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DZHAMBINOVA**

SMART WORKPLACES: A SYSTEM PROPOSAL FOR STRESS MANAGEMENT

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Projeto apresentado ao IADE - Faculdade de Design, Tecnologia e Comunicação da Universidade Europeia, para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Design de Interação realizada sob a orientação científica da Hande Ayanoglu, Professora Auxiliar do IADE - Universidade Europeia, e do Doutor Edirlei Soares Lima, Professor Auxiliar do IADE - Universidade Europeia.

Посвящаю эту работу своим родителям.

Сердечная благодарность вам за всё.

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Palavras-chave

Smart workplace environment, well-being, stress-relief, user-centered design, usabilidade

Resumo

Nas últimas décadas da sociedade contemporânea, o local de trabalho tem se tornado principal fonte de muitos problemas de saúde mental, como o stress, depressão e ansiedade. Os aspetos ambientais têm se revelado como as causas de stress, doenças, falta de produtividade, entre outros. Atualmente, com a chegada de novas tecnologias, principalmente na área de locais de trabalho inteligentes, a maioria dos estudos tem se concentrado na investigação de modelos de eficiência energética de edifícios e conforto térmico humano. No entanto, pouco foi aplicado ao reconhecimento do stress dos ocupantes e ao bem-estar geral das pessoas. Diante disso, o objetivo principal é propor um sistema de design de gestão do stress para um sistema de design interativo que permita adaptar as condições ambientais de acordo com as preferências de utilizador, medindo em tempo real as características ambientais e biológicas, auxiliando assim na prevenção de stress, bem como ajuda os utilizadores a lidar com o stress quando estão sob o mesmo. O segundo objetivo é desenhar e avaliar uma parte do projeto — o protótipo da aplicação móvel através da realização de testes de usabilidade. O sistema proposto resulta da abordagem de design centrado no utilizador, utilizando diversos métodos de usabilidade para identificar as necessidades, comportamentos e as expectativas dos utilizadores. Métodos aplicados, como Pesquisa de Usuário, Card Sorting e Revisão de Especialistas, permitiram avaliar o sistema de design de acordo com a análise heurística, resultando numa melhoria na usabilidade das interfaces e experiência. O estudo apresenta os resultados da pesquisa, a interface do design e os testes de usabilidade. De acordo com os resultados de User Research, a temperatura e o ruído são os stressores ambientais mais comuns entre os utilizadores, causando stresse e condições menos favoráveis para trabalhar, igualmente existe uma preferência por atividades físicas sobre as soluções digitais na gestão do stresse. Adicionalmente, os resultados de System Usability Scale (SUS) identificaram a usabilidade do sistema de design como “excelente” e “aceitável” com pontuação final de 88 pontos em 100. É esperado que essas conclusões possam contribuir para futuras investigações no campo de estudo dos smart workplaces e sua interação com os utilizadores.

Keywords

Smart workplace environment, well-being, stress-relief, user-centered design, usability

Abstract

Over the past last decades of contemporary society, workplaces have become the primary source of many health issues, leading to mental problems such as stress, depression, and anxiety. Among the others, environmental aspects have shown to be the causes of stress, illness, and lack of productivity. With the arrival of new technologies, especially in the smart workplaces field, most studies have focused on investigating the building energy efficiency models and human thermal comfort. However, little has been applied to occupants' stress recognition and well-being overall. Due to this fact, this present study aims to propose a stress management solution for an interactive design system that allows the adapting of comfortable environmental conditions according to the user preferences by measuring in real-time the environmental and biological characteristics, thereby helping to prevent stress, as well as to enable users to cope stress when being stressed. The secondary objective will focus on evaluating one part of the system: the mobile application. The proposed system uses several usability methods to identify users' needs, behavior, and expectations from the user-centered design approach. Applied methods, such as User Research, Card Sorting, and Expert Review, allowed us to evaluate the design system according to Heuristics Analysis, resulting in improved usability of interfaces and experience. The study presents the research results, the design interface, and usability tests. According to the User Research results, temperature and noise are the most common environmental stressors among the users causing stress and uncomfortable conditions to work in, and the preference for physical activities over the digital solutions for coping with stress. Additionally, the System Usability Scale (SUS) results identified that the system's usability was measured as "excellent" and "acceptable" with a final score of 88 points out of the 100. It is expected that these conclusions can contribute to future investigations in the smart workplaces study field and their interaction with the people placed there.

List of Acronyms and Abbreviations

BP — Blood Pressure
BVP — Blood volume pulse
ECG — Electrocardiogram
ED — Exhaustion disorder
EDA — Electrodermal activity
EMG — Electromyography
EWCS — European Working Conditions Survey
GSR — Galvanic Skin Respiratory response
HCD — Human-Centered Design
HSE — Health and Safety executive
HVAC — Heating, Ventilation, and Air Conditioning
IAQ — Indoor Air Quality
IEQ — Indoor Environment Quality
IR — Infrared sensor
ISO — International Standards Organization
KPI — Key Performance Indicator
OSHA — Occupational Health and Safety Administration
PD — Pupil dilation
PMV — Predicting Mean Voice
RA — Respiratory activity
RIP — Respiratory Indictive Plethysmography
SLR — Systematic Literature Review
SNS — Sympathetic Nervous System
ST — Skin Temperature
SVM — Support Vector Machine
UCD — User-Centered Design
UI — User interface
UPA — Usability Professionals Associations
UX — User Experience
WHO — World Health Organization

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1. Introduction

1.1 Background

Over the last decades of contemporary society, workplaces have become the main source of many health problems such as sedentary working, imbalance in work-life, and increased pressure for jobs (Lee, 2019). Furthermore, the workplace is one of the key drivers of the physiological, psychological, and socioeconomic well-being of the employees and the health of their family members, community, and society (Chu et al., 2000).

Mental health problems are the most common problem in the workplace, as increased stress, depression, and anxiety are the main causes of all absenteeism and are responsible for almost half of all work-related illnesses reported. Stress ranks first among all work-related health problems (Lee, 2019).

The World Health Organization (WHO) defines health and overall physical, mental, and social well-being as a critical issue in the workplace, as it is directly related to the person and is the organization's most important and costly asset.

Another study argues that there are seven key performance indicators (KPIs) to consider about health in the workplace, such as “fitness, physical comfort, physical nutrition, cognitive well-being, social well-being, emotional well-being, and environmental well-being”, Figure 1.

In addition to health, certain environmental conditions at work affect workers' productivity and participation due to their physical, mental, and social interplays. Moreover, “ergonomics, acoustics, lighting, thermal comfort and olfactory comfort, or any component of physical comfort that contributes to employee cognitive functions and their ability to cope with mental stress and fatigue” (Lee, 2019).

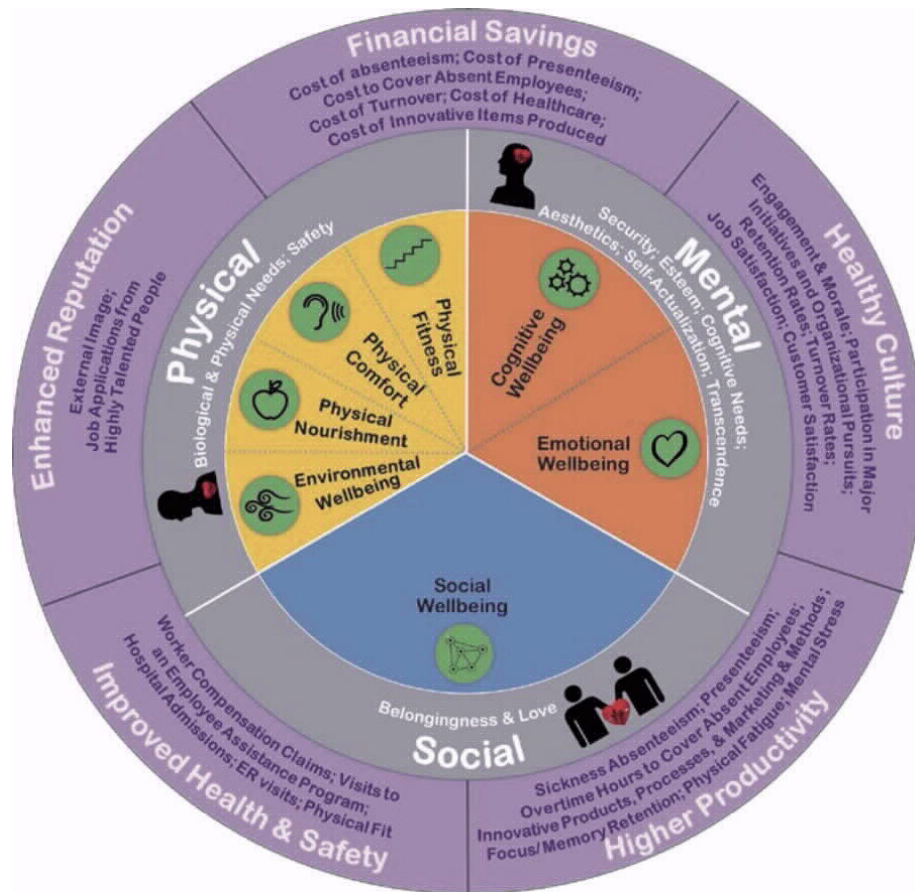


Figure 1. Seven KPIs of workplace health in three domains and their benefits in the PROWELL model. Source: (Lee, 2019).

Many studies have confirmed that the environmental aspects of the workplace, including environmental conditions (i.e., noise, lighting, air quality, thermal comfort), furniture layout, and ergonomics, are related to functional comfort, as illustrated in Figure 2. According to numerous field studies of office buildings that define the concept of comfort, people need to be more than healthy and safe in the workplaces they occupy, they need environmental support for the activities they must perform there (Vischer, 2008).

Nowadays, most people are spending their time indoors as buildings can provide human beings with satisfactory environments. The quality of build environments created using the different construction systems, including acoustic quality, air quality, spatial quality, visual quality, and thermal quality, is always assessed through indoor environment quality (IEQ). As one of the most important construction systems, heating, ventilation, and air-conditioning systems, in commercial

buildings, such as open-plan buildings, combine all this quality, in particular the air quality (IAQ) and indoor thermal quality (Lu et al., 2019).

Usually, human comfort measures are linked to different systems (e.g., lighting, ventilation, temperature), to define comfort and health conditions and, therefore, direct the design of buildings. The extent to which users can perform their tasks in the areas in which they are employed is defined

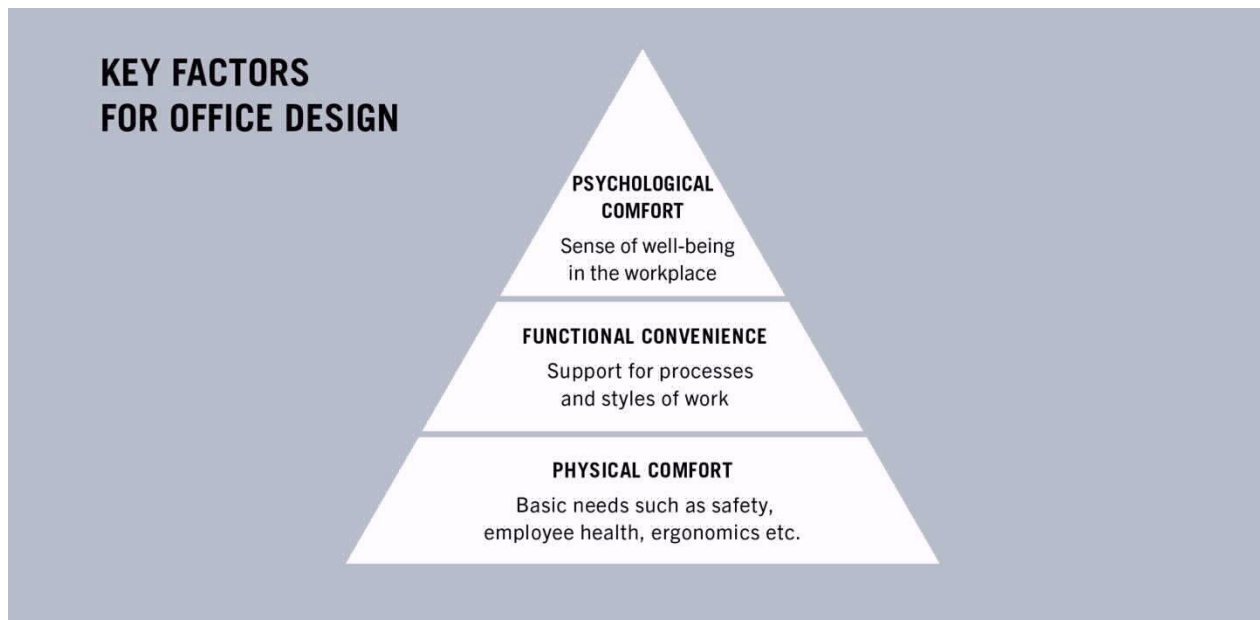


Figure 2. The work environment influences employee satisfaction and performance. Source: [Bene](#)

as functional comfort; it is a result of comfort motions as defined by environmental standards and the additional precision that user experience varies with the need for tasks (Vischer, 2008).

As mentioned previously (Vischer, 2008), physical comfort refers to fundamental human needs such as safety, hygiene, and accessibility that must be guaranteed, usually following the existing buildings' codes and standards, for the users to have a habitable environment. Nevertheless, functional comfort refers to the extent to which the environment supports tasks for users. Psychological comfort, including feelings of belonging, owning, and control of the workplace, is more abstract, yet equally important to users at work.

1.2 Problem definition

Research in computer technology is focused on the development of intelligent environments. Thus, smart, or intelligent environments and systems interact with humans in a way that is beneficial, adaptive, active, and unobtrusive (Ramos et al., 2010). Nevertheless, most of the found research, however, has focused on building energy efficiency and has scarcely been applied to occupant's stress level recognition and well-being overall.

Work-related stress is a reaction to excessive demands or pressure at work, described as the most common occupational problem existing mostly in each profession. These pressures are termed stressors, presented in Figure 3, as was stated earlier, stress could be a physiological and psychological reaction to the internal or external stressors. There are different types of stressors according to their origins: environmental, daily life events, workplace, chemical, and social. Those are identified in two groups: in the first are those that can be measured and quantified, such as environmental or chemical (temperature, humidity, air quality, etc.), and in the second group, we find those that cannot be measured or quantified, daily events (traffic, financial problem, change or loss of job, etc.) (Ramón-Fernández et al., 2018).

What causes stress is more typically how we interpret a problem than the situation itself. Internal reactions to external stimuli considerably impact how we react to possible stressors. Long-term stress is harmful in many ways, it can impair the immune system, strain the heart and blood vessels (Mucci et al., 2016), source of depression and anxiety (Melchior et al., 2007), may develop heart diseases, ulcers, arthritis, burnout, and exhaustion disorder (ED) (Wiegner et al., 2015).

There is a significant number of studies addressing stress to sleep disturbances, alcohol, and drug consumption, as well comorbid personality disorders, especially in the young population (Leppink et al., 2016).

Consequently, there are different types of stressors according to their origins, however, the present study will focus on those that can be quantified and measured: environmental and chemical stressors, such as temperature, air quality, humidity, and biological/physiological conditions, such as body temperature, heart rate activity and electrodermal activity (EDA).

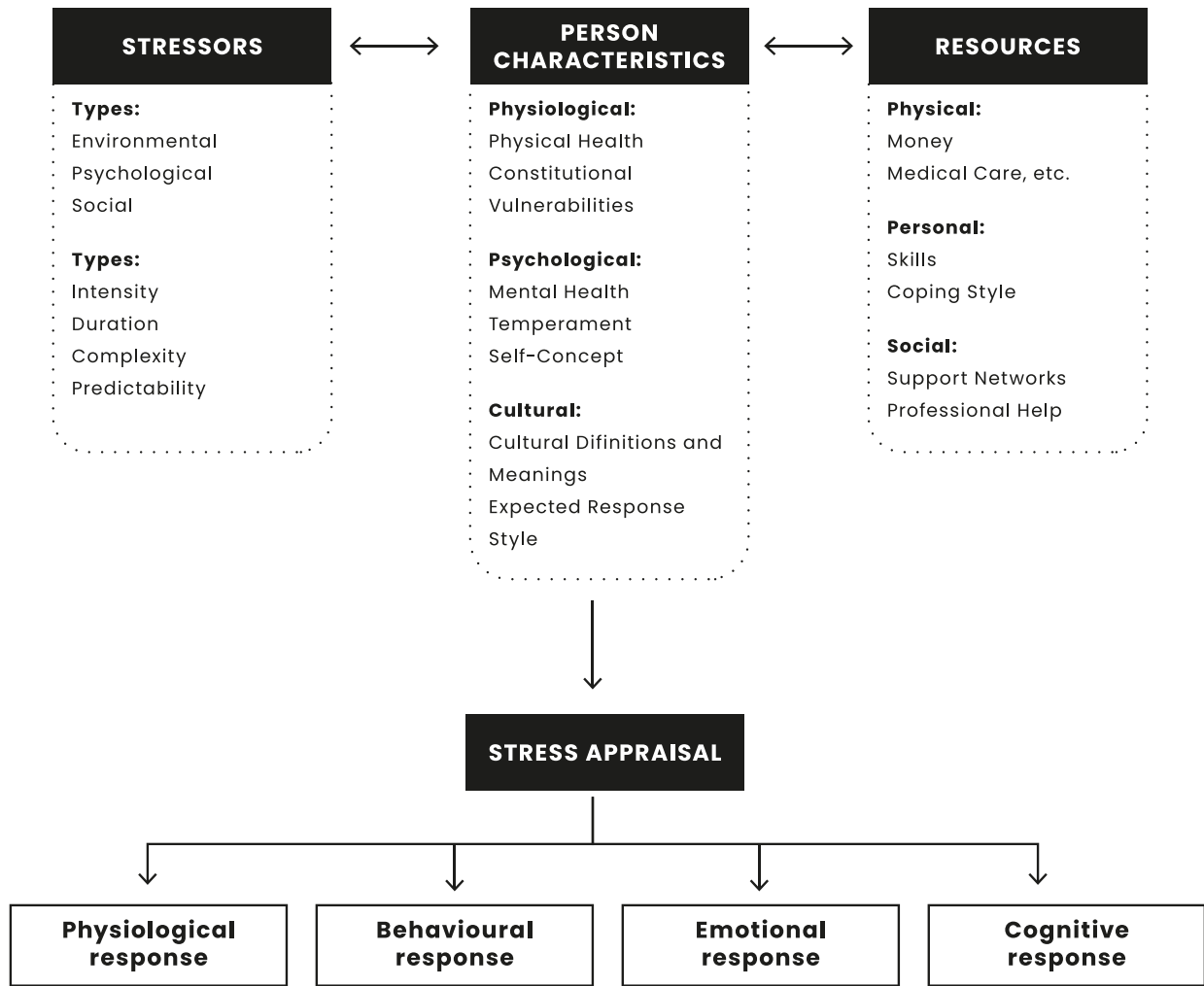


Figure 3. A general model of the stress process. Source: [Precipitating stress of mood disorders](#).

1.3 Objectives

The purpose of this study is to propose a stress management solution for an interactive design system that allows the adapting of comfortable environmental conditions according to the user preferences by measuring in real-time the environmental and biological characteristics, thereby helping to prevent stress, as well as to help users to cope stress when being stressed. The secondary objectives of this study are as follows:

- Investigate and analyze environmental stressors in the workplace and existing solutions in real-time predicting models and sensors.
- Conduct user research to identify current methods of stress-relief practiced by the users at their workplace, as well as identify environmental frustrations in the workplace.
- Evaluate a part of the system, a mobile application prototype by conducting usability tests.

1.4 Study diagram

Figure 4 represents the study diagram of the methodology process of the present thesis study.

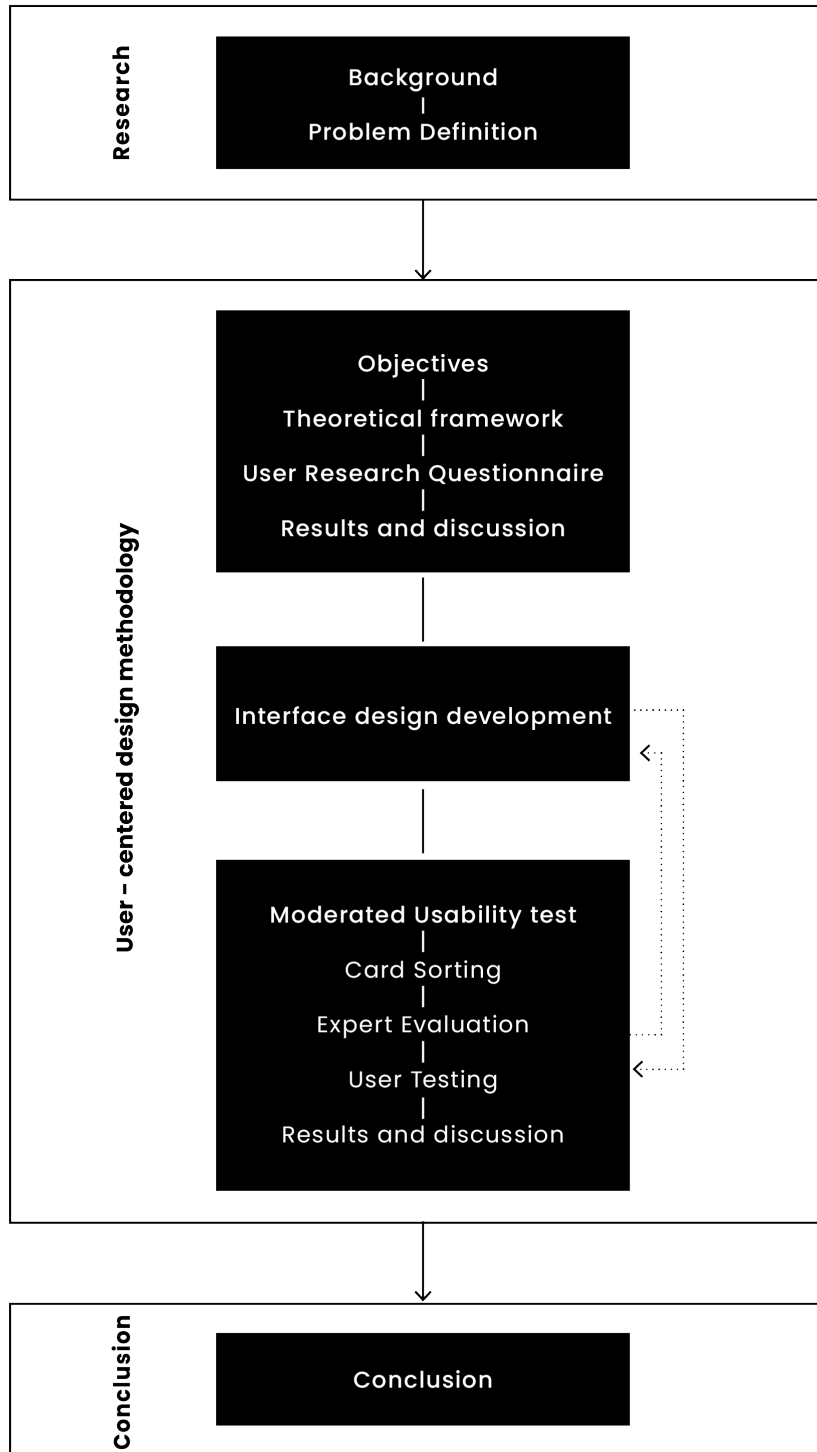


Figure 4. Study diagram

1.5 Thesis Structure

This section describes the structure of this document, which has been divided into five chapters, where each one describes their working methods used for the development of the project throughout the research.

Chapter 1 is an introduction to the project, consisting of a brief background description of the topic, an overview of workplace stress, its causes, and mental illness. This chapter also describes the problem definition, the main research objectives (primary and secondary), which serve as guides for research work in conceptualizing the proposed solution.

Chapter 2 of the document, the Theoretical Framework, provides an overview of previously studied works related to workplace environmental stressors, stress detection, and recognition, equally, predicting models and smart sensing technologies.

Chapter 3 presents the applied methodology and methods used for the development of the research.

Chapter 4 presents the project development process of the proposed system, outlines the design process, including Architecture Information testing, Low-Fidelity test with UX Experts, Usability testing of the system, methods, and procedures.

Chapter 5 the last chapter of the document followed by the results and conclusion of the overall project development, as well highlighted the limitations and final considerations for future work.

