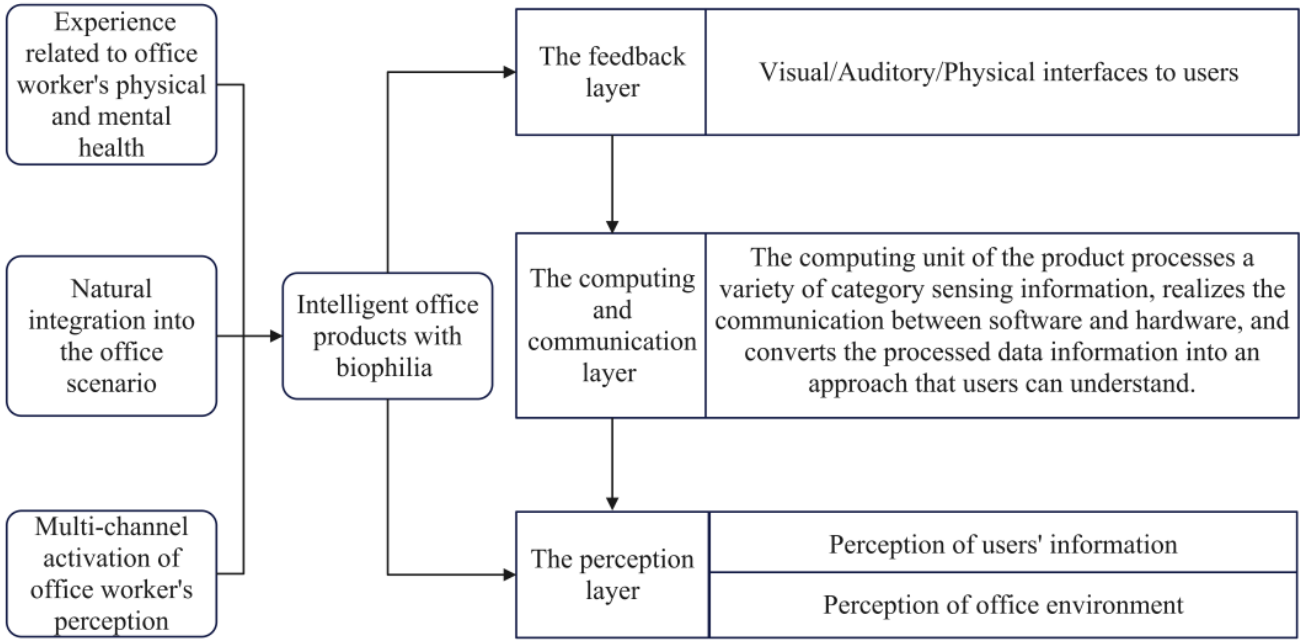


Figure 6. Illustration of the corresponding design framework.

The perception layer is used for collecting information from office workers and the office environment. The computing and communication layer is used for information processing and effective transmission. The feedback layer illustrates the information through a user interface. The information interaction in the framework is described as follows: The perception layer collects the user's physical health information, the environmental information, and other data; it then transmits them to the computing unit in the computing and communication layer for processing. Then, the processed information is transmitted to the feedback layer through the communication unit in the computing and communication layer. Through the visual, auditory, and physical interfaces of the office products, the feedback layer displays multi-channel information, such as visual data, sound, voice, and touch, to make office workers easier to understand. In this process, the biophilic performance is mainly developed from experience related to the users' physical and mental health outcomes, the natural integration into the office scenario, and the multi-channel activation of user perception, which are respectively reflected in the perception layer and the feedback layer.

The Internet of Things (IoT) is often used for information interactions between intelligent office products to achieve the intelligent experience of the office group and the diversified needs of work forms. Intelligent products based on the IoT usually contain software and hardware modules, such as core processors, wireless communication, information monitoring, and an interface. In order to implement the framework shown in Figure 6, the corresponding intelligent office products based on the IoT can be established through intelligent hardware, Wi-Fi modules, sensors, APP/PC interfaces, buzzers/LEDs, and other electronic components. The general information interaction pathway based on the IoT among office environments, office workers, and intelligent office products is shown in Figure 7.