2. Theoretical Framework

This section contains a summary and a series of published works and articles related to the subject area of this study, collected through a literature review.

2.1 Smart workplace

Smart workplaces are stated by Samani et al. (2012) as an environment that is capable to adapt itself to the requirements of users, freeing users from routine tasks that they need to perform, changing the environment to suit their preferences, and accessing services available at each moment by customized interfaces. Smart workplaces are powered by multiple devices that support everyday tasks. They can anticipate the user's intent, and perform tasks on their behalf, making it easier to complete other tasks.

A smart workplace, according to Le Gal (2005), is an environment that might enable its occupants to accomplish daily tasks by automating some of them and making user-machine communication simple and effective.

As mentioned in Marsá-Maestre et al. (2006) smart workplaces minimize the decision cycle and provide accessibility wherever the users are placed by collecting knowledge and information resources. This approach permitted a new way of looking at traditional offices, where it is expected that these environments smartly assist their occupants and, most importantly, enabling facilitate the creation of a selection of effective decisions.

Physical components such as sensors, controllers, and smart devices are necessary to create smart workplace environments. Then using the information collected by these sensors, the software may then reason about the environment and activate actions to modify the state of the environment, through the actuators. Such sensors/actuators networks need to be reliable and self-organized to develop a ubiquitous/pervasive computing platform.

In addition to its omnipresent decision-making support system (Samani et al., 2012), the smart workplace must include the following features:

- Learning demands and high-quality decisions can be met by ensuring individual access to relevant information and know-how resources.

- Provide optimum stress relief by preventing all regular stressful conditions.
- To ensure all technical workplace tasks will be provided with comprehensive, up-to-date technical support.

Therefore, in the ubiquitous environment, higher interaction between the environment and its users are expected and, following the changes in working processes and procedures, the policy approaches required to undertake management tasks will also change. This will diversify and increase the importance of the responsibilities of the decision-making-support system that supports decisions in the ubiquitous workplace.

2.2 Environmental stressors

2.2.1 Stress definition

It's no longer a secret that stress has become part of our lives. According to the European Working Conditions Survey (EWCS) in 2000, it was found that work-related stress is second to the most common health problem across the European Union (Houtman, 2005).

Nowadays, in modern society, it is observed that the work, social and academic environment has become more stressful (Zgheib & Conchon, 2017). It is believed that stress is the main cause of many harmful mental illnesses and behaviors (Boateng, 2016). According to World Health Organization data, depression and anxiety are two major mental disorders common in the young population, affecting about 300 million people worldwide (Mirón et al., 2019), (de Ramón-Fernández et al., 2018).

According to Ivancevich and Matteson (1996), stress is an adaptive response resulting from the relation between the environment and its occupants, “mediated by psychological processes of individual responses which in turn are a consequence of any external (environmental) action, situation or event that places excessive psychological or physical needs on the person” (Oosthuizen & Van Lill, 2008). Beehr and Newman (1978) outline job stress as, “a condition arising from the interaction of people and their jobs and characterized by changes within people that force them to deviate from the normal functioning” (Salami et al., 2010). Subsequently, another definition of

stress has been introduced that considers a person's coping skills as "events, that are threatening to an individual, and which elicit physiological and behavioral responses" (McEwen, 2000).

According to the studies of Kocielnik (2013), stress is experienced by people every day and is essentially related to the interaction between the environment and the individual. The estimation of being too stressed is often revealed late, when health problems already manifest themselves: people's ability to remember, recognize and understand their stress can be hampered by their lifestyle, with multiple tasks and responsibilities faced every day.

Concerning the occupational environment (Alberdi et al., 2016), work-related stress has been characterized as "the emotional, cognitive, behavioral and physiological reaction to aversive and noxious aspects of work, work environments, and work organizations. It is a state characterized by high levels of arousal and distress and often by feelings of not coping" (Mishra et al., 2011).

The symptoms are manifested in several psychological forms such as anger, frustration, and anxiety. Initially, stress develops because of the synchronization of the body and mind as we are facing the change, an internal development may not be recognizable at first however, the abnormal external signs will reveal the problem by affecting the nervous system and consequently is revealed in the form of sweat, fatigue, augmented heartbeat, speech impediment, anxiety, among others.

According to Kocielnik (2013) "The physiological signals of stress, as reflected by changes in blood pressure, heart rate, pupil dilation, sweat gland activity, reflected in skin conductivity, can be objectively measured in unobtrusive ways using modern sensor technology". There are many studies in (Alberdi et al., 2018; Jayathissa et al., 2020; Leonidis et al., 2021; Ramos et al., 2018; Xie et al., 2020) in this field indicate that these measurements can be effectively used for stress detection.

2.2.2 Types of stress

Stress can affect in different forms and each of them has specific characteristics, symptoms, and duration. As mentioned by Ramón-Fernández et al. (2018), the American Psychological Association (APA) categorizes stress into different types based on its duration: acute stress, acute episodic stress, and chronic stress. Acute stress is the most common, possibly short-term, and usually does not cause as serious damage as those found associated in the long run. When acute stress recurs with some frequency, it is called acute episodic stress, and if it persists for a long time,

it is known as chronic stress. This type of stress turns out to be the most harmful since it affects not only mental but physical health as well.

It is important to prevent stress from reaching high levels and to do so, it is necessary to detect it in advance and treat it in its initial stage, such as acute or episodic (Sharma et al., 2014). A lack of treatment for work-related stress can lead to long-term physical and mental complications for the individuals (Milczarek et al., 2009) as well as economic losses for the organizations.

The consequences of the long-term chronic stress result in manifestations like musculoskeletal disorders, depression, anxiety, increased probability of infections (Wijsman et al., 2013), chronic fatigue syndrome, digestive problems, diabetes, osteoporosis, stomach ulcers (Bickford Melanie, 2005; Cosmar Marlen, Grundler Robert, Flemming Danny, 2014; Peternel et al., 2012) and coronary heart disease are some of the examples.

2.2.3 Measurement of stress responses

The Sympathetic Nervous System (SNS) causes the stress response in humans (Kurniawan, et al., 2013), transporting psychological, physiological, and behavioral symptoms, as presented in Figure 5:

Psychological responses include an increase in strong negative emotions such as anger, anxiety, irritation, or depression, as well as making our emotional responses more intense, causing anxiety, frustration, and hostility (Peternel et al., 2012).

Physiological responses increase SNS activity, alter hormones in the body, and trigger responses such as sweating, the respiratory system and vocal tract, and changes in speech characteristics (Bickford Melanie, 2005). The most significant responses are an increase in heart rate and contractile force, dilation of blood vessels in the heart and skeletal muscles, and restriction of the blood vessels supplying internal organs. Redistribution of blood flow in superficial vessels causes changes in skin temperature, which can be detected by sensitive thermal imaging cameras (Cross et al., 2013).

Behavioral reactions include changes in gaze and blink rate in addition to changes in facial expression or head movement (Carneiro et al., 2012). Therefore, office work can affect patterns of

interaction with a computer, as well as overall General Somatic Activity¹ or body activity level (Peternel et al., 2012).

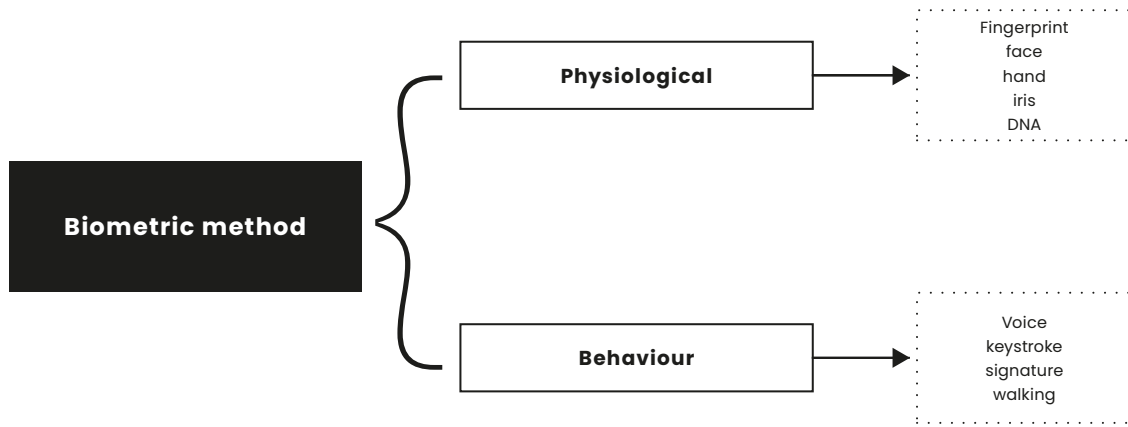


Figure 5. Biometric Method (Hadiyoso et al., 2019)

According to the author's Cross et al. (2013), psychophysiological measurements are commonly used to detect changes in stress levels. In several tests of wearable sensors, monitoring, and measurement of physiological information signals such as an electrocardiogram (ECG), electromyography (EMG), galvanic skin respiratory response (GSR), electrodermal activity (EDA), and respiratory activity (RA) have been most indicative of changes in stress levels. As well as respiratory inductive plethysmography (RIP), blood volume pulse (BVP), blood pressure (BP), skin temperature (ST), and pupil dilation (PD), as shown in Figure 6.

¹ General Somatic Afferent: nervous system with receptors responsible for sensitivity to pain, thermal sensation, touch, and pressure, to control voluntary movements and reflex arcs (Cherry, 2021).

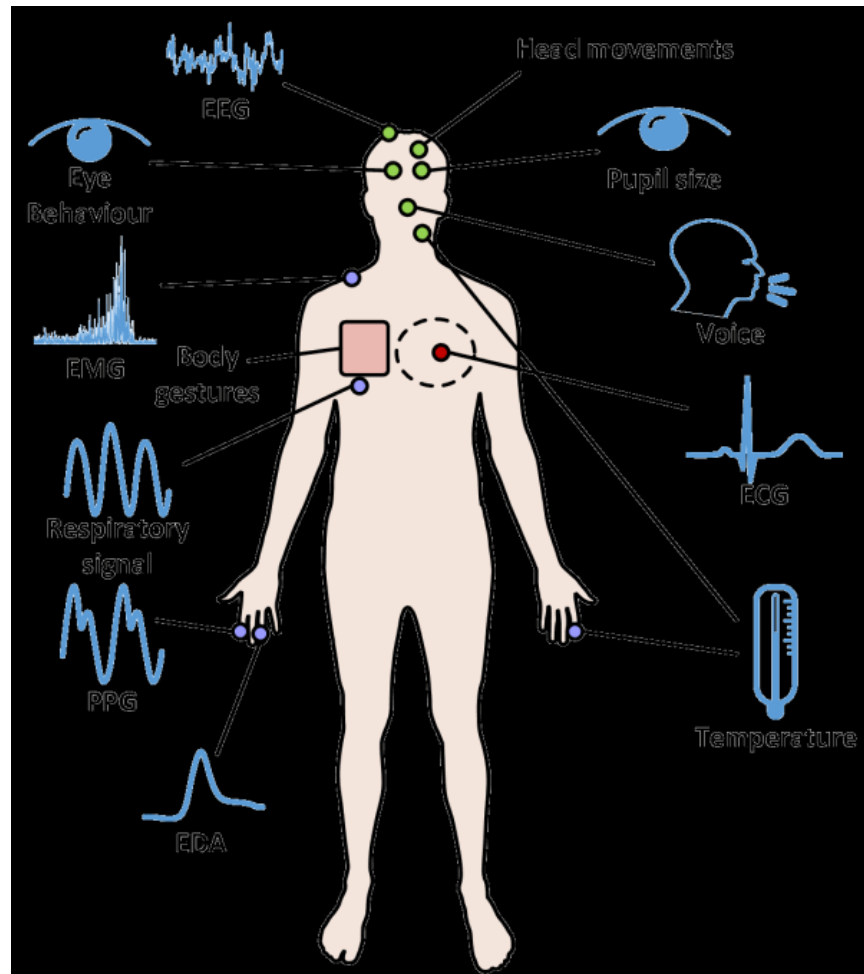


Figure 6. Common physiological and physical measures related to stress (Giannakakis et al., 2019)

Table 1, represents the summarized stress detection studies (Can et al., 2019) experiments executed in the controlled laboratory, as well each study can be ranked by its accuracy performance. It is evident, that Electrodermal activity (EDA), Heart Rate activity (HR), and accelerometer are the most common physiological signals used for stress detection. Nevertheless, despite stress detection being still in the early-stage studies, however, it has shown that it is possible to detect and predict the stress signal in individuals, as well as to measure them from the lower to higher levels.

Table 1. Stress detection experiments in controlled laboratory environments, adapted from (Can et al., 2019)

Authors	Stress Signal	Stress Test	Method	Accuracy %
(Santos Sierra et al., 2011)	EDA, PPG	Hyperventilation and Talk Prep	Fuzzy Logic	99
(Wijsman et al., 2011)	ECG, EMG, EDA	Arithmetic, Puzzle, Memory Tasks	Bayes, kNN, LSD	80
(Alberdi et al., 2012)	HRV	Stress in the traffic	Minimum distance classifier	90
(Hong et al., 2012)	Temperature, Heat Flux, EDA, Respiration, Accelerometer	Arithmetic Task, Cold Pressor and loud Sounds	Naive Bayes	82
(Soury et al., 2013)	Speech	TSST	SVM	72
(Baltaci et al., 2014)	Pupil Diameter	IAPS	DesicionTree	90
(Akhonda et al., 2014)	EEG, ECG, EMG, EOG	MEntal and Memory Task	SVM, kNN	95,8
(Aigrain et al., 2015)	Body movements	Arithmetic Task	SVM	85
(Zubair et al., 2015)	EDA, Accelerometer, Bluetooth	—	Logic Regression	91
(Mohd et al., 2015)	Facial Blood Flow	SCWT	Multiple REgression	88,6
(Liapis et al., 2015)	EDA	Fail Scenarios	LDS	98,88
(Abouelenien et al., 2016)	PPG, EDA, Respiration, Thermal Cam	Lie Detector	DesicionTree	73
(Vanitha et al., 2016)	EEG, ECG, EMG, EOG	Arithmetic Task	SVM	89
(Aigrain et al., 2016)	Body movements, EMG, EDA, Respiration	Arithmetic Task	SVM	85
(Huang et al., 2016)	Human Gaze, Mouse Click	Arithmetic Task	Random Forest	66
(Ciman et al., 2016)	Mobile application usage, Pattern-Physical Activity-Light Sensor-Screen-Events	Real life	SVM, ANN, kNN	70
(Gjoreski et al., 2016)	BVP-Skin Temperature-EDA-RR-Heart Rate (without context info)	Real life	Random Forest	76
(Gjoreski et al., 2017)	HR-IBI-HRV-EDA- Temperature	Real life	WEka Toolkit	70
(Giannakakis et al., 2017)	Facial Cues	Social Exposure and Stressful Media (IAPS)	kNN, SVM, Naive Bayes	91,68
(Akmandor et al., 2017)	ECG, GSR, REspiration, Blood Pressure, Blood Oximeter	Ice test and IAPS	SVM, kNN	95,8
(Mozos et al., 2017)	EDA, PPG, Speech, Acelelemeter	TSST	Adaboost	94
(Fernández, et al., 2018)	BioRadar	Mental Arithmetic Task	Multulayer Perception	0,94
(Vildjiounaite, et al., 2018)	Phone usage data for different application categories	Real life	HMM with MPM	68
(Akbar et al., 2019)	EDA, PPG, ECG, HR	Multitasking	CWT	—
(Hadiyoso et al., 2019)	ECG	Hjorth Descriptor ans SampEn	SVM	93,8

2.2.4 Characteristics of environmental stressors

According to Roelofsen (2002), a large part of scientific research has revealed that the improvement of the work environment has had positive results in increasing productivity and reducing the number of complaints. As well affirms that many researchers have ignored the effects of the importance of workplaces and indoor environment design is poorly regarded as a strategy for productivity and job satisfaction.

Poor perceived workplace environment quality and problems regarding the psychological work environment can increase sickness absence from work, mostly related to bad ventilation, a temperature that is too cold or too hot, and air pollution (Finell & Nätti, 2019).

Evans et al. (1996), have proven how the physical environmental factors can affect human well-being and, identified different types of ambient stressors.

2.2.4.1 Air temperature and humidity

Health and Safety Executive (HSE) explain heat stress occurs when our body is no longer able to control its internal temperature and its starts to fail. The body reacts to heat by increasing the blood flow to the skin's surface and, by sweating creating this way feeling of discomfort. In a research article from Woodward (2016), cold temperature causes muscle tens and affects concentration. Such temperatures as too hot or too cold can cause stress on individuals in different ways, some people are more vulnerable to it than others. The most common symptoms are inability to concentrate, muscle cramps, severe thirst, fatigue, headache, nausea, and others.

According to the Occupational Health and Safety Administration (OSHA), the recommended workplace temperature ranges between 20°C to 24°C and keeps humidity levels at 20% to 60%. The other study made by the Association of Entrepreneurs of the North Zone of Madrid suggests that for office work optimum temperature is between 18°C- 24°C, and the humidity level is around 40%-70% (Ramos et al., 2018). Such similar results demonstrate both studies.

2.2.4.2 Air Quality and Air velocity

Recent study results have demonstrated that air quality has a significant effect on the productivity and health of office workers (Roelofsen, 2002). Air pollution can significantly affect our health, according to several studies in (Marios. P. et al., 2016), the three most significant symptoms were experienced in more than 70% of indoor environments, are dry eyes, dry throat, and headaches.

Musculoskeletal complaints (e.g., pain in the neck, back, or extremities) and psycho-vegetative complaints (e.g., tiredness, depression, exhaustion, and sleep disturbances) are examples of the effects of stress on health associated with air pollution. Nevertheless, the combination of air pollution and chronic stress is still understudied by (Petrowski et al., 2019).

Workplace air quality is measured by a ventilation system, which regulates the amount of air that is released to the workplace environment, as well as by a circulating ventilation system to prevent air pollutants from accumulating in the workplace.

Therefore, according to Biophilic Design studies imitating natural environment in workplaces have provided positive emotional experiences (Ayuso Sanchez et al., 2018) and the other study defends the benefits of utilizing greenery in workplace environments, “workplaces with an abundance of plants in the study had 15% higher productivity than those without” (Holloway Cripps, 2016). There is a major benefit from utilizing greenery in the workplace environment since plants naturally purify the air.

2.2.4.3 Noise

Occupational noise, that is, unwanted sound (Muchinsky, 2000), has been related to a variety of adverse effects on well-being. Noise is one of the most common complaints of working people, especially in the open concept workplace or large spaces with little separation. According to the article Flooring (n.d.), multiple studies have shown that excessive noise in the office leads to low productivity, increase stress, and low job satisfaction. A study from the University of Sidney in 2013 found that lack of sound privacy was the main frustration for employees, and in third place was the noise level.

Many studies confirmed (Haneda et al., 2008; Jayathissa et al., 2020; Leonidis et al., 2021) that occupational noise exposure has been associated with a range of indicators of physical health, cardiac problems, sickness-related absenteeism, and self-reported fatigue (Westman & Walters,

1981). Furthermore, the same similarity was discovered on office workers between occupational noise exposure and symptoms of psychological distress. It was confirmed that noise has a negative impact on job satisfaction (Leather et al., 2003). The same study concludes the potential aspects of office design and benefits of acoustical treatments that minimize levels of noise, are more likely to yield continuing benefits to individual health and well-being in the workplace.

2.2.4.4 Lighting and brightness

The author of the study of the impact of the office environment on employee performance Roelofsen (2002) affirms that lightning levels have a very small effect on productivity unless it is necessary to perform a visually demanding task, as the human eye has an ability to adapt to a broad range of lighting conditions, even in low-level situations.

Thenceforth, lighting is one of the key elements of ergonomics in the workplace that influence personal well-being and health and act as a positive impact on motivation and performance. (Ikonne & Yacob, 2014). Bachner (2000) notes that lighting is needed to help workers maintain and generate their visual tasks. Poor lighting creates visual problems for workers which result in visual fatigue and discomfort, neck and back pain, especially in the individuals with a poor posture, and particularly when having constantly lean forward to perform tasks (Burton, 2008).

After all, lighting is often a complex task to design, especially it should be designed according to the tasks that individuals are performing in the workplace. According to the experience of Sanchez et al. (2018), “There is a positive correlation between the presence of greenery and satisfaction with the thermal environment, and there is a negative correlation between greenery and daylight satisfaction and the subjective perception of fatigue”. The results of this experiment demonstrated that workers feel drowsy during the day.

2.3 Contribution of Interaction design in smart workplaces

2.3.1 Interaction design

Design, according to Victor Papanek² (1985), is “(...) the conscious and intuitive effort to impose meaningful order”. Cooper et al. (2014) suggested a more complete definition of human-oriented design activities such as “understanding the desires, needs, motivations, and contexts of people using products (...); and behavior is useful, usable, and desirable, as well as economically viable and technically feasible”.

Interaction design is defined in several relatively distinctive ways. Some concentrate on the design product that a specific sense is “interactive”, other definitions concentrate on the design of “interaction” with computer-based systems (Mateosian, 2000). Interaction Design was described by Kolko (2010), as “creating a dialogue between a person and a product, system or service”. The same dialogue is physical and affective and reveals itself in form, function, and technology. Interaction design includes a holistic view of the relationship between the artifacts created those that are influenced by these artifacts, and the social, cultural, and business setting in which the event takes place (Fallman, 2008). Designing digital products, devices, services, and spaces with attention to the quality of the user experience (Löwgren, 2002) is at the foundation of interaction design.

As previously mentioned, Interaction Design approaches the communication between user and product. Therefore, Interaction Design consists of five essential principles:

- **Consistency:** using patterns helps the user to better assimilate the system, making navigation simpler and easier
- **Perceivability:** interactions should be obvious
- **Predictability:** should set accurate expectations in advance or feeling the upcoming event
- **Learnability:** interactions should be simple, easy to understand, and intuitive

² Victor J. Papanek (1923 - 1998), was an Austrian-born American who was among the first mainstream professional product/industrial designers. Was one of the twentieth century’s most influential pioneers of social and ecological design in the 1960s.

- **Feedback:** the user should receive feedback after performing some action on the interface

2.3.2 Usability

There are many definitions of usability and, all of them state that usability above all is a quality that many products have or should have. Mainly, what makes something usable is the absence of frustrations when using a system or a product.

Tullis & Alberts (2008, p.10) in their book describe three definitions of usability. The first definition comes from the International Standards Organization (ISO 9241-11 Ergonomics of Human System Interaction)³ which identifies three aspects of usability, defining it as “a product that can be used by specific users to achieve specific goals with effectiveness, efficiency, and satisfaction in a specific context of use”.

The following definition of usability mentioned in the book is from the UPA (Usability Professionals Association), which, in turn, focuses more on the product development process: "A usability is an approach to product development that incorporates direct user feedback throughout the development cycle to reduce costs and create products and tools that meet user needs." Therefore, usability throughout the development of a product tries to seek and reach all user needs to produce products that meet those same needs.

The last definition is from the famous book Don't Make Me Think, Krug (2000) that usability means making something that works well and that a non-experienced person can use for its proper purpose, without any frustration during the process.

³ <https://www.iso.org/obp/ui/#iso:std:iso:9241:-11:ed-2:v1:en>

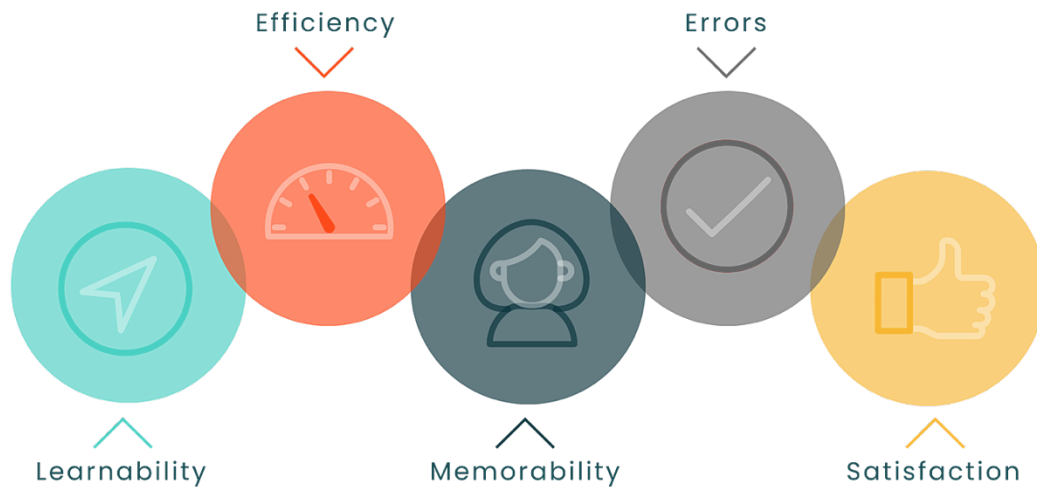


Figure 7. The Five Components of Usability. Source: [Nielsen Norman Group, image](#)

According to Hartson & Pyla (2012, p.6), “usability is the pragmatic component of the user experience”, as it must include effectiveness, efficiency, productivity, learnability, memorability, and the realistic aspects of satisfaction of the user, see Figure 7. True usability is invisible when something goes well no one notices (Rubin & Chisnell, p. 44).

Usability tests, also known as user tests, are a set of methods used to measure the characteristics of the interaction between a user and a product. The goal is usually to assess the usability of that product. Typically, usability testing focuses on measuring how successfully users can complete specific standardized tasks, as well as what problems they encounter doing so (Cooper et al., 2014).

2.3.3 Characteristics of user experience

The goal of good user experience design is what makes the product effective to its users when they interact with them. That so, usability is fundamental to the quality of the user experience, and it is necessary to consider them when creating a good user experience. Therefore, a basic set of characteristics were defined to create a successful system or product:

- **Usable** means the design, structure, and purposes of the product are clear and easy to use.

- **Equitable** is a helpful design that addresses the needs of diverse users with diversified abilities and backgrounds to support improved quality of life where everyone is given equal resources.
- **Enjoyable** means that the design should delight the user.
- **Useful** means the design should solve problems.

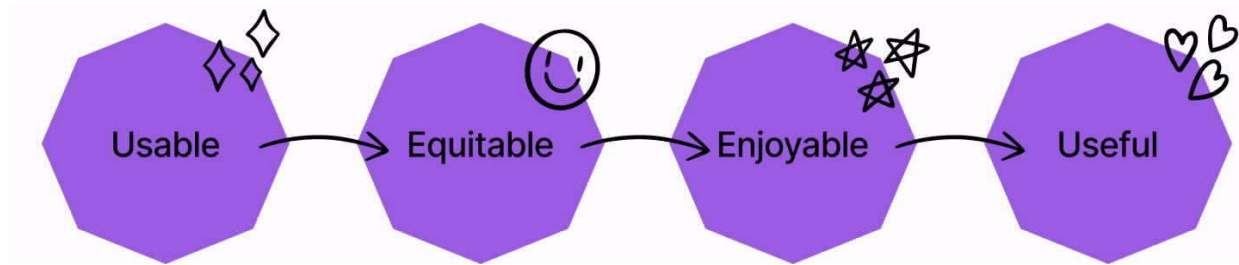


Figure 8. The four Characteristics of good UX, Source: [UX Collective](#)

2.3.4 User-Centered Design (UCD) and Human-Centered Design (HCD)

User-Centered Design is a multidisciplinary design approach based on an interactive design process in which the objective is to understand the user’s needs, priorities, and demands in each design process phase⁴. Each phase of the design process combines feedback, user characteristics, tasks, and input to preserve a potential design’s relevancy and usefulness. UCD is known as it leads to an increase in the usefulness and usability of the product, as it contributes to user satisfaction (Vredenburg et al., 2002).

HCD is a framework approach that focuses on solving problems, and involves as well, human perspective at each design process phase. According to ISO 9241-210:2019(E)⁵ Human-Centered Design “aims to make systems usable and useful by focusing on the users, their needs, and requirements, and by applying human factors/ergonomics, and usability knowledge and

⁴ <https://www.interaction-design.org/literature/topics/user-centered-design>

⁵ https://en.wikipedia.org/wiki/Human-centered_design

techniques”. Also, focuses on increasing efficiency and effectiveness, and human well-being. HCD consists of three phases:

- **Inspiration Phase:** Directly learn the users and deeply understand their needs
- **Ideation Phase:** unite the learnings and identify the opportunities and design imaginable solutions
- **Implementation Phase:** the final phase to bring the solution to life

It is noticeable that both design framework approaches share certain characteristics, as they both focus on the user (and users are human after all), seek satisfaction, solve problems, and respond to their needs. Nevertheless, there are differences between the two, the UCD focuses on more individual users, developing usable, functional, and useful products, while the HCD is directed at humans generally, designing for society and community benefit, as illustrated in Figure 9.

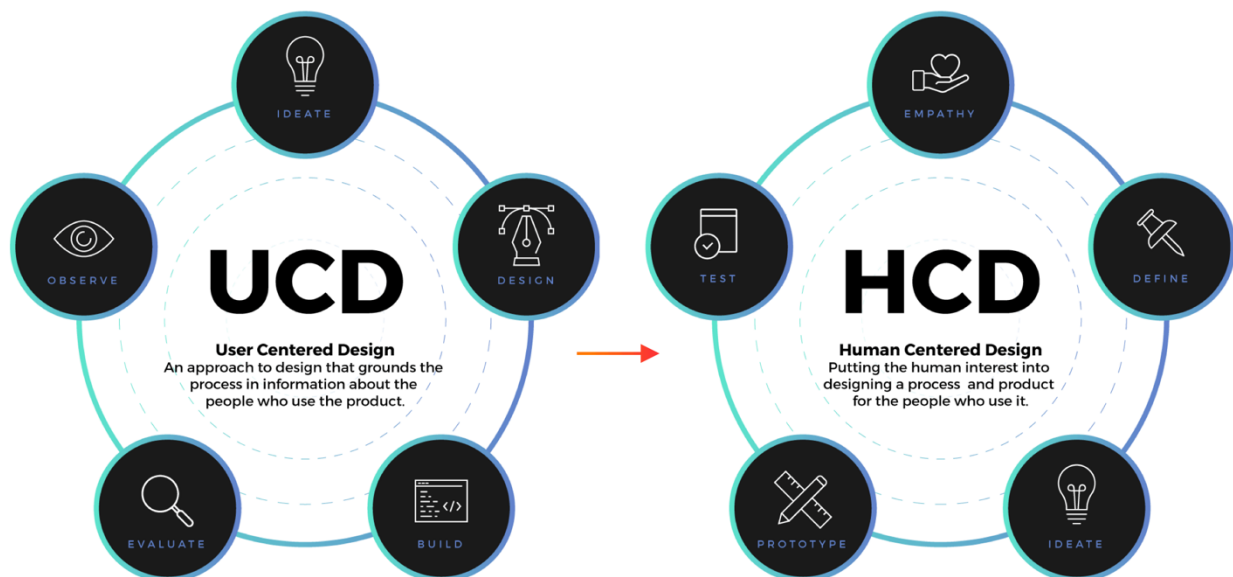


Figure 9. User-Centered Design vs Human-Centered Design, Source: [Level Next](#)

2.4 Smart workplace and correlation with interaction design

In the past few years, smart workplaces have grown a significant amount of interest, particularly with the Covid-19 pandemic, people have become even more aware of the environment that surrounds them on a daily basis, and there is a greater concern for safety and health in workplaces. Technological advances, exemplified in Figure 10, as well had a great impact on the development of smart workplaces, as they tend to facilitate and accelerate users to carry out their tasks.

According to the previously mentioned interaction design concepts, the interaction between the user and a product or service is crucial, as it plays a vital role in the usefulness of the products. Therefore, it is essential to design the system's interfaces that are equitable, perceivable, and user-friendly, to ensure that everyone, regardless of age, gender, and location, can interact and use the product. Especially with new technological features arrival in sensing models that allowed control and monitor spaces in smart workplaces or intelligent ambient, the interaction should be perceivable and visual interfaces clear and simple to use.



Figure 10. Smart workplace technology. Source: [Siemens](#)

3. Methodology

The research approach of this study is based on a user-centered design methodology which is a design process that focuses on users' needs throughout the whole design process. The methodology consisted of two collection methods, qualitative and quantitative, alternating according to the different research phases.

In the first phase, we proceeded to a literature review to synthesize the relevant literature for the study and elaborate on the theoretical context necessary to understand the selected topic. Then, in a second phase, there was a need for a better understanding of the users, the environment that surrounds them, and their needs, and in this way, we proceed with the preparation of a questionnaire survey, administered online, thus aimed at people whose working environment fits in the context of the theme (e.g., office, co-working space, workplace room, library). The data and information collected were analyzed and the respective conclusions are drawn.

In the third methodological phase, user research methods were applied. This practical phase of the project consisted of concept development, the definition of the main requirements for the project, conducting moderate usability tests such as card sorting to validate the system architecture by users, design interface, interface prototyping, review of the prototype by the experts and, finally, the evaluation with the potential target audience.

As illustrated in the study diagram (see section 1.4), the design process did not follow a linear sequence but rather revealed itself to be an iterative process, that is, we needed to return to some of the previous steps to reorganize ideas, concepts, or correct errors made, as we intend with this phase to approach reality and what best works for users, thus seeking a better usability experience and interaction between the user and the system.

3.1 Literature Review criteria

A systematic literature review was conducted according to publications related to the study theme of this thesis from the following databases:

- Google Scholar

- IEEE
- ScienceDirect

To avoid missing out on any relevant studies, it was decided to conduct more generic search strings to get a wider number of searches in the primary results. Afterward, filter the most irrelevant studies to reach the final studies for data extraction purposes. Followed by guidelines (Ali, 2018) for the selection that should be focused on the topics of the research problem statement. The strategy to acquire the search terms is as follows:

- Identify the main terms and build a search term based on them
- Find alternative synonyms and keywords for each main term
- Analyze terms and synonyms in the most relevant articles
- Combine terms using Boolean OR / AND operators
- Collect data by the limited period 2000-2020 in English

Primary keywords used in research:

- Personalized workplace + wellbeing
- Interaction design + usability
- Thermal comfort + smart workplace + stress detection
- Personalized smart workplace + environmental stressors + wellbeing

The results of the literature review can be found in Chapter 2 — Theoretical Framework.

3.2 User Research method

This section will describe the methods (Baxter et al., 2015) that were conducted during the research per phase with the following analyses:

User Research phase

The goal of this phase is to understand the users, their needs, and their surroundings, as well as help us to find out what workers are aware of the influence of the indoor workplace environment on their

health. To that end, it was important to conduct a survey questionnaire to collect data from workers by using the online tool (see chapter 4.2).

Ideation phase

Designing the information architecture of the system using the card sorting usability testing with the potential users for structuring and organizing the system content so that is effective and perceivable for the users. The fundamental study that defines the system and design development. After that, it should give a clear view of the navigation system plan (see chapter 4.3)

Designing and prototyping phase

After defining the structure of the system, following the next phase, the design phase of interface elements and graphic components. At this stage, wireframes were developed, followed by low-fidelity prototyping. It was considered to perform a moderate usability test in this phase before moving on to the implementation phase. Therefore, it was decided the expert review test to inspect the low-fidelity prototype according to the heuristic evaluation in order to ensure the elimination of possible usability issues in the next phase of the study (in chapter 4.4)

Implementation phase

Implementation of the high-fidelity pilot study and application of a System Usability Scale (SUS) usability satisfaction questionnaire, to measure the satisfaction, efficiency, and effectiveness of the proposed system. It is also intended to assess the perceived need for and importance of a proposed system of workers in their workplace.

4. Project Development

4.1 Phase I – User Research

As a part of the user-centered design methodology, user research is the main pillar of the study as it focuses on understanding the users, their needs, expectations, and behavior. This method of study leans to learn and identify the potential users by conducting user interviews, questionnaires, or direct observations. In this phase, it was decided to conduct an online questionnaire in order to know the user closely.

Method

An online survey was used to understand the current potential target audience's experience regarding the workplace environment conditions, as it was crucial to understand and evaluate their behavior and relationship with the environment. The unfolded users' frustrations and how they responded to the stress during the day. The questionnaire directed linked to one of the secondary objectives research study topics: to conduct user research on what stress-relief methods users practice when they experience intense stress during the working day.

Participants

In this study, participants were invited to participate the study, involving 11 males and 20 females, aged between 18 and 65 years old. The main study criteria for the selection of participants focused only on office-type workplace workers.

Procedure and Materials

The questionnaire was carried out in the online form using the Google Forms platform and shared by email, and WhatsApp chat group. One of the main requirements for this survey questionnaire was to interview and collect data from users who work or use spaces such as offices, co-working spaces, or other types of office workplaces. One of the challenges was to contact participants who have returned to the physical office mode, as most of the people continue to work remotely due to the Covid-19 pandemic. The questionnaire consisted of a total of twenty-two questions (shown in Appendix C), divided into two parts, the first part focused on the workplace environment conditions

evaluation, and the second part addressed the coping stress techniques practiced by participants. The questions were classified both open and closed, to collect quantitative and qualitative data.

Results and Discussion

Overall, the study collected and evaluated 31 survey responses, consisting of 65% of females and 35% males, mostly young adults from the Z Generation (18-24 years old) and Millennials (25-34)⁶ (74%), followed by 13% of adults aged between 35-44, and the older group aged between 45-65 (13%).

The participants were asked to choose which workplace suit best, the description in the table that can be seen in Table 2, and mostly described as open space/fixed desk (41,9%), in the second place, highlighted the open space/ desk-sharing and home office (12,9%), following by open space/hot-desking and private room (9,7%). It becomes evident that most companies provide workplaces with an open concept layout.

Table 2. Demographic data and participants' working space

	Total (n = 31)	
	n	%
Gender		
Male	11	35,5%
Female	20	64,5%
Age		
18-24	12	38,7%
25-34	11	35,5%
35-44	4	12,9%
45-54	2	6,5%
55-64	2	6,5%
Which best describes your workplace?		
Open space / fixed desk	13	41,9%
Open space / desk sharing	4	12,9%
Co-working space	2	6,5%
Home office	4	12,9%
Private room office	3	9,7%
Open space / hot-desking	3	9,7%
Cubicle space	1	3,2%
None of the above	1	3,2%

⁶ <https://www.kasasa.com/exchange/articles/generations/gen-x-gen-y-gen-z>

The first part of the questionnaire consisted of a total of fourteen questions regarding the workplace environmental conditions, participants were asked how they feel about the lighting conditions during the day while they perform their usual tasks, one of the main factors is low or bad luminosity that can lead to the overall malaise, provoke headaches, and eye pain learned from Chapter 2. Most of the participants have a positive response: 42% were very satisfied with the lighting conditions, on the Likert scale, 32% were satisfied and 7% experienced dissatisfaction, shown in Figure 11.

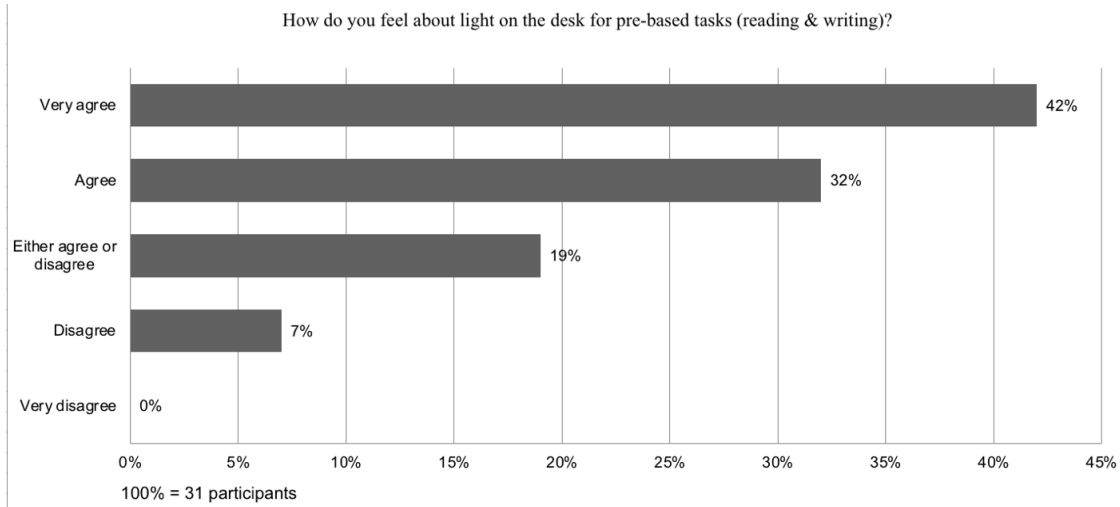


Figure 11. How would participants describe their lighting conditions at the workplace.

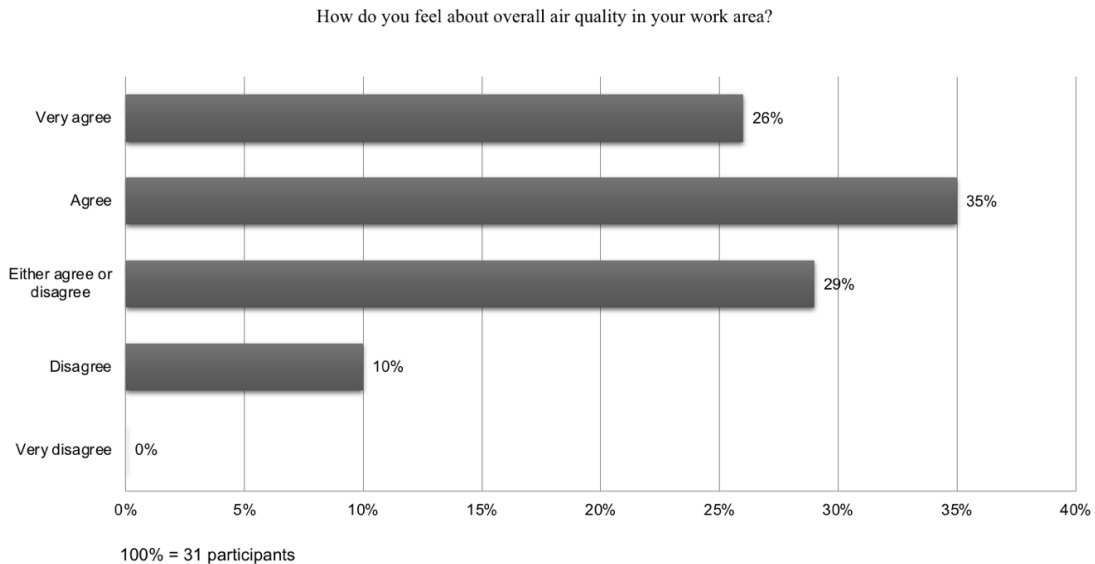


Figure 12. Workplace air quality results.

Proceeded, it was asked how participants feel about the air quality, see Figure 12, and odors in their workplaces, here, it was intended to understand are workers aware of the air quality they breathe daily at their workstation and as well the occupational odors which continuous disposal to unwanted or chemical odors could lead to illness. Both parameters had similar results, on average, 26% of the participants responded that they were very satisfied with the conditions, around 35% replied as satisfied, 29% said they were neither satisfied nor dissatisfied, that is, they do not have a formed opinion or feel indifferent towards odors and air quality, and 10% responded that they are not satisfied.

However, when participants were asked about the indoor temperature in their workplaces, shown in Figure 13, the results were quite interesting: 26% of the participants responded that they were dissatisfied with the temperature, the same percentage (26%) selected the option “neutral” (neither satisfied nor dissatisfied) and, finally, the same value of 26% of participants replied as satisfied. The remaining 6% of people reported that they feel very dissatisfied with the ambient temperature in their workplace. This differentiation may prove that the difference in body mass index (BMI), age, and gender may be the factors influencing thermal satisfaction.

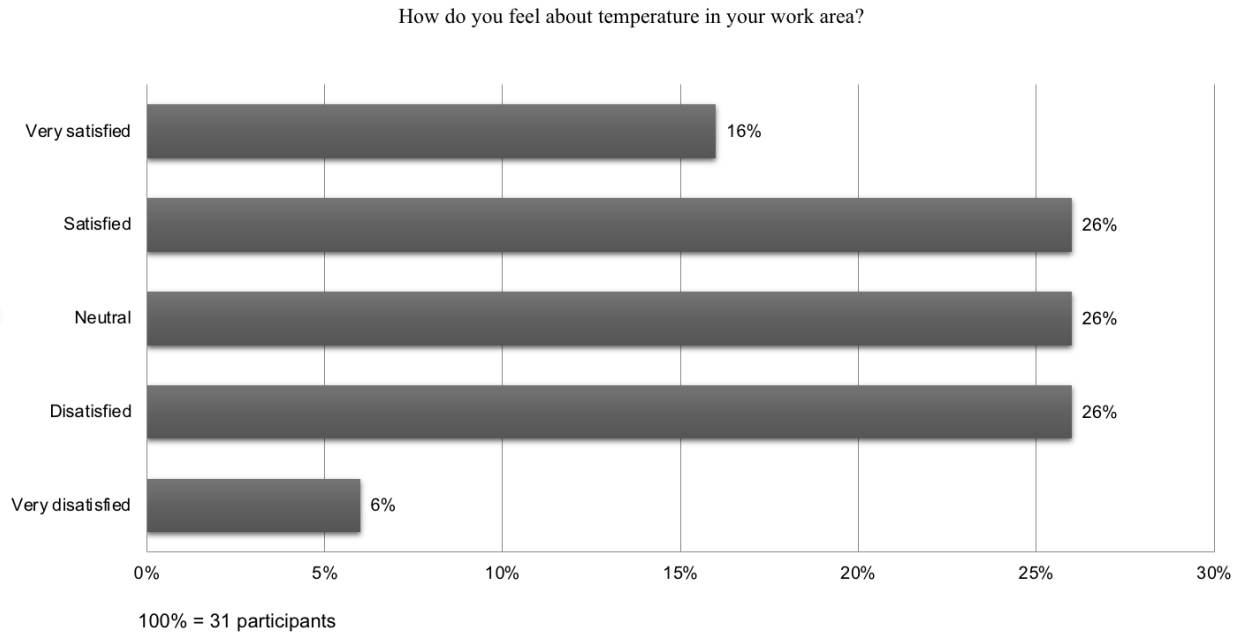


Figure 13. How participants regarding the temperature at their workplace.

Then, to identify how participants would describe the temperature in their workplace depending on the season, focusing on two seasons with a significant temperature range, that is, summer and winter. In the event, 42% responded as “neutral” to the winter temperature in the office, and 29% affirm that their workplace tends to be warm during the winter, however, 19% felt the workplace was cold. Although 45% responded neither satisfied nor dissatisfied with both seasons, winter, and summertime, 19% replied feeling warm in summer and the same quantity answered as cold, and 10% of participants replied that the workplace is hot during the summer.

Based on these results, it can be observed that in many workplaces there is no stable temperature or programmed / conscious thermostat regulation, which indicates a concern for the comfort and well-being of the people who occupy these places.

An additional interesting observation was taken from the question of how participants feel when faced with noise in the workplace. Occupational noise can be caused by several factors surrounding the participants: in this case, they were asked about the noise from conversations between colleagues (occupational noise) and the noise from office equipment, as shown in Figure 14. Thus, 16% answered that they were satisfied with the level of occupational noise at the workplace, 26% replied dissatisfied, 23% as very dissatisfied, and 19% took a neutral position concerning occupational noise.

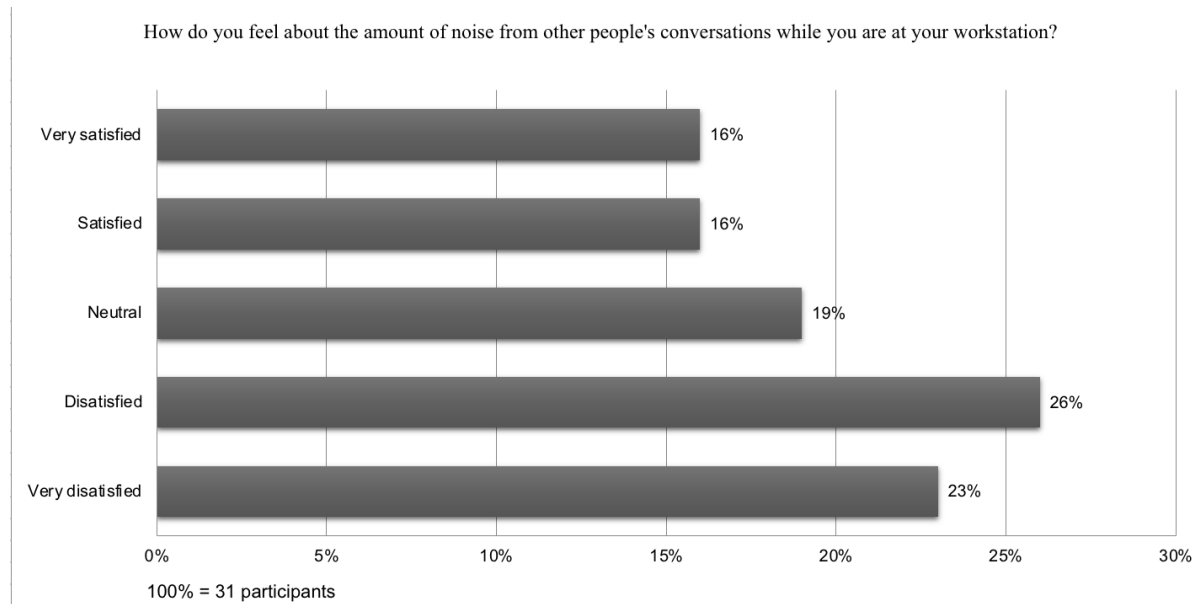


Figure 14. How do participants feel about the amount of conversational noise.