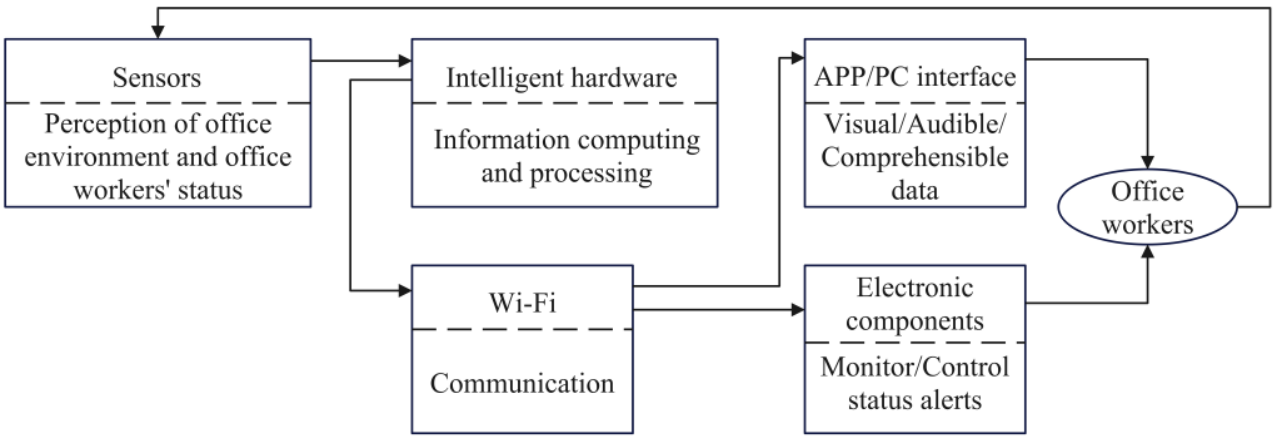


Figure 7. Corresponding general information interaction pathway.

4. Case Study

4.1. Illustration of Design Scheme

A design scheme of an intelligent office product that mainly focuses on reminding to drink water (P_1) is proposed based on Figure 8. It consists of the handle module and the coaster module. The handle module has the characteristics of easy assembly and disassembly and can be used together with existing cups of the office desktop. It also reserves function access ports for meeting personalized demands. The details of the biophilic performance for this design scheme are shown in Figure 8.