In terms of equipment noise (Hongisto, 2008), 19% of the total number of participants replied they were unsatisfied with the noise, 13% showed neutral, and the majority answered that they are comfortable, indicating that their workplaces were not affected by the noise of printers, copiers, etc.

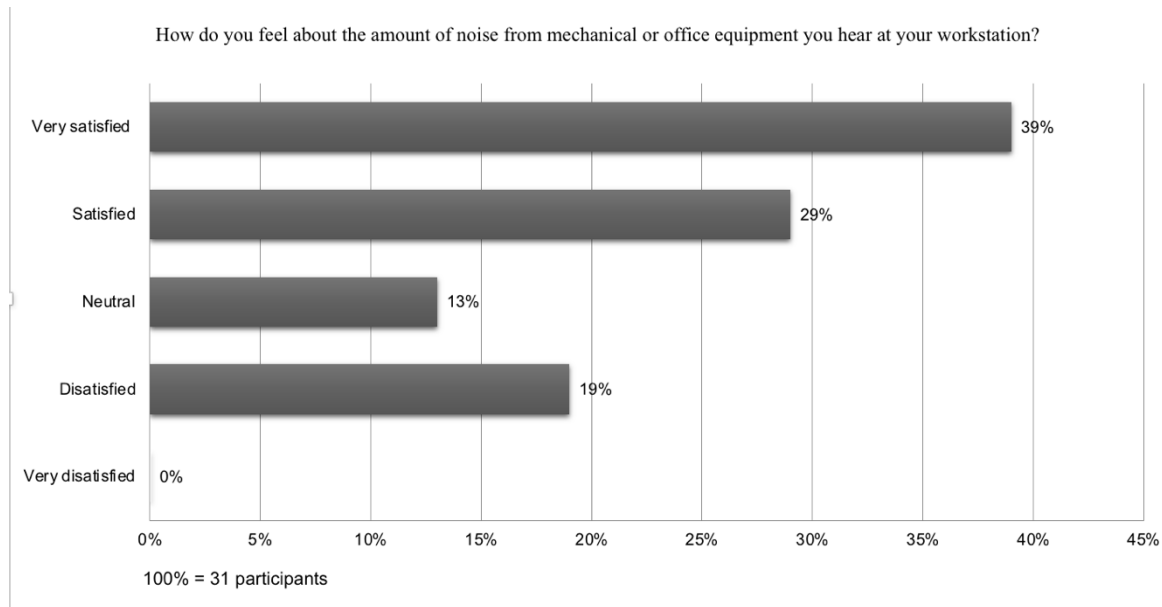


Figure 15. How do participants feel about the amount of equipment noise.

As demonstrated in Figure 16, more than half (52%) of the participants responded that they feel quite satisfied with the air circulation in their workplaces, while 48% took a neutral position. The perception of air circulation is based on general air movements around the bodies and in specific parts of the body⁷. It is important to emphasize that air circulation and ventilation, are two important factors for the physical health of occupants, as continuous ventilation significantly reduces the presence of tiny viral particles suspended in the air, the aerosols, which in turn are responsible for air transmission. And especially in closed environments, they can represent an agent for the spread of viruses⁸ or bacteria.

⁷ <https://journals.sagepub.com/doi/full/10.1177/1420326X17732613>

⁸ <https://aip.scitation.org/doi/10.1063/5.0029118>

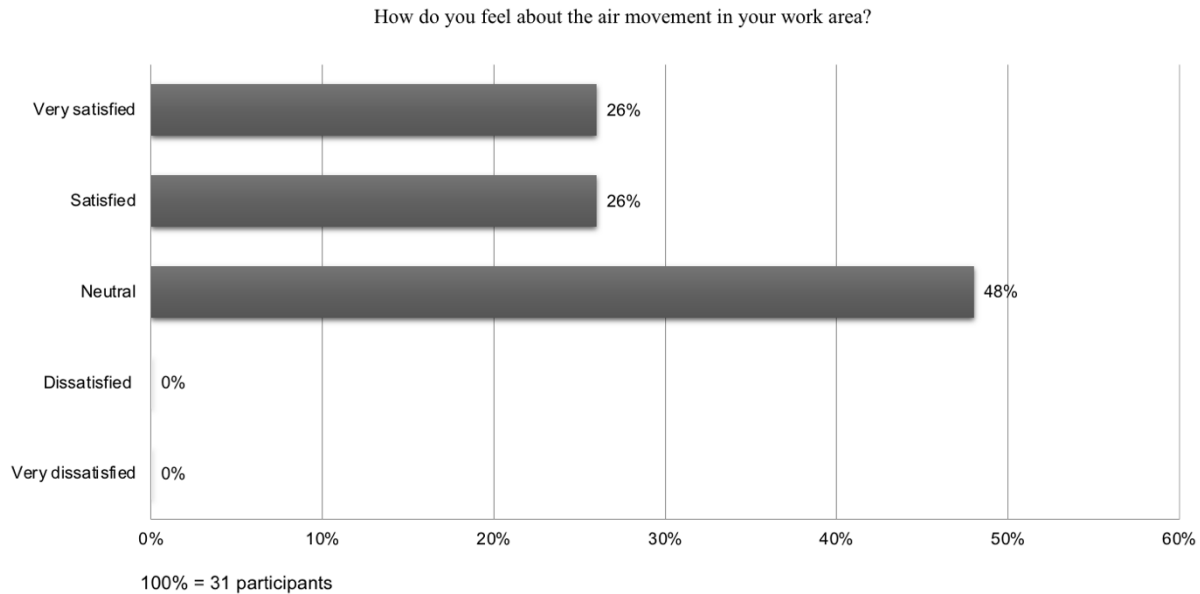


Figure 16. How do participants feel about the air movement.

To clearer insight into the needs of the target audience, we ask participants to rate from 1 to 7, with 1 as the most important and 7 as the least important, which should be improved to increase their well-being in the workplace. As being most important, the participants ranked the temperature. According to a study carried out in 2016⁹, the greatest dissatisfaction that people express about the workplace is precisely the temperature of the respective environment, where it was also revealed that employees have greater difficulties in concentrating in spaces that are either too hot or too cold. Thus, the temperature is an important factor for personal comfort regarding working conditions in offices.

Secondly, we have the privilege of privacy and access to windows to the outside. Lack of privacy can lead to decreased performance and stress in individuals, due to both noise pollution and visual distractions¹⁰, often associated with open-concept spaces. The windows, in turn, allow access to natural light and, consequently, less stress on vision, while allowing an escape into the visual field. Both conditions mentioned in this second point are associated with positive results for the occupants, namely greater satisfaction, well-being, and performance (Jamrozik et al., 2019).

⁹ <https://www.kensington.com/news/ergonomic-workspace-blog/how-office-temperature-affects-productivity-and-state-of-well-being/>

¹⁰ <https://www.aristaint.com/en/inspire/4-consequences-of-lack-of-privacy-in-an-office>

And the third factor classified as the most important was the air movement: if the ventilation of closed spaces was already an important aspect to consider in a pre-pandemic context, with the pandemic situation that we are currently experiencing, this aspect has gained special prominence in the conscience and in people's lives. The association of lack of ventilation with the possibility of further dissemination of the Covid-19 virus (among many other bacterial and viral particles that are harmful to human health that also spread) made this point assume the top of people's concerns regarding the conditions of work.

In the second part of the questionnaire, participants were asked if they feel stressed during the day at their work, to understand how participants are aware of their overall stress and following results: 16% responded that they did not feel stress at all, 36% responded slightly stressed, 32% felt stress moderately, 13% very frequently and 3% extremely frequent. In total, 26 participants replied as yes, they feel stressed at work, Figure 17 represents the collected data. It can be concluded that participants are aware of the stress during the day and on average, feel stressed.

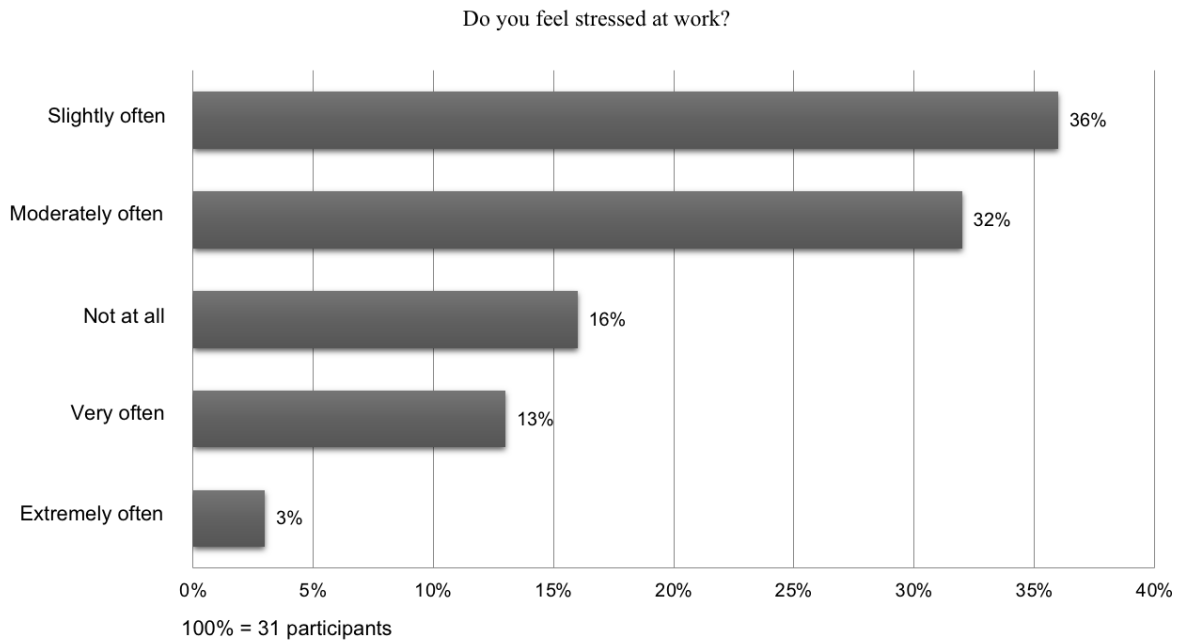


Figure 17. How participants feel about the stress

Next, to better understand how people deal with stress, we ask what participants do when they feel they are under a lot of pressure. For this, we had to analyze the qualitative data and we concluded that the technique most practiced by the participants is to take a short break: go outside to get fresh air, walk and do breathing exercises. There were those who answered that they used to listen to

music, meditate and go to the gym. We concluded, therefore, that participants tend to move away from their workplace to calm down and recharge their batteries.

In addition to the solutions mentioned above, we tried to understand if participants tend to resort to digital solutions, as the field of health and wellness applications is growing¹¹. About 73% of respondents responded that they do not use mobile applications to deal with stress, and 23% responded that they often use wellness applications. And only 4% answered that they usually use applications to play games on their smartphones.

Therefore, for respondents who often use mobile apps, we asked an open-ended question about what design styles they like to see in wellness applications, and many responded that they prefer

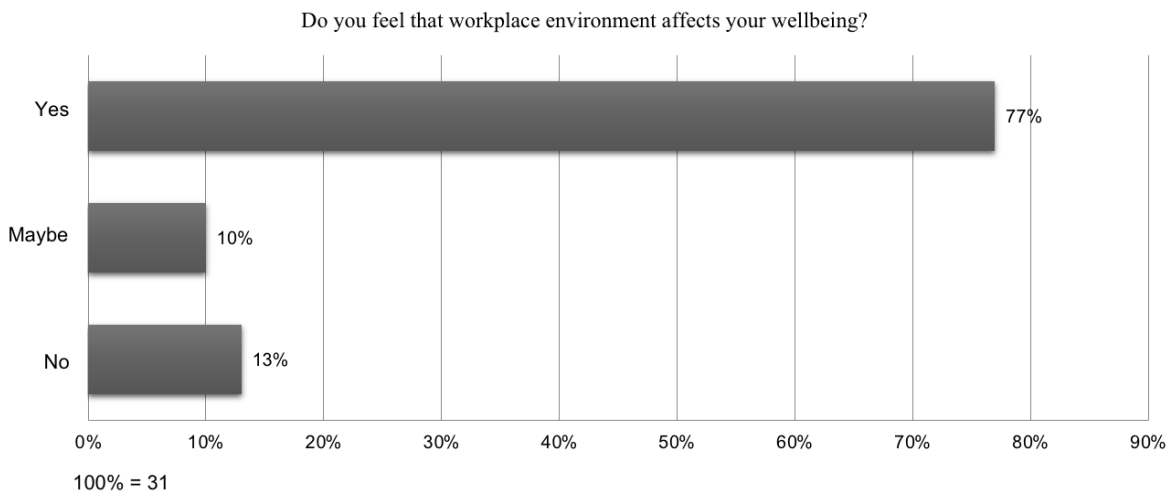


Figure 18. How workplace environment affects occupants.

minimalist design, simple, clean, easy to navigate, with smooth colors and illustrations. Some gave the Headspace application as an example.

To complete the survey, we asked the participants if they found that their workplace affected their well-being, see Figure 18, and 77% answered yes, 13% did not agree that the work environment affected their mental and physical health and 10 % believed it might. However, all would like to work in a healthy and safe workplace.

¹¹ <https://www.statista.com/outlook/dmo/digital-health/digital-fitness-well-being/digital-fitness-well-being-apps/worldwide>

Conclusion

The results obtained in this questionnaire allowed us to understand the needs, frustrations, and behaviors of the participants. Most participants are aged between 18 and 34 years old and work in the open concept layout spaces. Participants replied that odor, air circulation, and lighting are not the important factors for their general well-being and aim that they are satisfied with the conditions present in their workplaces. However, it was possible to realize that factors such as occupational noise (conversations between colleagues or telephone conversations) and temperature are their main frustrations that aim to create stress or distraction during the performance of their tasks, as most responded that they feel stress at work. To that end, we still ask how they usually deal with or respond to stress at work, and we realize that everyone prefers to go out, take a walk and try to relax, that is, participants seek to leave their workplace to change the environment and breathe fresh air. It was noticed as well that despite the growth of applications directed at well-being, meditation, or other techniques to deal with stress, participants prefer more traditional methods, such as going out and taking a walk.

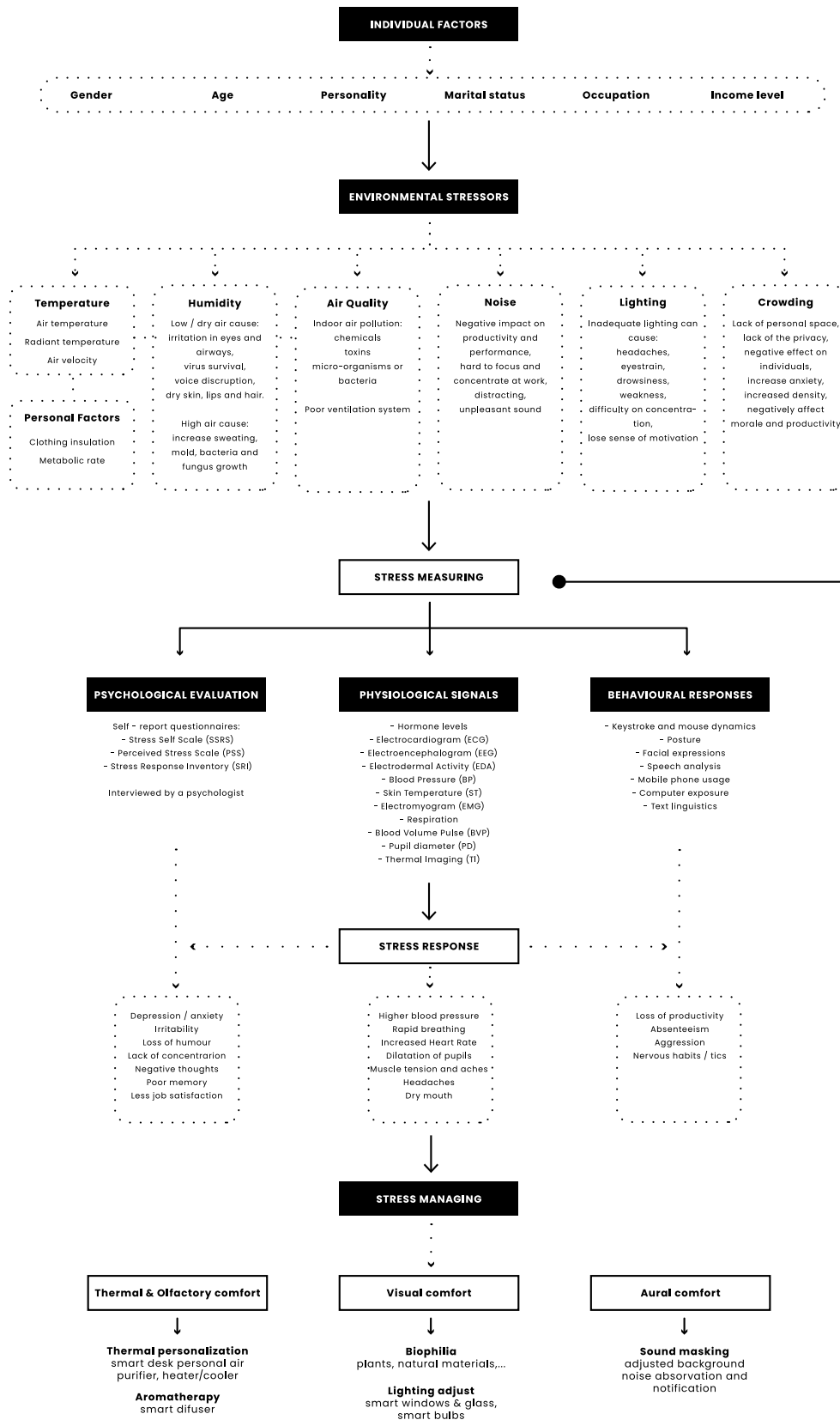
In summary, we can conclude that most users feel that their work environment can influence their general well-being and health, and there is great concern about this influence.

4.2 Phase II – Definition of the project

The aim of the study, inspired by studies mentioned previously, is to build a smart workplace—stress management design system. Combining collected data from workplace occupational sensors and unobtrusive biometric sensors that allow measuring and monitoring in real-time environmental and biological/physiological signals, the purpose of the study pursues to prevent environmental workplace-related stress, as well as help users cope with stress when being stressed and increase user well-being overall in the workplace. Therefore, the present study proposes a design system solution that will focus on designing and evaluating one part of the proposed system — the mobile application.

Since the project is geared toward workplace types such as offices and co-working spaces, the project designs a mobile application that helps employees to look for a place where they can work, book the workplace using the application, control the environment of the room, monitor the building in real-time: for the occupancy, crowdedness, wayfinding, booking, and access.

Furthermore, the second major part of the application will be focusing on workers' health, monitoring in real-time their health activity by sending them notifications of any changes in their body (physiological signals and behavior), any signs that could indicate the stress augmentation, and as well environmental factors such as temperature, air quality or noise level, the concerning aspects learned from the survey study on Chapter 3, as well Figure 19, illustrates the collected data from the theoretical framework in Chapter 2.



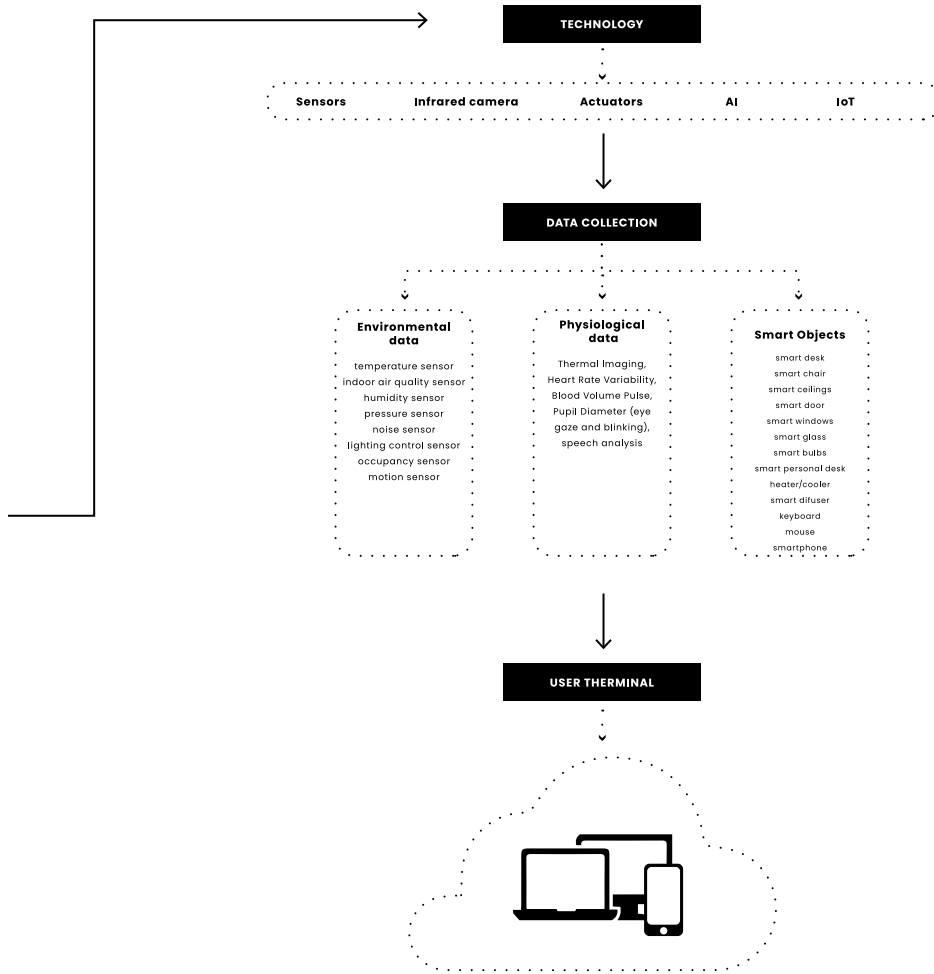


Figure 19. Data model illustration of the potential relationship between the stress predicting system and users.

4.3 Phase III – Ideation

As was mentioned earlier, the project is an interactive design system used in a combination with IoT sensors capable to collect environmental data of the workplace and track a user’s biological/physiological characteristics from which is it possible to detect stress signals. The goal is to use the user experience design to help workers recognize and manage stress. Given that, it was decided to develop a mobile application as one of the possible solutions where users can interact with the system. A user workflow diagram tends to illustrate user flows and the design of the system project. As a start, the user flowchart was idealized according to the main functions of user research needs, Figure 20. The main structure, of the application, was designed with four categories: Dashboard, Places, Preferences, and Building.

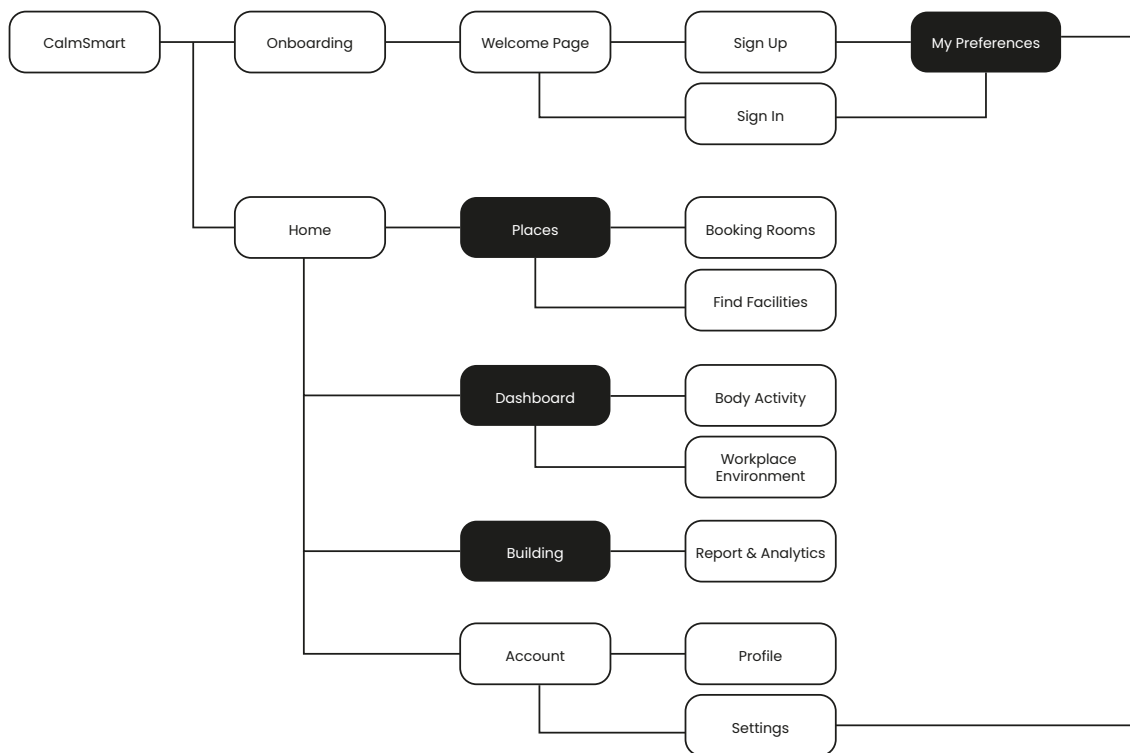


Figure 20. User flow chart.

Since the project focuses on user experience design, it was crucial to design effective and findable navigation through the system. In this case, structuring a successful Information Architecture (IA) was fundamental as it helps users understand where they are, what they've found, what's around and what to expect¹². Louis Rosenfeld and Peter Morville in their book¹³, defined the most important components of IA: Organization of Schemes and Structures, Labeling Systems, Navigation Systems, and Search Systems. As stated by the authors mentioned above, the information of systems needs to understand the “information ecology”, which can be visualized in Figure 21, composed of the context, content, and users. And so forth, a usability test was conducted to understand how users perceive the system structure.

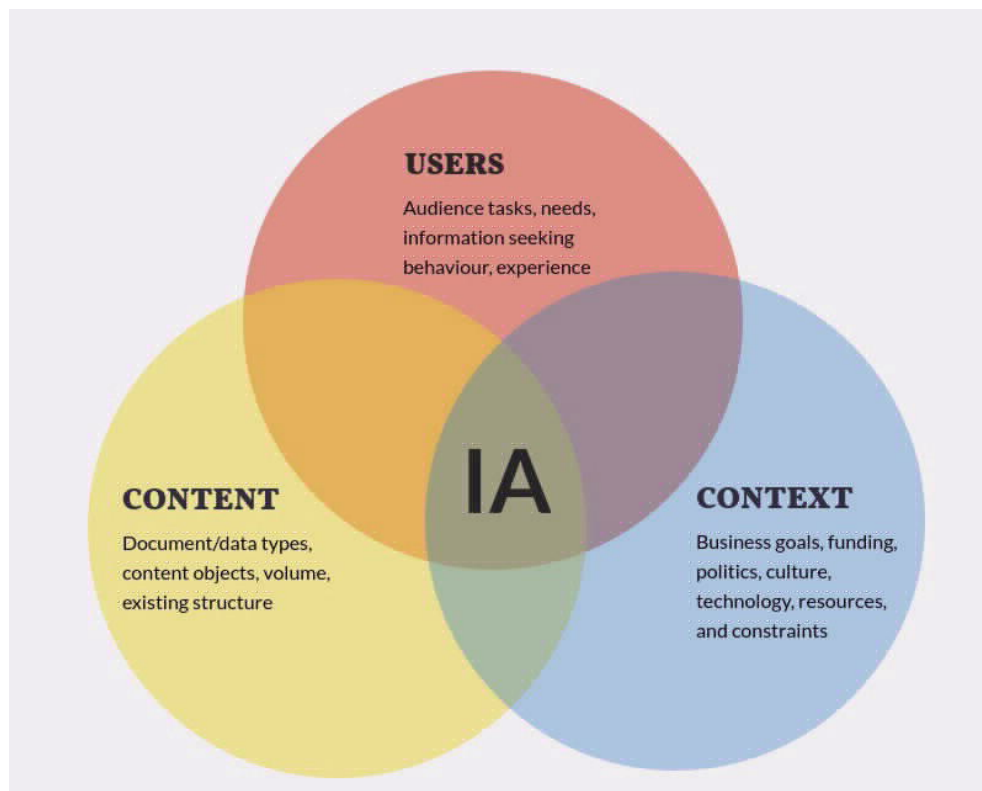


Figure 21. “Information Ecology” Venn diagram by Morville & Rosenfeld. Source: [Visme, created by Lucia Wang.](#)

¹² <https://www.usability.gov/what-and-why/information-architecture.html>

¹³ Information Architecture for the World Wide Web: Designing Large-Scale Web Sites by Peter Morville and Louis Rosenfeld

4.3.1 Card Sorting

In this phase, it was considered to use an additional user-centered design method, once again to gather the user opinion. Card sorting is much like user research as they're both focused to understand the user preferences, behavior, needs, and values. Therefore, conducting Card sorting testing is fundamental to understanding the *modus operandi* of users' thinking, organizing, and distributing the information architecture of the proposed system.

Method

Card sorting is a simple user research method used in creating the information architecture (IA) (Nielsen, 2004) in which content or features of web design or software interface are written on index cards and given to users to sort into related groups and categorize, helping for instance how users associate different concepts within an information space. Comparing how different users group and categorize cards can help identify trends in how users approach interface tasks, information that is useful for designing more user-friendly interface hierarchies, and navigation systems (Brucker, 2010; Sundt & Eastman, 2019). Card sorting is described as well as a user-centered design method for increasing a system's findability (Spencer, D. 2020).

Variations in card sorting procedures are utilized throughout professional sectors and academic fields of study to generate varied datasets for either qualitative or quantitative analysis. The same variants are frequently defined by the status to which the investigator determines the labels indicated on the cards, therefore the names or categories by which they are classified. (Conrad & Tucker, 2019). In an open card sorting testing, participants are able to create and name their own groups of cards (Spencer, D. 2009). This means that participants will be able to group content freely, without pre-determined groups. They will also be able to name the groups any way they want and create as many of them as they see fit. The open method allows for more learning, as it is possible to obtain information both on the terminology used by the participants (since they will name the groups) and on what they understand the content of each group to be. In the closed card sorting variation, "participants assign the cards to predefined groups" (Goodman, et al., 2012). Pre-determined groups are offered for participants to choose where each card should go. This type helps

to validate the terminology created by the project team, as it allows to see if users identify the label and associate it with the content to which it belongs.

Participants

In total, 15 participants voluntary took part in this test most participants are female (60%), and the rest are male (40%) and are between 18 and 54 years of age, 7 participants with bachelor's degrees, 7 with master's degrees, and 1 participant with a professional degree. No specific criteria were defined.

Procedure

The participants were invited to participate in remote online moderated Card Sorting Testing, following filling in a 5-minute online Reverse category description survey, with a total of 8 questions. The Card Sorting is consistent in a total of 28 predefined cards and 6 predefined categories as well, see Figure 22: *Welcome page, My Preferences, Places, Dashboard (My Workplace), Building, My Profile*. As well, participants were informed to suggest their own categories. The questionnaire was conducted using Google Forms, divided into 4 different sections: demographic data (age, gender, education, years of employment, workplace type, and the familiarity familiar with the concept “smart workplace”), the instructions and consent form, link to the card sorting, and post-study Reverse Category questionnaire.

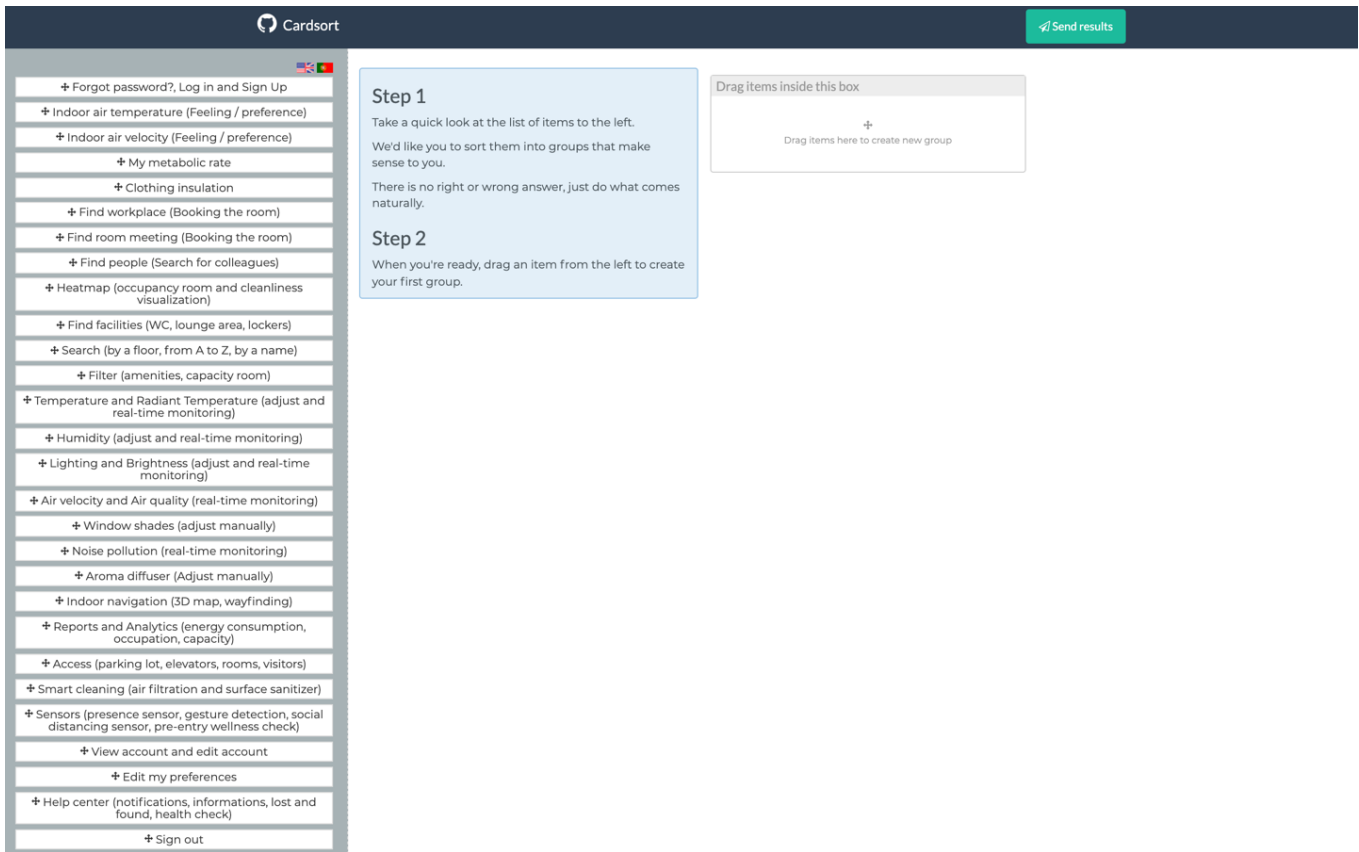


Figure 22. Online Card Sorting Testing

Results and discussion

As can be observed in Table 3, a total of 15 participants participated in this questionnaire, with about 2 dropouts, leaving a total of 13 participants who completed the test. It is noticeable that all participants have higher education, which means that all have at least a bachelor's degree. Regarding professional experience, 86.7% had been employed for at least 5 past years.

Furthermore, participants were asked about what type describes best their current workplace, to understand what the most common existing office workplace layouts and styles are. Some of the participants selected two options, one is working from home due to the confinement period of the

Table 3. Demographic data

	Total (n = 15)	
	n	%
Gender		
Male	6	40%
Female	9	60%
Age		
18-24	3	20%
25-34	10	66%
35-44	1	7%
45-54	1	7%
Education		
Bachelor degree	7	47%
Master degree	7	47%
Professional degree	1	6%
Employed in the past 5 years		
Yes	13	87%
No	2	13%

Covid-19 pandemic. As represented in Figure 23, the most common workplaces are Open spaces with fixed desks and open spaces with hot desking. Only 13,4% responded to be familiar with the concept “smart workplace”, 46,7% shown to be more or less, and 40% responded not at all.

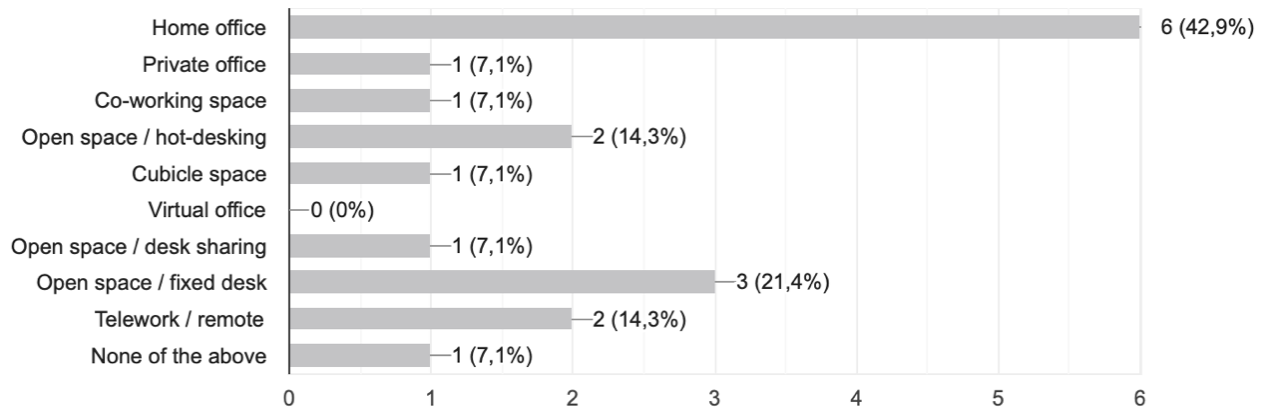


Figure 23. Participant's type of workplace.

To comprehend if the predefined category names make any sense to users, we use a card sorting technique, a reverse quiz (see Appendix C).

Lastly, participants were asked if during the test they felt any difficulty most of them responded no and a few responded, “a bit” or “sometimes”. To understand if there were any difficulties during the test, we asked the participant about their experience and mostly responded they did not have any difficulty, however, some had issues with the terms: “clothing insulation”, “heatmap” and “dashboard”, found it confusing “*for someone who is not under the theme...*”. Was suggested to add a brief description of the smart workplace definition as they did not know the meaning. In conclusion, all participants responded that they never used a similar application, nonetheless, the overall experience for each was quite positive, some of them replied that the project is “very useful”, “has real potential”, and “nice idea”, “interesting”, and “important”.

Conclusion

After analyzing the results illustrated in table 5 (see Appendix F), we can conclude that most participants were able to classify the cards within the predefined categories, and there were also some who suggested new cards. Although some have different names, however, the definition of each feature is covered by the predefined categories. Regardless, that many were unfamiliar with the concept of a smart workplace, many of them were able to understand the logic and classify the cards according to the categories. In addition, some of the suggestions were quite interesting, such

as the cards: "find a room", "find amenities", "search ...", "find people", were classified in the category "Filter and search", that is, using the label " Filter and Search" as the fastest way to find information. Logic arising from daily contact with digital products.

Based on the results obtained from the Card Sorting Testing, an IA, in Figure 24, was constructed and prepared for the next phase of project development, wireframe designing, prototyping, and evaluation.

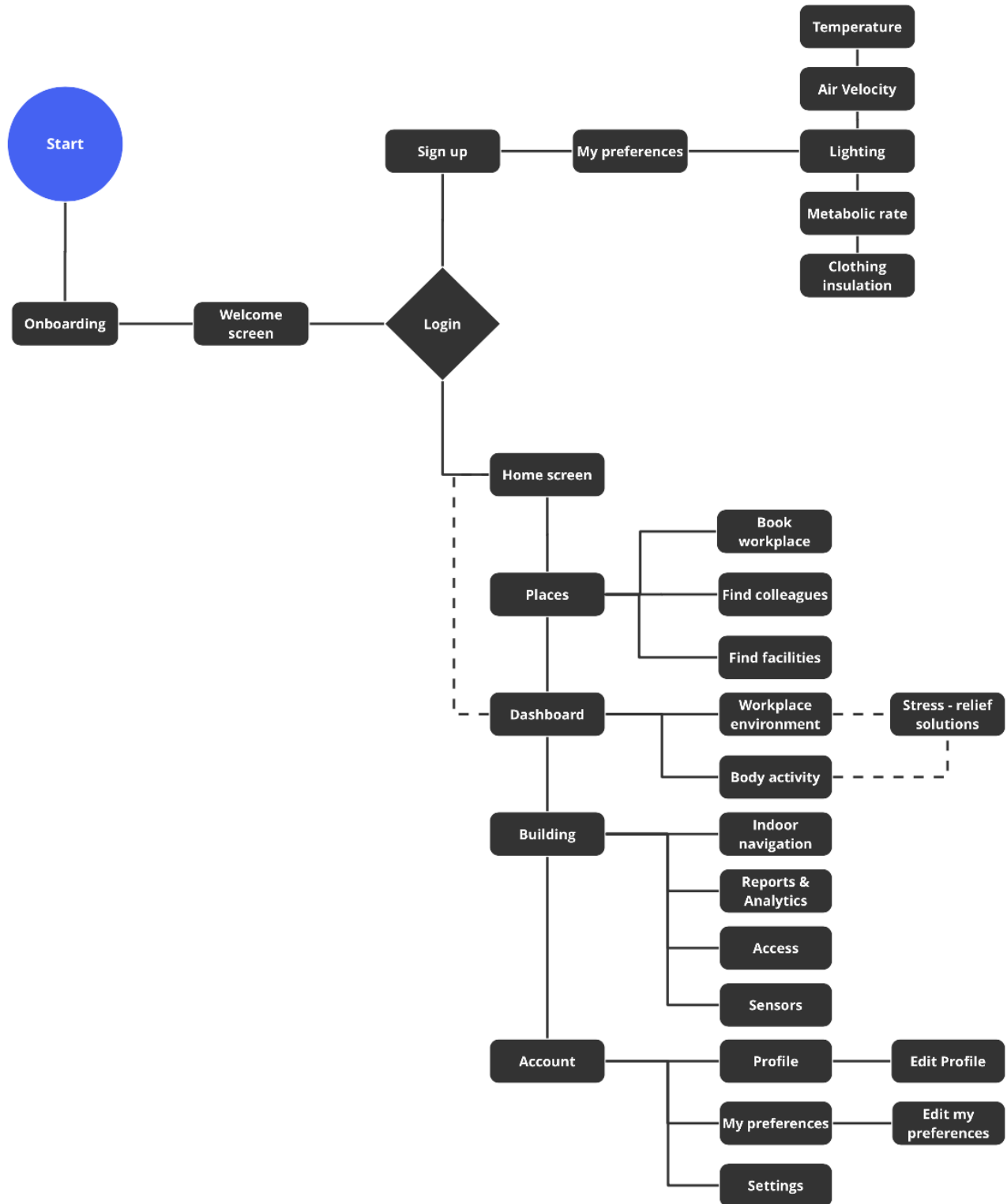


Figure 24. IA of system navigation plan

4.4 Phase IV— Design and Prototyping

4.4.1 Process Flowchart

Once the user flowchart was defined, the navigation plan was created following the Card Sorting Testing (Figure 20), which helps in the detailed visualization of the entire process and illustrates the necessary steps in using the mobile application. The navigation plan shows the structure of this project, which consists of six main parts: Onboarding, Sign In the process, Home, Places, Dashboard, and Building.

1 — Onboarding: Welcoming screens with a brief introduction about the application **CalmSmart**, with some short descriptions of how to use the application, and where to find relevant features. The purpose is to get users familiar with a new interface.

2 — Sign In: The sign-in process helps to identify the users (first-time users will need to create a new account). This process takes a small amount of time to create an account, as the users will have to pass through the personalization process where the following information is needed for the system functionality: *age, gender, occupation, marital status, metabolic rate, and clothing* (required variables to help system measure body activity to detect stress level), then the workplace environment preferences, such as air temperature and air movement.

3 — Home: The main screen of the application, where other functions can be accessed, as well as where the main information is located such as the health tracker, stress index indicator, notifications, and booked places, among others.

4 — Places: In this part, users can reserve their workplace rooms or desks by type, see the floor occupancy, and search for the facilities or colleagues.

5 — Dashboard: The second main part of the application where users can monitor their body activities, stress level, health checker, personalize stress relief solutions (*smart diffuser, lighting, sound masking*), and personalize the indoor environment.

6 — Building: This section collects general information about the building, such as the indoor navigation, reports and analytics of the building occupancy (to consult the busiest days, floors, and rooms), get access to the visitors or to restricted areas, and consult in real-time indoor environments of the social spaces.

4.4.2 UX Expert Review

It was decided to conduct an expert review at this stage, evaluating the low-fidelity prototype in order to validate the information architecture along with the navigation flow and interaction between the interfaces, and fix the possible usability issue before moving to the high-fidelity prototyping.

Method

Expert evaluation requires usability experts to review the interface and validate it against usability principles (heuristics). Heuristics are a group of mental procedures used in interactive design to ensure good usability and are intended to find adequate and simple answers to identify problems and potential solutions. According to Nielsen (1994)¹⁴, the best-known method, there are ten usability heuristics:

- **Visibility of system status:** The system must always keep users informed about what happens at the time of interaction by providing suitable feedback in a short time.
- **Match between system and the real world:** Instead of using system-oriented terms, the system should communicate in users' language, using words, and phrases that are familiar to them.
- **User control and freedom:** Users frequently select system functions by accident, it is necessary to think of functions like *undo* and *redo* so that the users can undo and redo their actions as needed.
- **Consistency and standards:** During the interaction users should not have doubts about the meaning of the words, icons, or symbols used. It is essential that the interface follows the conventions of the platform.
- **Error prevention:** Good design that prevents errors from occurring, explains in simple language when they occur, and helps users to avoid errors quickly and easily
- **Recognition rather than call:** Important to keep icons and action elements always visible and information should be findable. Users should not have to remember information from one part of the dialogue to another.

¹⁴ <https://www.usability.gov/how-to-and-tools/methods/heuristic-evaluation.html>

- **Flexibility and efficiency of use:** Unseen by the beginner user, accelerators may frequently speed up the interaction for the expert user, allowing the system to accommodate both inexperienced and experienced users. Allow users to customize common surgical tasks.
- **Aesthetic and minimalist design:** Irrelevant or unnecessary elements should be excluded so the purpose is clear and simple.
- **Help users recognize, diagnose, and recover from errors:** Error messages must be articulated in simple language; without codes, clearly and precisely showing the problem and suggesting a solution.
- **Help and documentation:** The system must provide help and documentation, and such information should be easy to find, focused on the users' tasks, and divided into clear, understandable steps.

In an expert review testing, it is fundamental that the experts have good knowledge and understanding of the heuristics, as well as must have experience in the field. As Nielsen and Molich (1990; Nielsen 1994) stated in their study, about 75% of problems will be found by five experience experts, due so they recommend the use of five evaluators, certainly at least three, as illustrated in Figure 27. Additionally, most articles suggested that the evaluation should be done between 3-5 evaluators. More than five experts revealed their study did not bring additional benefits.