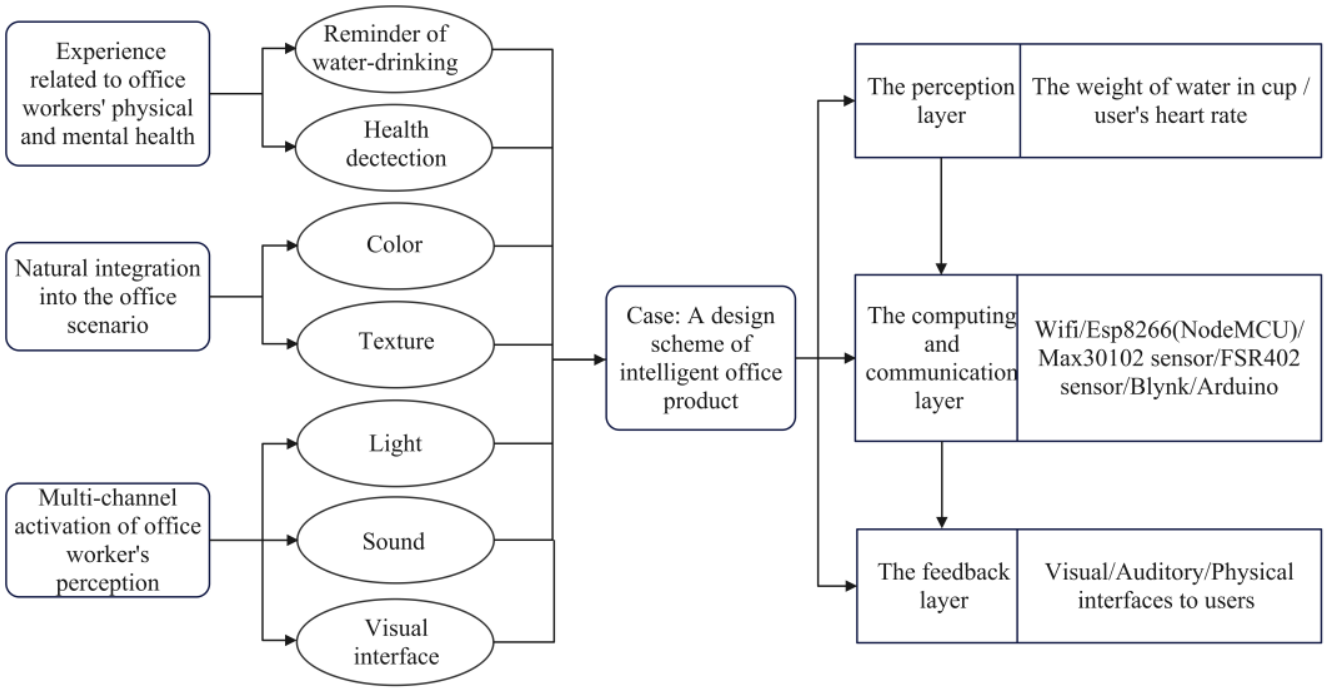


Figure 8. The details of biophilic performance for the case design scheme.

Because the function of health detection (P_4) had a relatively strong correlation, it was selected as the secondary function. The aspect, the experience related to users' physical and mental health outcomes, was manifested in the functions P_1 and P_4, respectively. Color and texture were the main design points used to illustrate the aspect of natural integration into the office scenario. White and green were selected as basic colors, and cork and silicone were used to enhance the sense of connection with nature. Light, sound, and a visual

interface were used for the multi-channel activation of user perception. The rendering and main interface are shown in Figure 9.

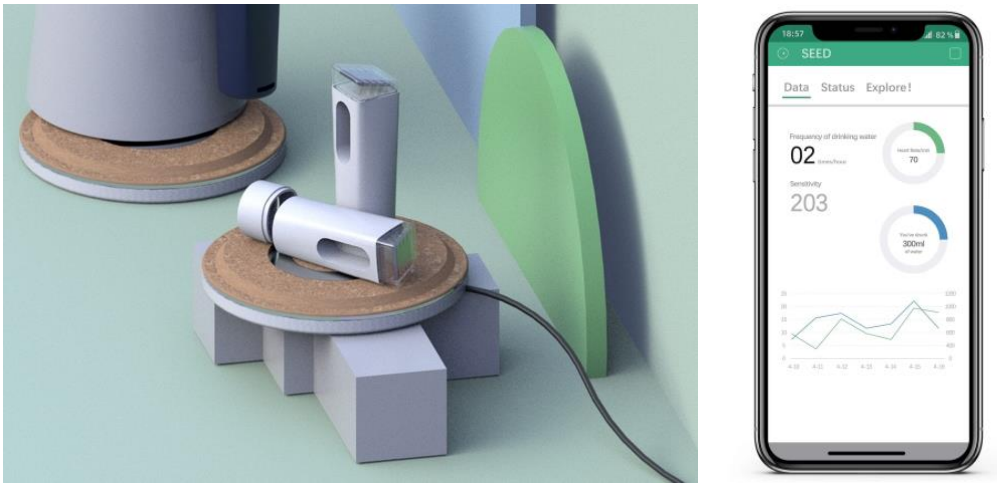


Figure 9. The rendering and the main interface.