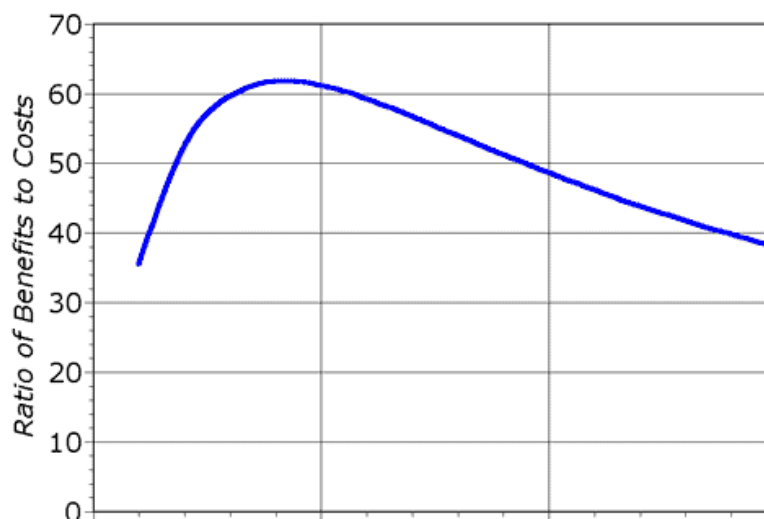


Figure 25. “Curve showing how many times the benefits are greater than the costs for heuristic evaluation of a sample project using the assumptions discussed in the text. The optimal number of evaluators in this example is four, with benefits that are 62 times greater than the costs”. Source: nngroup.com

Participants

The selection of experts for design review requires a usability inspection by the expert with good knowledge of the usability guidelines and best practices, design principles, and human-computer interaction, as well as the experience in the UX design field, according to Nielsen Norman Group. Therefore, the experts were selected according to their experience in UX design and project diversity to be able to identify possible UX issues and lead to new insights.

Four experts aged between 26 and 34 years old, two females and two males. All were highly educated, with two participants with bachelor's degrees, one master's degree, and the other one with Ph.D. Regarding experience in user experience design, values vary, one of the experts has 8 years of experience, others have 6 and 3 years and one expert has 2 and a half years. Two of the participants are employed as UX/UI designers, one participant is UX Researcher, and the fourth participant is working in the UX product design field.

Procedure and Material

Four experts were invited to realize remote online (due to the Covid-19 pandemic) UX expert review testing. In the beginning, experts have introduced the objectives of the study. Next, they performed six tasks to navigate through the five main systems of the mobile application. At the end of the procedure, they filled out 10 minutes online questionnaire with a total of 25 questions. The questionnaire (shown in Appendix E) was divided into three different sections: demographic data, heuristics evaluation, and additional feedback or comments that the evaluator wanted to highlight or added suggestions. In Figures 25 and 26 the low fidelity prototype interface system is presented.

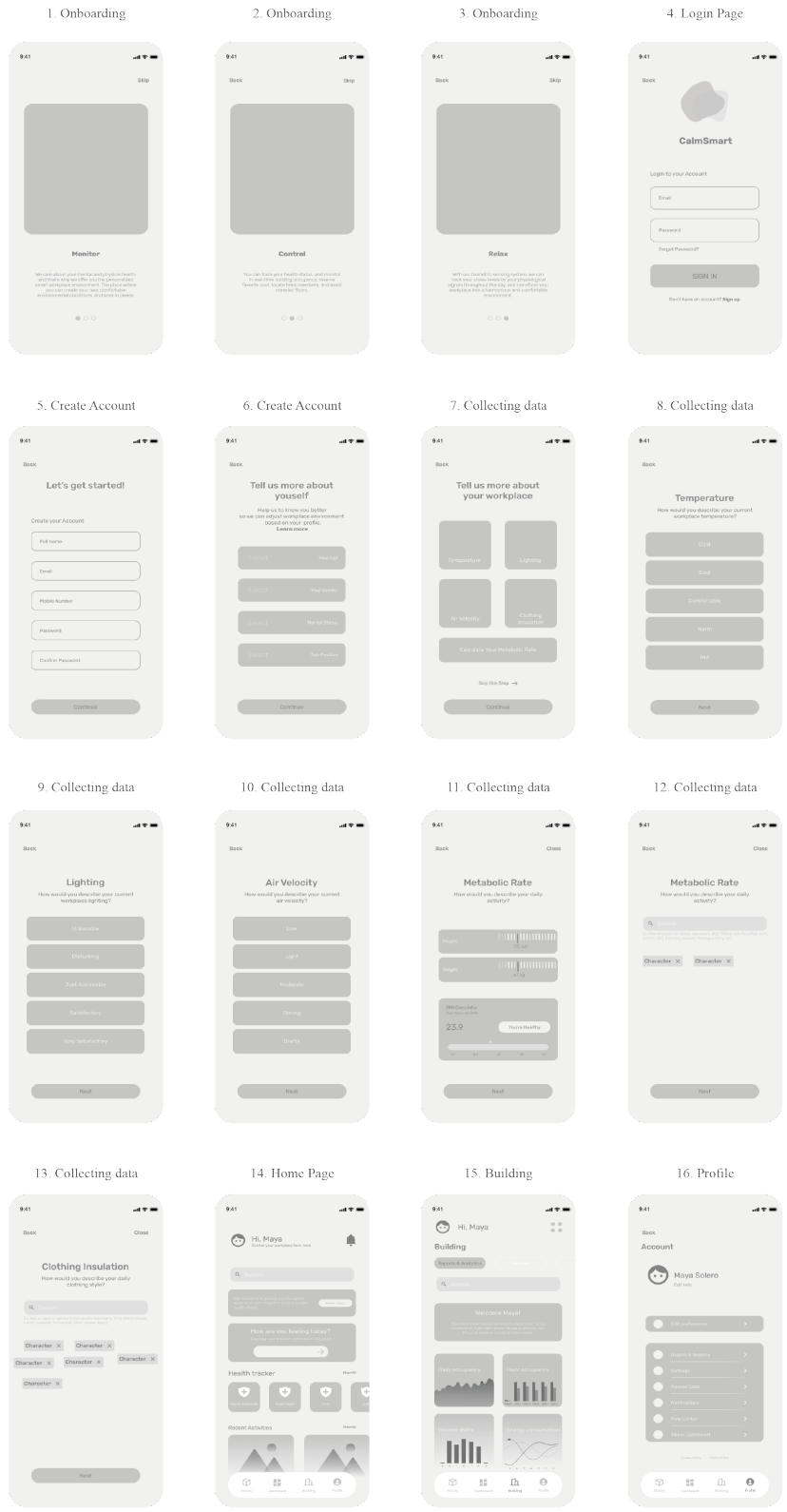
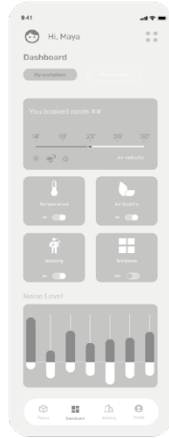
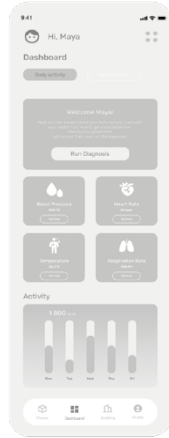


Figure 26. Proposed low fidelity prototype interface.

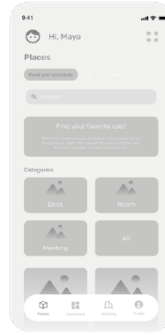
17. Dashboard — Workplace



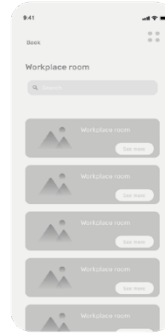
18. Dashboard — Body Activity



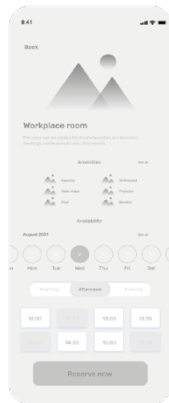
19. Places



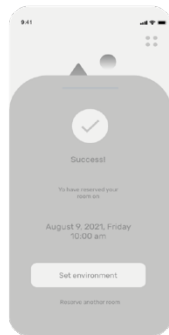
20. Places — Booking



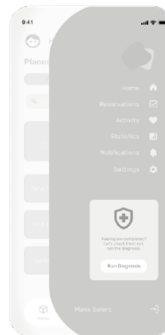
21. Places — Booking



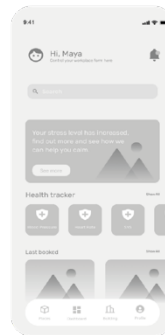
22. Places — Booking



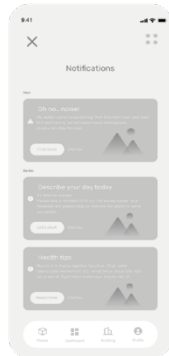
23. Sidebar Menu



24. Notifications



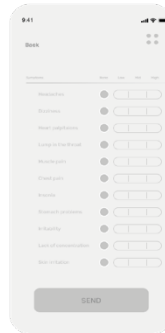
27. Notifications



25. Health Check



26. Stress Check



28. Personalization

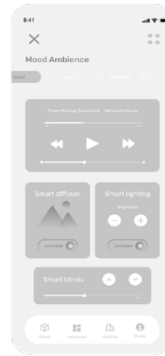


Figure 27. Proposed low fidelity prototype interface.

Results and conclusion

In summary, the results were quite positive regarding the study purpose. All experts responded that there are benefits to having this application to notify stress levels and that the proposed system accomplishes the goal. 75% responded as excellent when asked about the usability of application navigation interfaces and only 25% considered as poor. Concerning the IA structure method of application, the opinions were divided among the experts, 50% replied as effective and 50% as neither effective nor ineffective, however, 75% of experts answered that the application looks effective and 25% shows neutral. Additionally, we asked does the application communicates the idea of the concept through the prototype and all answers were positive, 75% strongly agree with 25% agree. The experts agreed as well that the challenges presented by the proposed system are appropriate to motivate people to use the application, as stated *“If we find the right conditions for us, there is an increase in happiness and well-being, increasing productivity.”*

Overall, we can conclude that the concept of the project has been successfully delivered through the low fidelity prototype, which was one of the concerns. Nevertheless, the experts have stated usability issues from the overall system interfaces. Thus, the problems reported regarding the following five heuristics:

- Match between the system and the real world.
- User control and freedom.
- Consistency and standards.
- Error prevention.
- Help users recognize, diagnose, and recover from errors.

Therefore, user **control and freedom** were highlighted as major usability issues and that was decided to make them a priority. After carefully reading, analyzing, and taking these suggestions into account, several design features have been changed and adjusted to improve the performance of the high-fidelity prototype.

4.5 Phase V – Implementation

4.5.1 High fidelity prototype

After the completion of the first usability iteration and analysis of the inspection of the interfaces by the experts, some usability problems considered to be serious were detected, and therefore it was extremely important to correct them before moving on to the final phase. The respective following revisions:

- Improve the contrast between colors, see Figures 32 and 33.
- Improve language for the menu buttons — Places, see Figure 29.
- The sidebar menu should correspond to the native API's menu.
- Help users to recover from errors and error prevention, see Figure 29.

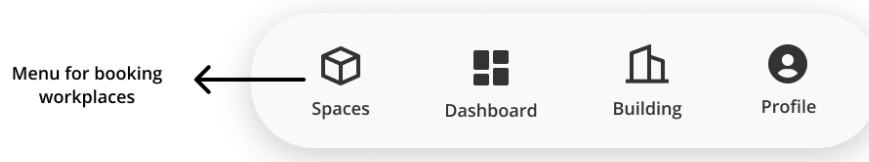


Figure 28. Prototypes improve language for menu categories.

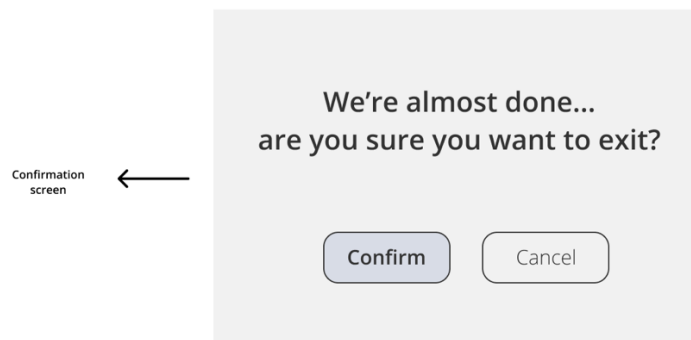


Figure 29. Error prevention, let the user the freedom to choose and recover from errors.

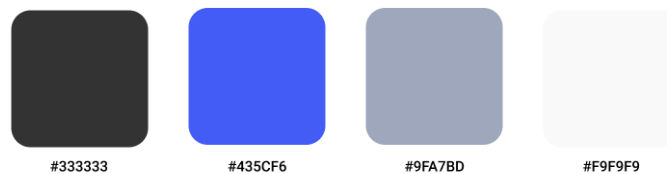
A high-fidelity prototype, unlike the wireframes and low-fidelity prototypes, should closely match the look and feel of the final product, as it is more refined and polished. To define a color palette of the design interfaces and consider the UX expert reviewers, it was decided to adopt a more

robust and minimalistic design, so the colors should be considered clean as well. Since the system is oriented toward the wider public, the blue color is shown to be the favorite color for the visual experience by most males and females, according to a survey¹⁵. While the black tones colors symbolize modernity, elegance, and intelligence. The grey tone chosen for the background has a smoothing effect and works along with the other colors. All colors were tested for accessibility, to provide legibility for all users, even with visual disabilities, such as colorblindness. For color testing, were used an online tool from Adobe Color, see Figures 31 e 32.

The figures below present the color palette and design overview of the proposed mobile application.

Color Palette

Primary Colors



Secondary Colors

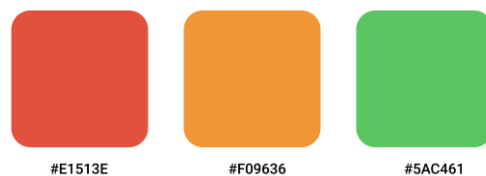


Figure 30. The color palette of the proposed system.

¹⁵ <https://babich.biz/blue-color/>

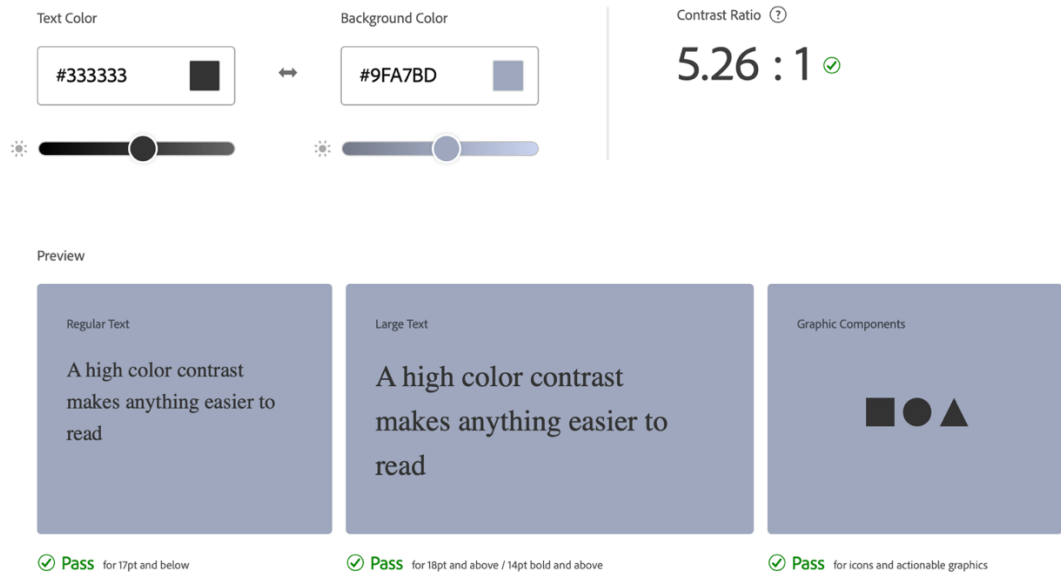


Figure 31. Accessibility contrast checker. Source: [Adobe Color](#)

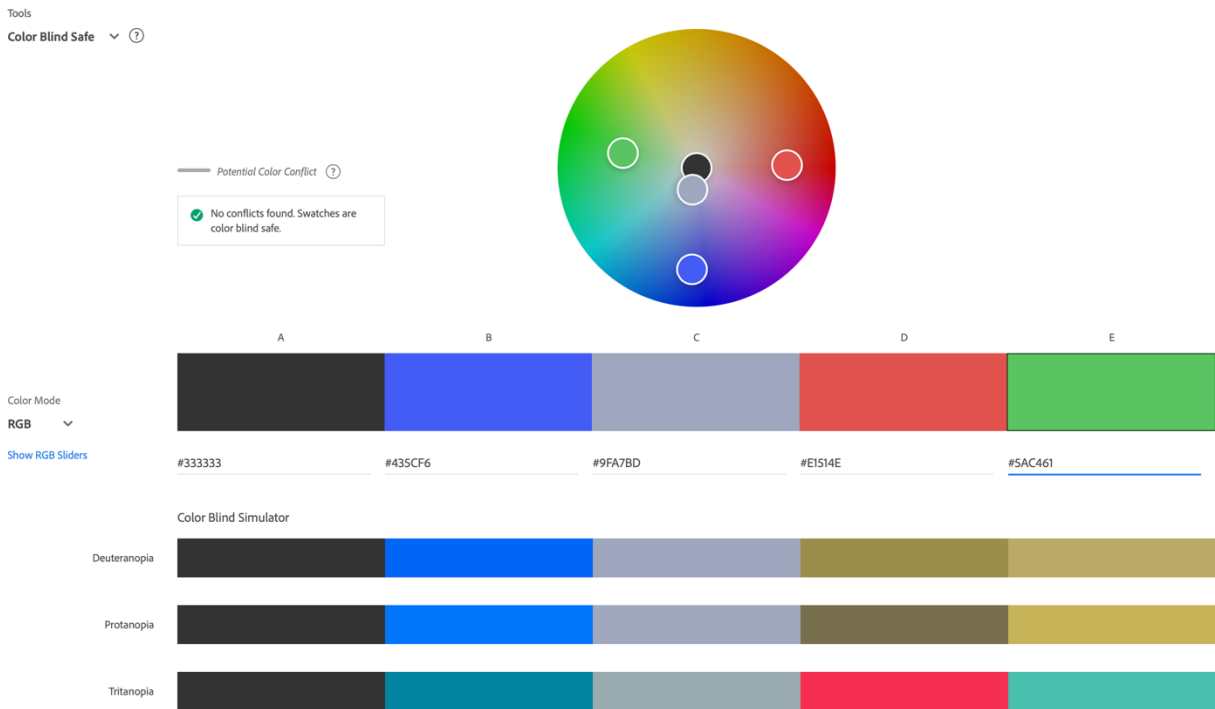


Figure 32. Accessibility Colorblind checker. Source: [Adobe Color](#)

The primary typography font chosen was the Open Sans, a humanist sans serif typeface that has been shown with great readability in UI design, along with the Roboto font, used as a secondary font.

Typography

Open Sans Regular

ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz
1234567890

Open Sans Semibold

ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz
1234567890

Roboto Regular

ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz
1234567890

Figure 33. High-fidelity typography style

4.5.2 Unmoderated User Testing

The main objective of this step is to evaluate the high-fidelity prototype of the system with users, and test the interfaces and navigation flow, usability, and interaction between the proposed mobile application and the user. Likewise, it is expected to find the real opinion about the system, whether it fulfills the main objective and whether there is a need for such a system.

Method

Unmoderated usability testing, as it sounds, is testing without monitoring or guides, usually, it is done remotely. Unmoderated studies are as well a faster way to evaluate prototypes and consume less time than the moderated, however, according to Nielsen Norman Group¹⁶ involves more detailed planning. Thus, it is essential to complete several steps: a) define the study goal, b) choose software for testing, c) define tasks and prepare questions, d) pilot test, e) recruit participants, and finally, f) analyze results.

Participants

To conduct unmoderated testing five to ten participants will uncover at minimum 82% of usability issues (Faulkner, 2003). For this study, ten participants volunteered to participate in this usability testing.

Procedure and Materials

A user protocol was organized with a brief introduction to the system along with the instructions and tasks to perform, a similar procedure that was applied in the previous study. For more convenience, Google Form was used as an online tool to share the test, and Figma software was used as well, for designing interfaces and prototyping ([link to high fidelity prototype can be found here](#)). Each task has a corresponded link to perform a task, additionally, after evaluation participants were asked to score the prototype system in the System Usability Scale (SUS) created by Brooke (1996) questionnaire to measure the user experience and satisfaction, which later was modified by Bangor, et al. (2008) to 10 questions for measurement subjectively the usability of the systems. Additionally, it was added an open-ended question (shown in Appendix F), in order to gather a more detailed point of view of the participants regarding the mobile application interface system they have tested.

The participants performed six tasks to test the usability of the onboarding flow, check the health status, book a workplace room and navigate through the system (shown in Figures 34 to 38).

¹⁶ <https://www.nngroup.com/articles/unmoderated-usability-testing/>

Afterward, participants completed the tasks, they were asked to answer the System Usability Scale (SUS) questionnaire, using the Likert ranking on the scale from 1 to 5, which 1 corresponds to Strongly Disagree and 5 is Strongly Agree. The main goal is to measure the system usability, according to ISO 9241:11¹⁷ standards defined characteristics: *satisfaction*, *effectiveness*, and *efficiency*.

The feedback was collected from the 10 system usability scale questions:

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need to support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

As well, it was asked the following questions for additional feedback:

- How difficult you found this test?
- Do you think there is a need for this app?
- My overall feeling about the interaction of the application is...
- What is your feeling of the visual design of the application?
- Does the prototype of the application bring the ideation from the concept?

More open-ended questions were added to gather more opinions and points of view from the participants regarding the prototype they tested.

¹⁷ <https://www.iso.org/obp/ui/#iso:std:iso:9241:-11:ed-1:v1:en>



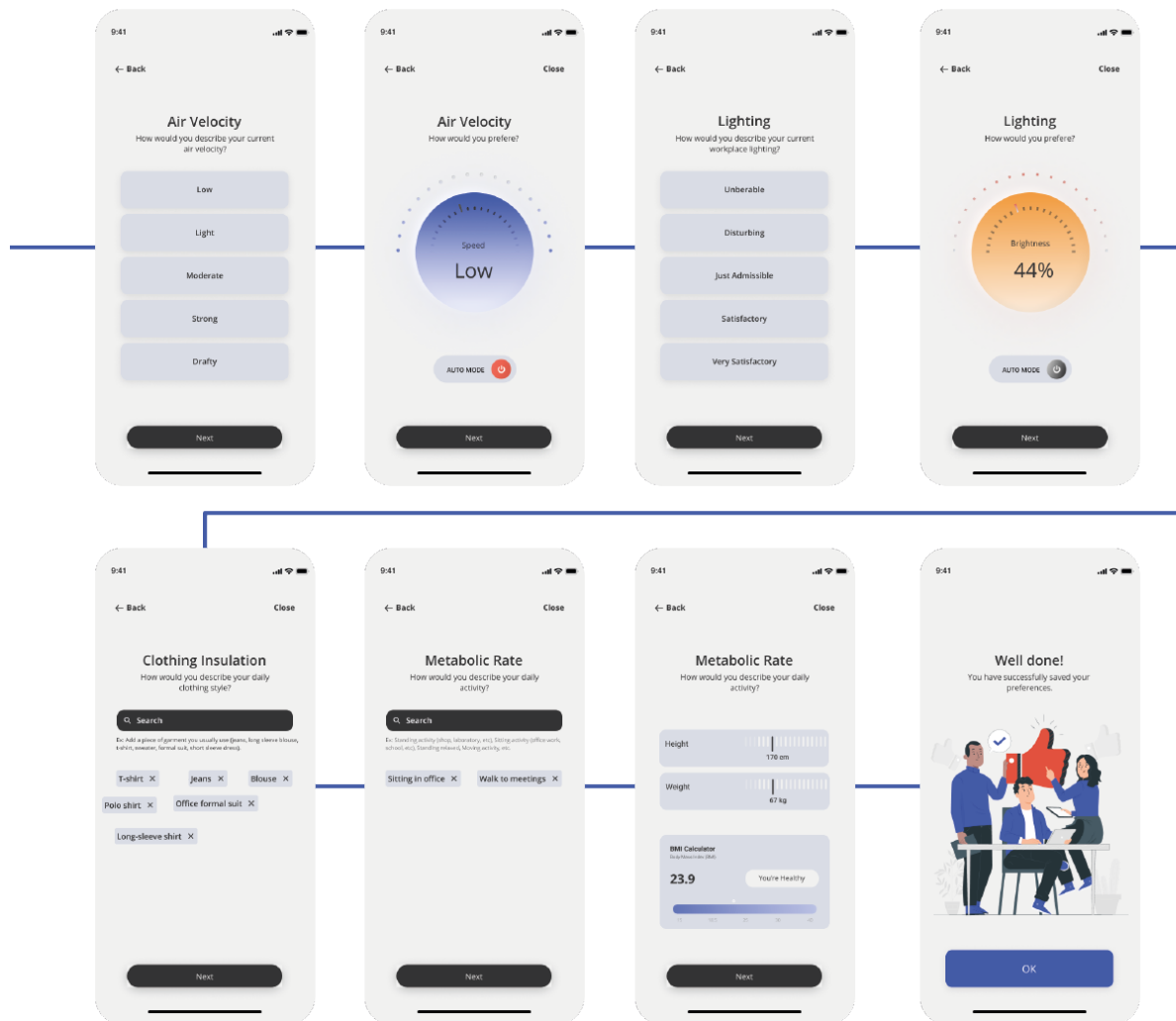


Figure 34. Task 1: Go through the onboarding process and complete the registration form. A higher resolution of interfaces is available [here](#).