4.2. The Prototype Design and Evaluation

An interactive prototype was used for the evaluation of the design scheme. The developing requirements for the interactive prototype included several items. Firstly, it needed to connect with the IoT in the office. Then, the data, such as the office workers' heart rates and the weight of the water in cups, could be collected in real time. Thirdly, the office group needed to be able to see the data through mobile access. Max30102 and FSR402 sensors were chosen to perceive the users. Based on Blynk and Arduino, the data from the sensors were computed and processed. The implementation details of the interactive prototype are shown in Figure 10.

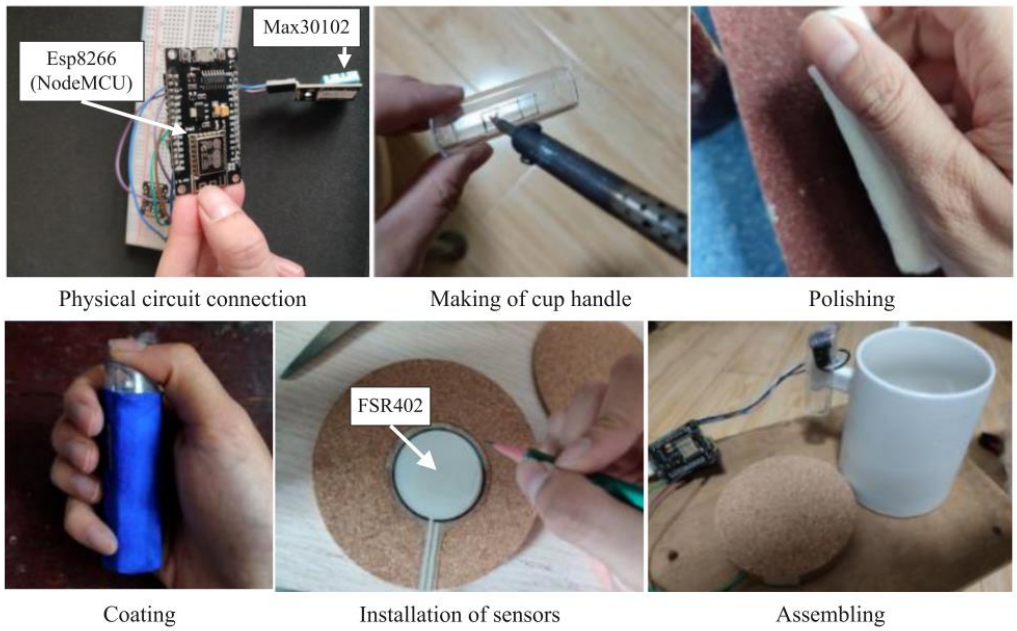


Figure 10. The implementation details of the interactive prototype.

Participants were divided into the prototype group and the concept group. We defined the evaluation set as $V = \{v_1, v_2, v_3, v_4\}$, where $v_1 \sim v_4$ represent the willingness for use in an office environment, the biophilic performance, the need of function for heart rate detection, and the need of function for the reminder to drink water, respectively. A total

of 14 participants were recruited, and their scores were ranked from 0 to 3. The prototype group was asked to use the prototype during one hour of working, and the concept group was provided the rendering and the illustration of this design scheme. The evaluations are shown by Table 7 and Figure 11.

Table 7. The data of the prototype group and the concept group.