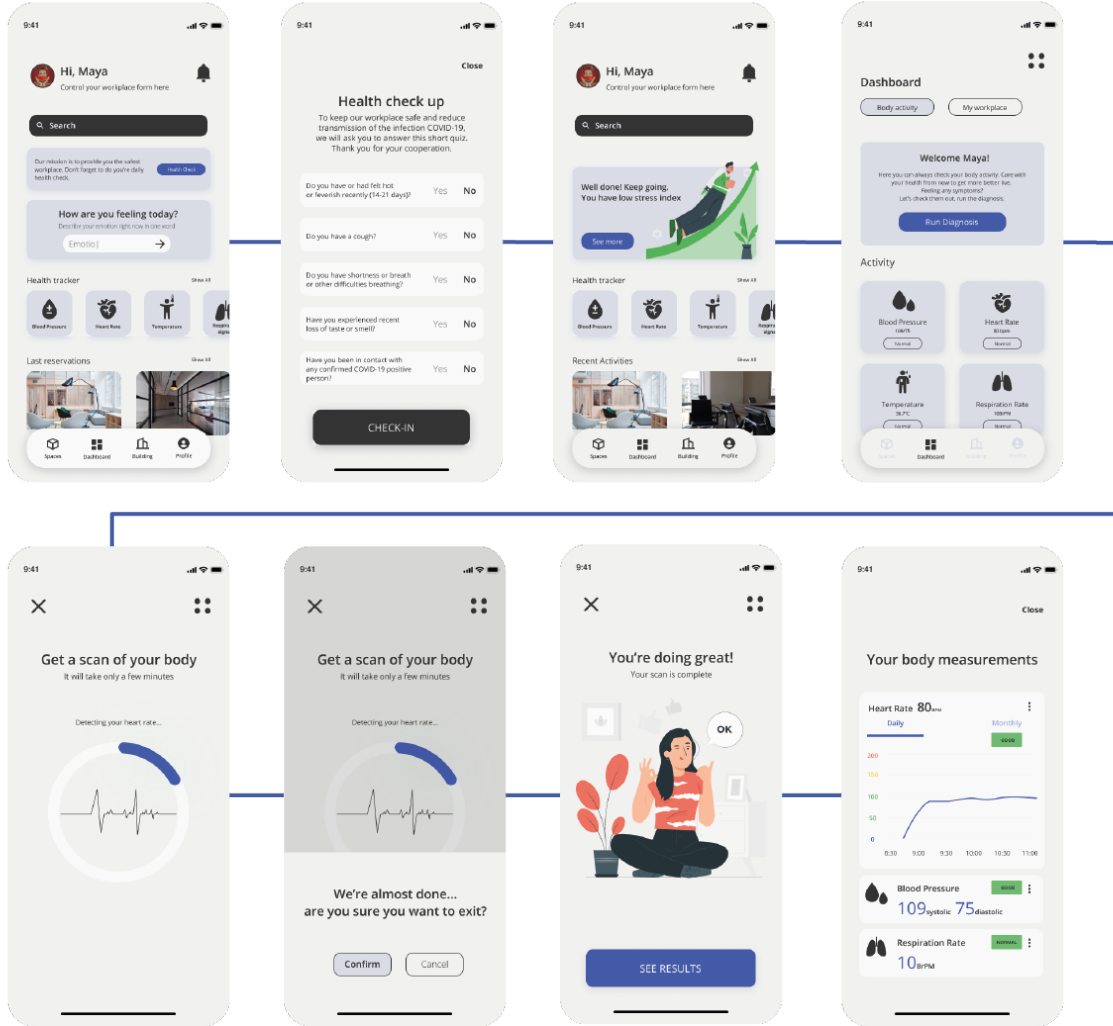


Figure 35. Task 2: Go and check your Health status, run a diagnosis, and see your body activity. A higher resolution of interfaces is available [here](#).

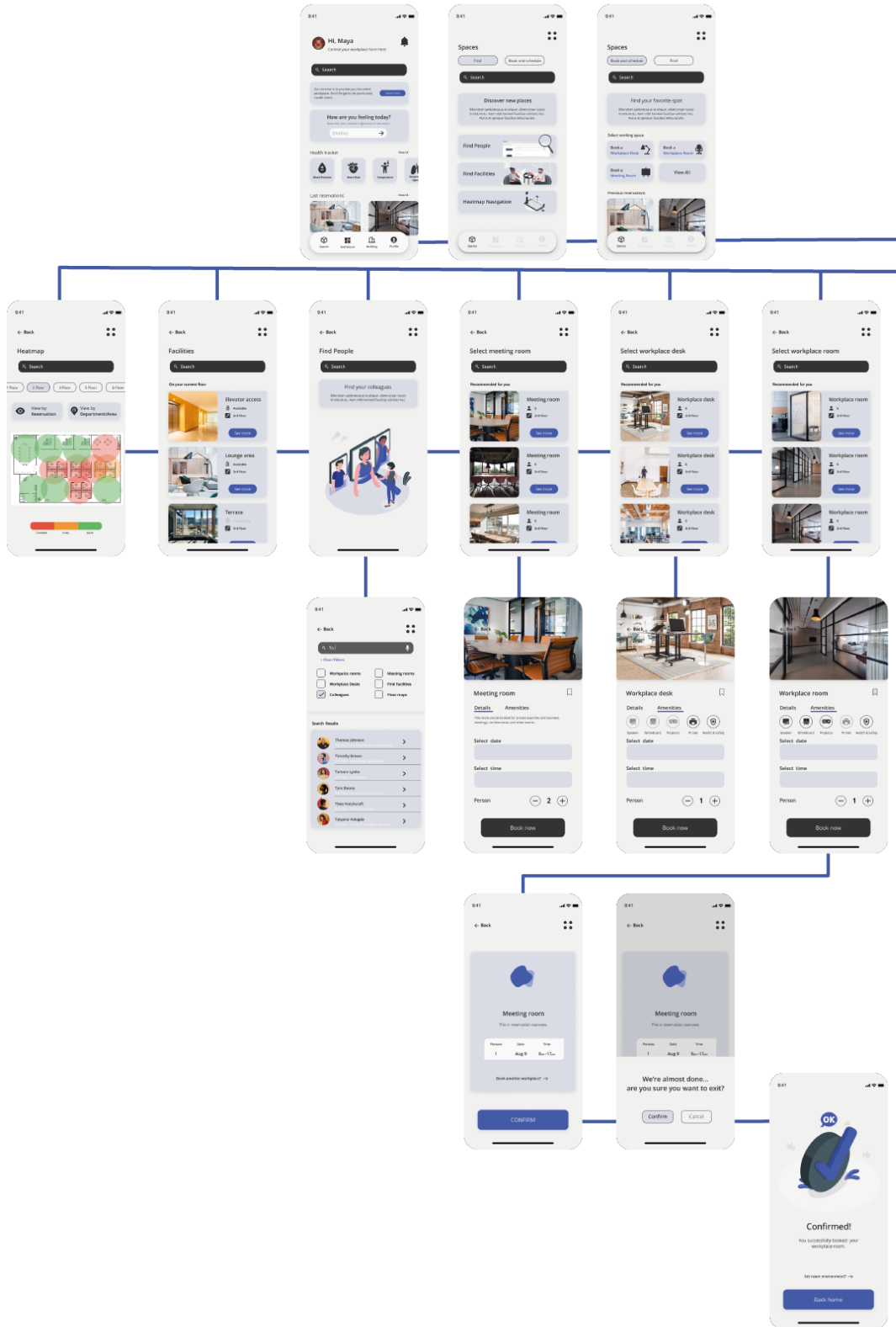


Figure 36. Task 3: Go and book a workplace room so you can work quietly. A higher resolution of interfaces is available [here](#).



Figure 37. Task 4: On your Homepage, you received two notifications. Find and read them. A higher resolution is available [here](#).

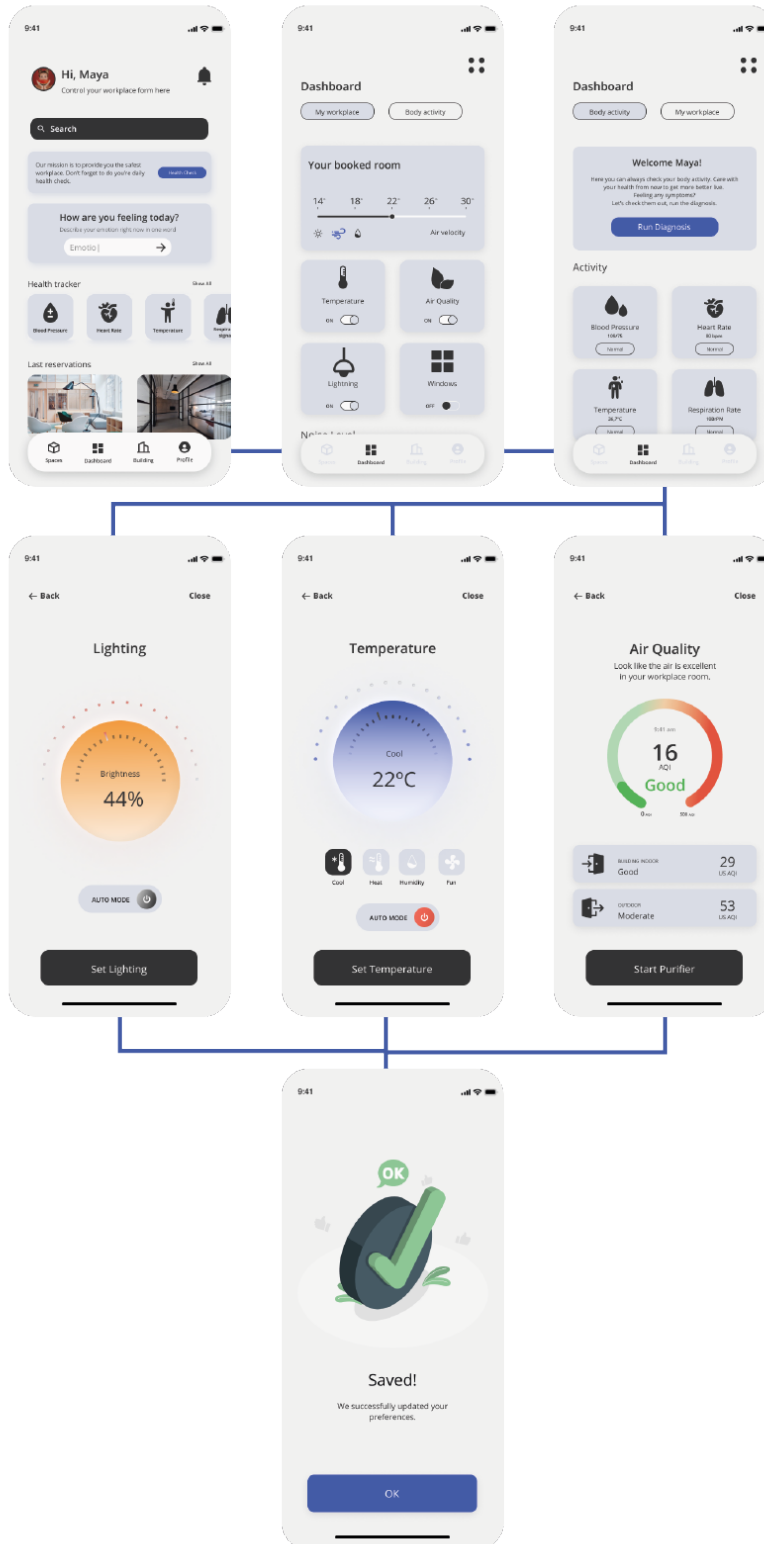


Figure 38. Task 5: View your current workplace temperature and air quality. A higher resolution is available [here](#).

Results and discussions

The calculation of the SUS score results was followed by using this formula:

$$((Q1-1) + (Q3-1) + (Q5-1) + (Q7-1) + (Q9-1) + (5-Q2) + (5-Q4) + (5-Q6) + (5-Q8) + (5-Q10)) \times 2.5$$

The final score results calculation can be in the Table below.

Table 4. SUS Score Results

Users	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	SUS Row scale	SUS Final score
User 1	5	1	5	1	5	1	4	1	5	2	38	95
User 2	4	3	5	2	5	2	5	3	4	1	32	80
User 3	5	1	5	1	5	1	5	1	5	1	40	100
User 4	4	1	4	1	5	1	5	1	4	1	37	92,5
User 5	5	2	4	2	4	2	3	2	5	2	31	77,5
User 6	4	2	5	1	4	1	5	1	4	1	36	90
User 7	4	1	5	1	4	2	5	1	4	2	35	87,5
User 8	4	3	4	1	3	2	4	1	4	2	30	75
User 9	4	1	5	1	5	1	5	1	5	1	39	97,5
User 10	4	2	5	1	4	1	5	1	3	1	35	87,5
Average score											35,3	88,25

The final SUS score results have shown in Table 4, that the participants have scored the high-fidelity prototype of the system 88 points out of 100 points, a B grade from the grade scale, ranked as “excellent” from the adjective ratings, and lastly “acceptable” from the acceptability ranges. To interpret and measure the results more meaningfully, the table score represented the approaches in Figure 39 was adapted (Kortum et al., 2015).

Following additional questions, it was asked participants how participants found the test, the tasks they were given and their overall opinion, mostly found the tasks “very easy” and “easy” to

perform, as illustrated in Figure 40. Which could mean that test was overall intuitive for the participants.

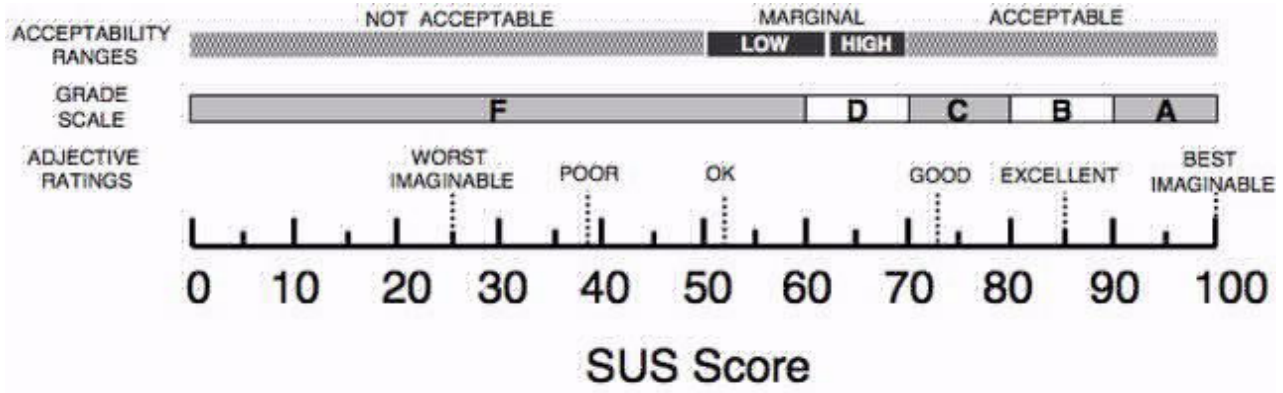


Figure 39. SUS Score scale was adapted (Kortum et al., 2015).

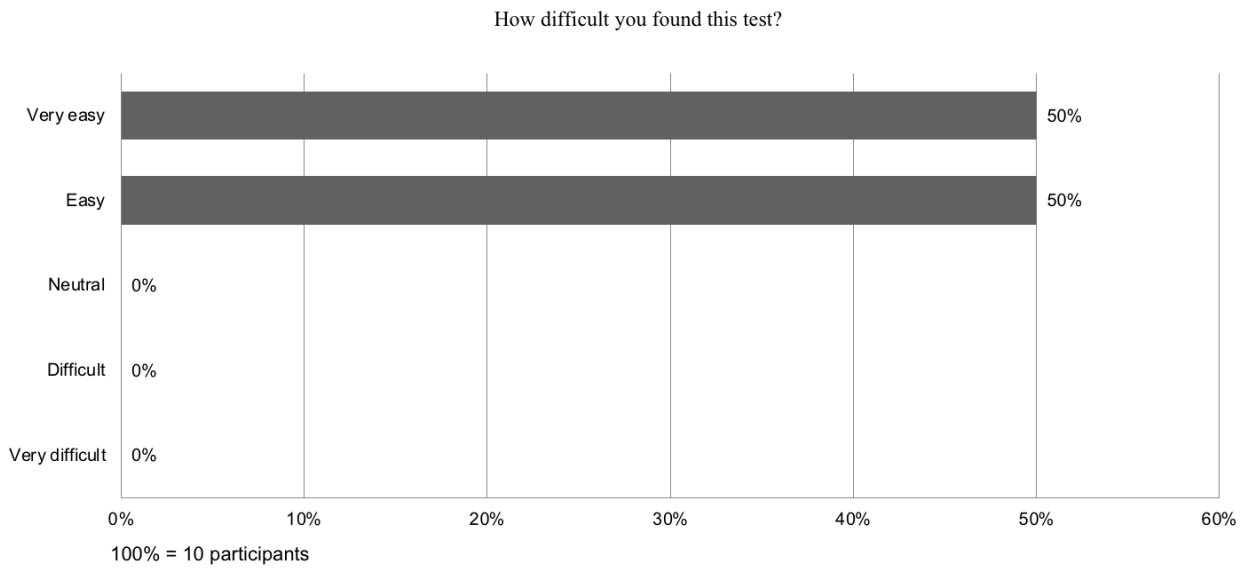


Figure 40. How difficult participants found the test.

Proceeding, to understand if participants found the need for this application it was asked about their opinion, and most responded positively that they think there is the need, and 10% of participants showed neutral, as shown in Figure 41. It can be considered that there is a general need for an application capable to measure stress levels and aloud to monitor and control room environment conditions.

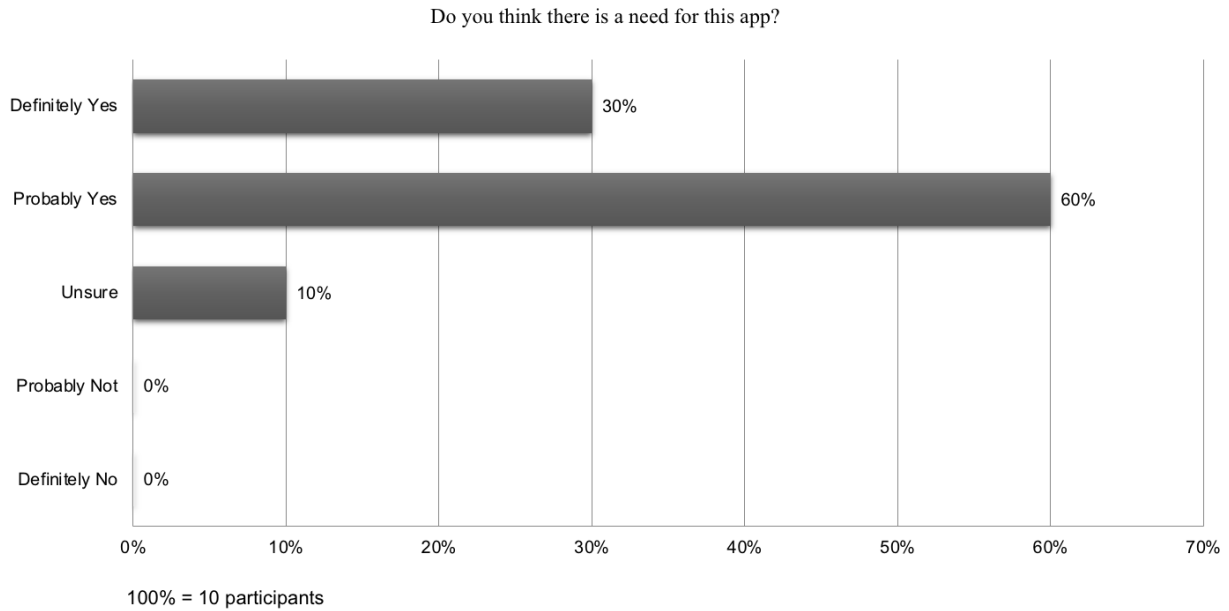


Figure 41. The importance of the proposed system

In the next question, the overall feeling about the interaction of the application was asked to participants, it was considered important to understand the interaction between the application and users as is a part of the main goals of the proposal system. As result, participants responded as satisfied, they evaluate the interaction between the interfaces as satisfactory.

Further, it was asked what their feelings about the visual design of the application are, ranked from 1 to 5, which confusing as 1 and very clear as 5, and all participants found the visual design of the interfaces very clear. This could result from the minimalistic concept, using simple and clear language, contrasting colors, and legible typography, as suggested by UX experts from the previous usability testing.

In the next question, participants were asked if the application brings the ideation from the concept, that is if the application design clearly communicates the study case of the project, and the results are shown in Figure 42, which most of the participants agreed with the statement and only 10% stated as neutral. Overall, the outcomes were positive and shows that the prototype strongly communicates the ideation of the study.

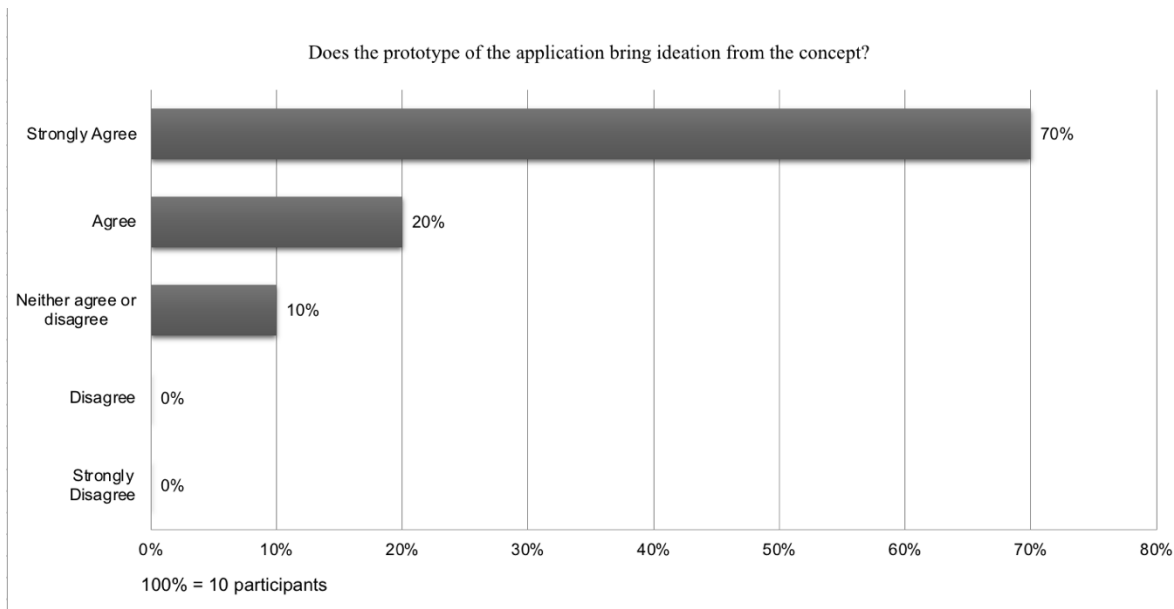


Figure 42. If the prototype brings the ideation from the concept

The following questions were open-ended questions to collect more individual feedback regarding the prototype, and it was requested to the participants to describe their overall experience with the product, in the following, can be observed the quotes from the testers:

- “Easy to use and to understand. Clean design. Interesting”
- “Satisfaction”
- “Useful, simple to use”
- “It was a good and interesting experience”
- “The product seems easy to use, at least for me that is accustomed to using apps overall. The test is straightforward, and the steps allowed are only the ones that guide us towards the goal”
- “It was simple and good overall”
- “Rich in the content of the services this app offers”
- “Easy to use”
- “A useful application. This is not a vital necessity, but it adds comfort to the work. If it was available at my work, I would use it”
- “The screens have a clean design that makes appealing the user experience. The settings are easy to use. In general, it makes me feel that it’s a useful app for a daily improvement of my life quality”

Furthermore, participants answered what they liked the most about the application and mostly replied that they liked the design, they found it very clear, clean, appealing, and intuitive to use, others highlighted the importance given to the workplace environment and concern about the employees, the ability to choose and control the rooms and the heatmap navigation, to avoid crowded areas for the quieter zones.