Group Number	Data	v_1	v_2	v_3	v_4
The concept group	Mean	2	2.29	1.43	2.43
	SD	0.534	0.488	0.535	0.787
The prototype group	Mean	2.57	2.71	2.57	2.43
	SD	0.816	0.756	0.976	0.535

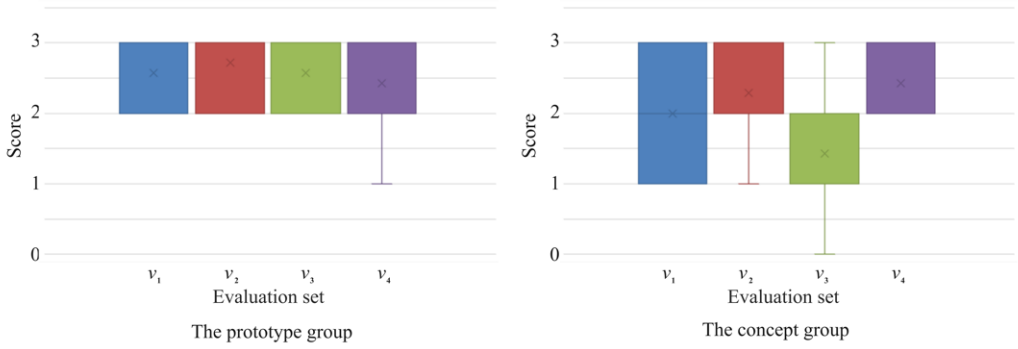


Figure 11. The evaluations of the interactive prototype and the concept.

It can be seen that the evaluations of the prototype group were better than those of the concept group in terms of the willingness for use in the office, the biophilic performance, and the need of function for heart rate detection. For the need of function for the reminder to drink water, the two groups were basically the same. The above results not only show that the practical operation experience of the design scheme was better than the users' expectations, but they also show that the framework for integrating biophilic design with intelligent products in the office has a certain practical feasibility. It also means that the design scheme of this case has the value of iterative design, and this provides a reference for the related intelligent product design in the office.

5. Conclusions

This paper proposed an approach to improve biophilia and intellectualization simultaneously in the design of office environments. Office workers were investigated from three aspects, including the health needs, the user experiences of office environments, and the practicability of the office products' functions. A total of 12 biophilic patterns, which are suitable for the office environment, were illustrated, and a corresponding design framework of the intelligent office products that could be used to display intelligent functions was developed. Then, a case study including, the design scheme, the prototype, and the evaluation was described to verify the feasibility. The significant research outputs from the present study are as follows:

(a) The details of the physical and mental discomforts of office workers were obtained by the user study. The correlation results from the perspectives of office workers' concerns and the mental impact on office workers support the design of intelligent environments in the office. For example, the six office environmental factors showed different degrees of correlation with each other; additionally, some office environmental factors and some intelligent functions also had correlations. These quantitative relationships can provide references to meet different requirements in the office environment design.

(b) The biophilic patterns for the office environment and the corresponding design framework of the intelligent products provide a design approach of the office for designers to enhance biophilia and intelligence at the same time. The 12 biophilic patterns derived from the biophilic design theory consider the needs and experiences of office workers. The design framework and the general information interaction pathway provide a systematic pathway to implement intelligent functions in the office quickly. The above makes the patterns and the corresponding design framework more suitable for intelligent office design.

(c) A case study of intelligent office product was described to show the design process with the proposed framework. A usable interactive prototype of the design scheme was developed and then evaluated in real office environments. The results indicate that the user experiences of the biophilic performance and the needs of intelligent functions were beyond the users' expectations. It helps designers to perform similar or related designs on this basis.

Moreover, this study paid more attention to the human factor in the office. Both the user study process and the user evaluations in the real office environment were aimed to give office workers more comfortable working experiences and more suitable intelligent functions. It can be seen as a preliminary study on office environments from the perspective of the integration of biophilia and intellectualization. It still possesses limitations. Intellectualization is a kind of combination of multiple intelligent functions, which are displayed by intelligent products in office environments. However, the intelligent office environment is more than the integration of multiple intelligent functions in the office: it is an environment that can make office workers feel healthier, more convenient, and more effective through intelligent functions. Hence, the effects of the cooperation of different intelligent office products on biophilia in overall office environments, as with the interactional impacts between different intelligent functions, biophilia patterns, and so on, need to be considered in further works.

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