Then, for future improvements, testers were asked what they liked at least, and some responded, “nothing or everything was great”, others made suggestions for more “warming” personal feedback while they complete the tasks or the ability for personalization of the background colors according to the user personality (more colorful system).

Finally, it was proposed to participants to scale from 1 to 5, being 1 not at all, and 5 very likely, how would they recommend this product to a friend, in result (see Figure 43) all participants would very likely or somewhat likely recommend the application to a friend, as well, some of them would use the system frequently (60%), very frequently (20%) or occasionally (20%).

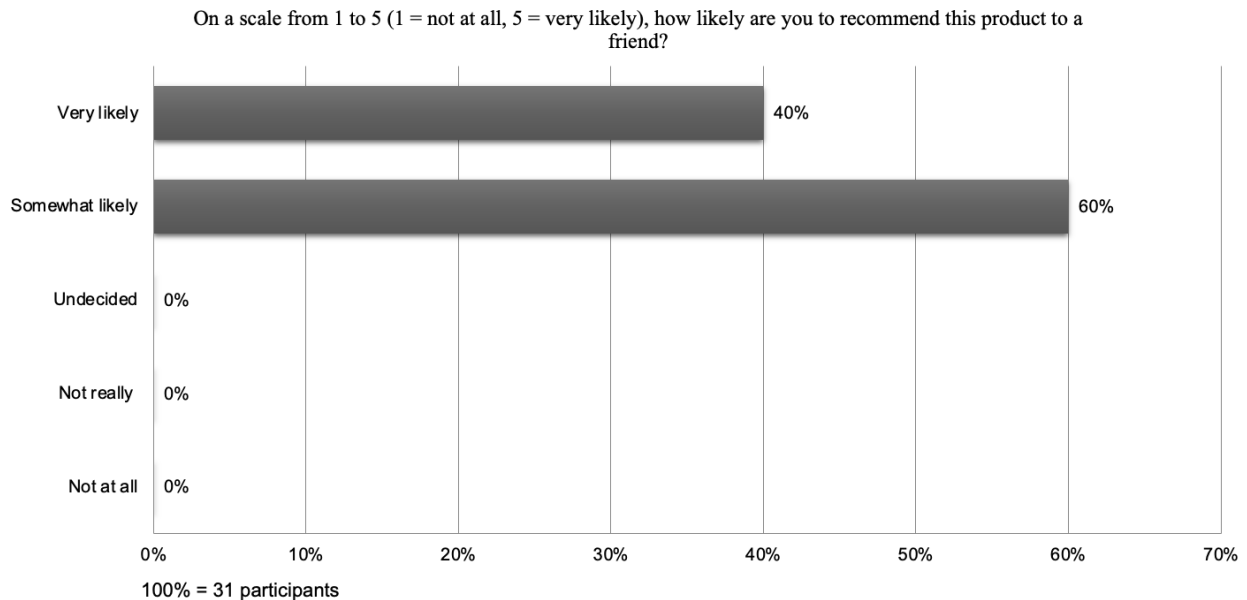


Figure 43. How likely would participants recommend this product to a friend.

Conclusion

Ten participants volunteered to participate in the last usability testing of the study, evaluating the high-fidelity prototype. The system interfaces were developed and designed in Figma software, digital design, and prototyping tool, which allowed to share prototypes with testers through the links managed by the software and facilitated the organization of the unmoderated user testing. To measure the user experience and evaluate the usability of the system, it was proposed to integrate the System Usability Scale (SUS) model as a system evaluator. The SUS results identified that the system's usability was measured as "excellent" and "acceptable" with a final score of 88 points out of the 100.

On the open-ended questions, participants replied with positive results, defining the system as easy to use, useful content, clean and appealing design, and liked the importance given to the employees managing and controlling their workplace environment.

The results described above, are without a doubt, the influence of feedback review of the system from the expert evaluation, performed by the UX experts, which in the initial stage (low-fidelity prototyping) permitted to identify and correct the usability issues.

5. Conclusion and Future Work

This thesis study arises from the preoccupation of the workplace occupants' mental and physical health and awareness of their daily stress levels caused by the environment surrounding them. As mentioned in the problem statement (see Chapter 1), work-related stress is a reaction to excessive demands or pressure at work, described as the most common occupational problem existing mostly in each profession (Navarro-Tuch et al., 2018). These pressures result in stressors that can lead to the biological/physiological and psychological stress reaction in a person, consequently, there are different types of stress according to their origins, however, the present study will focus on those that can be quantified and measured: environmental and chemical stressors, such as temperature, air quality, humidity, and biological/physiological conditions, such as body temperature, heart rate activity and electrodermal activity (EDA) (Ramón-Fernández et al., 2018).

Therefore, people need to feel healthy and safe in the workplace they occupy, such as environmental support is fundamental for staying comfortable during the day (Vischer, 2008). Despite the constant advancement in the world of technology, many studies have been focused on developing intelligent ambient or smart workplaces, however, few efforts have been made around occupants' well-being, such as stress recognition and workplace environment personalization.

The main purpose of this study was to present a stress management solution for an interactive design system within the field of Interaction Design, the field that provided communication between the system and users, as well as their needs, behavior, and experiences. The design system combines collected data from workplace occupational sensors and unobtrusive biometric sensors that allow measuring and monitoring in real-time environmental and biological/physiological characteristics to prevent environmental workplace-related stress, as well as help users cope with the stress when being stressed, and additionally increase user overall well-being in the workplace. As mentioned above, a part of the system was developed within the scope of the concept of smart workplaces (intelligent environments with an integration of the IoT technology), which is a mobile application — the design system capable of recognizing and monitoring the person's psychological and physiological state, detecting stress according to the biological signals, and reacting, using stress-relief techniques (sound masking, aromatherapy, and mood ambiance). The stress coping techniques can be activated automatically according to the user's preferences or adjusted manually

using the mobile application interfaces. Additionally, the workplace reservation was added, along with the building set, uniting, thus, all smart workplace features within a single application.

The design process, based on the user-centered design approach (UCD), allowed the design, and evaluate the final prototype, using methods to investigate users' needs, motivations, and expectations to deliver a good user experience through the interaction process. The findings of the user testing during the project development can be beneficial for further investigations in the smart workplaces field and designing interfaces of the mobile application. Following user testing results and discussions revealed:

1. During the usability tests, participants were shown to be unfamiliar or little familiar with the concept of the smart workplace. Over the card sorting test where participants were asked to categorize cards according to their expectations, many experienced difficulties in categorizing the cards, as were unfamiliar with certain terms, such as heatmap and dashboard.
2. According to the user research results, temperature and noise are the most common environmental stressors among the users causing stress and uncomfortable conditions to work.
3. While feeling stressed in the workplace, it is common for users to leave their workplace for a short walk or breathe fresh air outside the building to relax, compared to what is expected, almost none of them resort to applications of mindfulness or stress-relief techniques. There is a clear preference for outdoor physical activities to manage stress rather than using digital solutions, such as mobile applications.
4. The evaluation by experts in the initial phase of digital interface design proved to be very effective, as the reviewers had the chance to detect the usability issues (violated heuristics), the given feedback, and new insights regarding the design system allowed to correct issues before the final usability testing.
5. Overall, the design system solution was well accepted and received positive feedback from the usability testing. Participants that volunteered to evaluate the prototype, replied that the visual design of the application system was very clean, clear, and appealing, and found the system rich in content. The potential to control and set the room environment,

additionally the given concern about the occupants' mental well-being are the highlights of the project.

The proposed system and mobile application as a part of it can contribute to future additional investigations in the smart workplaces study field and their interaction with the people placed there. Complex systems, such as this, require technological solutions, as they involve connectivity to virtual networks, and thus, it is important to value the privacy and security of the users. The combination of the visual aspects of the smart workplaces, such as colors, textures, shapes, and dimensions, has been proven that stimulate productivity, sensations, and emotions. Thus, the design system must be strategic and user experienced, focusing on the user as the center of the entire system. As represented in the study results, an interactive design must be perceptible and explicit as much as it can be to afford a good user experience.

5.1 Limitations

The present study had some limitations and constraints from the beginning of the project, with the most relevant fact that it was not possible to implement the entire interactive prototype system. This is due to the fact, that the study occurred during the COVID-19 pandemic, which implied a limitation in the evaluation and the validation of the proposed design system, as well due to the limitation of the deadline. Additional limitations observed that deserve attention was the fact that the usability testing sessions were executed remotely, which brought the followed limitations:

1. Not being able to directly observe the interaction between the participant and the prototype, such as the user's body language and facial expressions. Some people may change their natural posture while being observed through the camera or being filmed.
2. Due to the technological limitations, it was not possible to test the prototype on participant's smartphones, as Figma software required at least 14.5 iOS version to be running and 8.0 on Android, since not all participants had the sufficient version to test the prototype on their smartphone, it was decided to use Safari and Google

Chrome browsers instead. Which limited the direct interaction with the prototype, user gestures when interacting with the application are important in user experience as they inform if the interface interaction is successfully done.

As for recommendations for future investigations from the project developed here, we suggest:

- To implement a fully functional high-fidelity prototype (as a final product) for testing in the real case scenarios, with the possibility to monitor the environmental conditions (temperature, air quality, noise, lighting, and humidity) and user physiological signals and evaluate the user interface along with the performance of the stress-relief techniques in the real context. The research (see Chapter 2) and usability testing (see Chapter 4), indicate that the main environmental stressors causing stress are: temperature and noise. Therefore, these variables should be measured and tested separately, along with the stress relief techniques (sound masking and aromatherapy), as well as the other environmental conditions, as there is a great concern that there may be interference between them which could impact the system performance.
- The next step must study the data privacy concerns and the challenges of supporting the collected data in the workplace environment, the user privacy and the data usage must be clear and transparent and must correspond to the EU General Data Protection Regulation (GDPR) privacy standards. As well as cybersecurity must be the priority in the next phase and permanently be a part of the system development processes, as well for the workflows that involve the use and sharing of information, the use of software, infrastructure, and devices. In summary, the ethical and safety aspects of personal data should be considered.
- Implement a more detailed facility management platform architecture, explaining the organization of the connectivity between building equipment and devices, as well as the data organization in the cloud-based services and applications, which will allow connecting smart workplace securely and automatically to the leading services, such as dashboards, remote controls, analytics and reports to the users.

- Also, for future recommendations, we suggest considering the voice-activated personal assistants that will make a smart workplace even smarter and bring a great utility to task performance.

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Appendix A — Literature Review

Table 5. Literature review overview

Title	Year	Authors	Keywords	Abstract
Using smart offices to predict occupational stress		Ane Alberdi, Asier Aztiria, Adrian Basarab, Diane J. Cook	Stress, Smart office, Automatic assessment, behaviour, Physiology	Occupational stress is increasingly present in our society. Usually, it is detected too late, resulting in physical and mental health problems for the worker, as well as economic losses for the companies due to the consequent absenteeism, presenteeism, reduced motivation or staff turnover. Therefore, the development of early stress detection systems that allow individuals to take timely action and prevent irreversible damage is required. To address this need, we investigate a method to analyze changes in physiological and behavioral patterns using unobtrusively and ubiquitously gathered smart office data. The goal of this paper is to build models that predict self-assessed stress and mental workload scores, as well as models that predict workload conditions based on physiological and behavior data. Regression models were built for the prediction of the self-reported stress and mental workload scores from data based on real office work settings. Similarly, classification models were employed to detect workload conditions and change in these conditions. Specific algorithms to deal with class-imbalance (SMOTEBoost and RUSBoost) were also tested. Results confirm the predictability of behavioral changes for stress and mental workload levels, as well as for change in workload conditions. Results also suggest that computer-use patterns together with body posture and movements are the best predictors for this purpose. Moreover, the importance of self-reported scores' standardization and the suitability of the NASA Task Load Index test for workload assessment is noticed. This work contributes significantly towards the development of an unobtrusive and ubiquitous early stress detection system in smart office environments, whose implementation in the industrial environment would make a great beneficial impact on workers' health status and on the economy of companies.
Sensor-Based Smart Office Control System	2019	Syed Zulqadar Hassan, Tariq Kamal, Umar Riaz, Muhammad Abbas Khan		Smart offices make life easier for employees and customers. Office automation makes the system more transparent and can share information more openly, thus creating a huge impact on the operation of the industrial sector and enterprises. This research has potential to control full office load and separate portion load. It can control the lights of office by light intensity control. It measures the temperature by sensors and then turns off or turn on the different devices accordingly to maintain the temperature. It also includes the knock command for turning on or off a device. This all process is controlled by using the android mobile app, windows software, knock command and Bluetooth. After temperature comparison AC and heaters are turned on automatically. Light intensity increases or decreases according to day light. LCD displays show no. of persons entered, meeting room availability, amperes, and voltages etc.
Review on occupant-centric thermal comfort sensing, predicting, and controlling	2020	Jiaqing Xie, Haoyang Li, Chuting Li, Jingsi Zhang, Maohui Luo	Personal comfort model Data-driven Internet of Thing (IoT) Building control	Ensuring occupants' thermal comfort and work performance is one of the primary objectives for building environment conditioning systems. In recent years, there emerged many occupant-orientated technologies aiming to optimize thermal comfort while saving energy. These attempts offered opportunities to move the indoor thermal environment control from the one-fits-all approach toward a new paradigm with occupant-centric merits. A timely review of this emerging field would help to fill the knowledge gap and provide new insights for future research and practice. This study performed a literature review to summarize recent occupant-centric thermal comfort practices following a framework with three themes: sensing, predicting, and controlling. The results show that occupant-centric thermal comfort control has become a hot research topic in recent years. A wide range of variables and data-collecting sensors were utilized to support the concept. Among all the potential variables, occupants' comfort feedback, skin temperature, and air temperature are the top three popular input features for thermal comfort prediction. Using different machine learning algorithms, data-driven thermal comfort models were reported to have a median predicting accuracy of 84% and some of them can predict thermal comfort at a personal level. Cases implementing occupant-centric thermal comfort control strategy were reported to save air-conditioning energy by 22% and improve thermal comfort by 29.1%. These observations from the literature support the prospects of the new thermal comfort paradigm. Additionally, the challenges and opportunities in this emerging field were discussed.

Reduction of stress levels and increased productivity inside offices using emotional domotics	2018	Aura C. Figueroa-Ramos and José Carlos Morales-Camilli M. Rogelio Bustamante-Bello and Sergio A. Navarro-Tuch	Emotional domotics, stress, workspaces, productivity, relaxation.	The aim of this report is to apply emotional domotics concepts to environmentally design workspaces to promote productivity and inspiration and reduce stress levels through induced relaxation using ambient variables. Due to the fact that the highest stress levels are present within offices, this proposed design falls exclusively to workspaces. The first section of this report details the main goals of this research, whereas the second section defines the current problem related to high stress levels inside offices and the definition of emotional domotics. The third section details the suggested design. The fourth section elaborates on the obtained results. Finally, the last section includes the conclusions that came from the results and future work that must be done to improve this project.
Real-Time Personalized Monitoring to Estimate Occupational Heat Stress in Ambient Assisted Working	2015	Pablo Pancardo, Francisco D. Acosta, José Adán Hernández-Nolasco, Miguel A. Wister and Diego López-de-Ipiña	personalized monitoring; ambient assisted working; occupational heat stress; ISO; wearable sensors; ambient intelligence	Ambient Assisted Working (AAW) is a discipline aiming to provide comfort and safety in the workplace through customization and technology. Workers' comfort may be compromised in many labor situations, including those depending on environmental conditions, like extremely hot weather conduces to heat stress. Occupational heat stress (OHS) happens when a worker is in an uninterrupted physical activity and in a hot environment. OHS can produce strain on the body, which leads to discomfort and eventually to heat illness and even death. Related ISO standards contain methods to estimate OHS and to ensure the safety and health of workers, but they are subjective, impersonal, performed a posteriori and even invasive. This paper focuses on the design and development of real-time personalized monitoring for a more effective and objective estimation of OHS, taking into account the individual user profile, fusing data from environmental and unobtrusive body sensors. Formulas employed in this work were taken from different domains and joined in the method that we propose. It is based on calculations that enable continuous surveillance of physical activity performance in a comfortable and healthy manner. In this proposal, we found that OHS can be estimated by satisfying the following criteria: objective, personalized, in situ, in real time, just in time and in an unobtrusive way. This enables timely notice for workers to make decisions based on objective information to control OHS.
Real-Time Intelligent Thermal Comfort Prediction Model	2020	Farid Ali Mousa, Heba Hamdy Ali	Thermal comfort, chicken swarm optimization, momentum back propagation, neural network, bio-inspired optimization algorithm	Real-time prediction model of indoor thermal comfort depending on Momentum Back Propagation (MBP) function is established by using Arduino hardware and mobile application. The air temperature indoor, air velocity, and relative humidity are gathered via temperature sensor and transferred via Bluetooth to the mobile application to predicate thermal comfort. A significant challenge in designing MBP is to decide the best architecture and parameters as the number of layers and nodes, and number of epochs for the network given the data for the AI issues. These parameters are usually selected on heuristic and fine-tuned manually, which could be as boring as the performance assessment may take hours to test the output of a single MBP parameterization. This paper tends to the issue of determining appropriate parameters for the MBP by applying chicken swarm optimization (CSO) algorithm. The CSO algorithm simulates the chicken swarm searching for the best parameter employs the Fitness function of these parameters which yielding minimum error and high accuracy. The proposed accuracy approximately equals 98.3% when using the best parameters obtained from Chicken Swarm Optimization (CSO). The proposed methodology performance is assessed on the collected dataset from weather archive and in the context of thermal comfort prediction, that mapping relations between the indoor features and thermal index.

<p>Preparing Workplaces for Digital Transformation: An Integrative Review and Framework of Multi-Level Factors</p>	<p>2020</p>	<p>Brigid Trenergy Samuel Chng Yang Wang, ZAinal Shah Suhaila, Sun Sun Lim, Han Yu Li, Peng Ho Oh.</p>	<p>Digital transformation, digital disruption, digital technology, workplace, organization, employee, literature review, multi-level framework</p>	<p>The rapid advancement of new digital technologies, such as smart technology, artificial intelligence (AI) and automation, robotics, cloud computing, and the Internet of Things (IoT), is fundamentally changing the nature of work and increasing concerns about the future of jobs and organizations. To keep pace with rapid disruption, companies need to update and transform business models to remain competitive. Meanwhile, the growth of advanced technologies is changing the types of skills and competencies needed in the workplace and demanded a shift in mindset among individuals, teams, and organizations. The recent COVID-19 pandemic has accelerated digitalization trends, while heightening the importance of employee resilience and well-being in adapting to widespread job and technological disruption. Although digital transformation is a new and urgent imperative, there is a long trajectory of rigorous research that can readily be applied to grasp these emerging trends. Recent studies and reviews of digital transformation have primarily focused on the business and strategic levels, with only modest integration of employee-related factors. Our review article seeks to fill these critical gaps by identifying and consolidating key factors important for an organization's overarching digital transformation. We reviewed studies across multiple disciplines and integrated the findings into a multi-level framework. At the individual level, we propose five overarching factors related to effective digital transformation among employees: technology adoption; perceptions and attitudes toward technological change; skills and training; workplace resilience and adaptability, and work-related wellbeing. At the group-level, we identified three factors necessary for digital transformation: team communication and collaboration; workplace relationships and team identification, and team adaptability and resilience. Finally, at the organizational-level, we proposed three factors for digital transformation: leadership; human resources, and organizational culture/climate. Our review of the literature confirms that multi-level factors are important when planning for and embarking on digital transformation, thereby providing a framework for future research and practice.</p>
<p>Meditated Atmospheres: a multimodal Mediated Work Environment</p>	<p>2017</p>	<p>Nan Zhao, Asaph Azaria, and Joseph A. Paradiso</p>	<p>Human-centered computing — Ubiquitous and mobile computing systems and tools. Additional Key Words and Phrases: Ubiquitous Computing; Smart Office; Face Tracking; Heart Rate Variability; Perception; Wellbeing; Adaptive Building; Multimodal; Restoration; Productivity; Augmented Reality; Mediated Atmospheres</p>	<p>Atmosphere - the sensorial qualities of a space, shaped by the composition of light, sound, objects, people, etc. - has remarkable influence on our experiences and behavior. Manipulating it has been shown to be powerful, affecting cognitive performance, mood and even physiology. our work envisions and implements a smart office prototype, capable of digitally transforming its atmosphere - creating what we call Mediated Atmospheres (MA) - using computationally controlled lighting, video projection and sound. Additionally, we equipped this space with a modular real-time data collection infrastructure, integrating a set of biosignal sensors. Through a user study (N=29) we demonstrate MA's effects on occupants' ability to focus and to recover from a stressful situation. Our evaluation is based on subjective measurements of perception, as well as objective measurements, extracted from recordings of heart rate variability and facial features. We compare multiple signal processing approaches for quantifying changes in occupant physiological state. Our findings show that MA significantly ($p < 0.05$) affect occupants' perception as well as physiological response, which encouragingly correlate with occupants' perception. Our findings is a first step towards personalized control of the ambient atmosphere to support wellbeing and productivity.</p>
<p>Improving Stress Management and Sleep Hygiene in Intelligent Homes</p>	<p>2021</p>	<p>Asterios Leonidis, Maria Korozi, Eirini Sykianaki, Eleni Tsolakou, Vasilios Kouroumalis, Danai Ioannidis, Andreas Stavridakis, Margherita Antona and Constantine Stephanidis</p>	<p>ambient intelligence; smart home; stress management; sleep hygiene; sleep monitoring; contextual awareness</p>	<p>High stress levels and sleep deprivation may cause several mental or physical health issues, such as depression, impaired memory, decreased motivation, obesity, etc. The COVID-19 pandemic has produced unprecedented changes in our lives, generating significant stress, and worries about health, social isolation, employment, and finances. To this end, nowadays more than ever, it is crucial to deliver solutions that can help people to manage and control their stress, as well as to reduce sleep disturbances, so as to improve their health and overall quality of life. Technology, and in particular Ambient Intelligence Environments, can help towards that direction, when considering that they are able to understand the needs of their users, identify their behavior, learn their preferences, and act and react in their interest. This work presents two systems that have been designed and developed in the context of an Intelligent Home, namely CaLmi and HypnOS, which aim to assist users that struggle with stress and poor sleep quality, respectively. Both of the systems rely on real-time data collected by wearable devices, as well as contextual information retrieved from the ambient facilities of the Intelligent Home, so as to offer appropriate pervasive relaxation programs (CaLmi) or provide personalized insights regarding sleep hygiene (HypnOS) to the residents. This article will describe the design process that was followed, the functionality of both systems, the results of the user studies that were conducted</p>

				for the evaluation of their end-user applications, and a discussion about future plans.
Humans-as-a-Sensor for Buildings— Intensive Longitudinal Indoor Comfort Models	2020	Prageeth Jayathissa, Matias Quintana , Mahmoud Abdelrahman and Clayton Miller	indoor environmental quality; thermal comfort models; personalised comfort model; machine learning; ecological momentary assessment; occupant behaviour	Evaluating and optimising human comfort within the built environment is challenging due to the large number of physiological, psychological, and environmental variables that affect occupant comfort preference. Human perception could be helpful to capture these disparate phenomena and interpreting their impact; the challenge is collecting spatially and temporally diverse subjective feedback in a scalable way. This paper presents a methodology to collect intensive longitudinal subjective feedback of comfort-based preference using micro ecological momentary assessments on a smartwatch platform. An experiment with 30 occupants over two weeks produced 4378 field-based surveys for thermal, noise, and acoustic preference. The occupants and the spaces in which they left feedback were then clustered according to these preference tendencies. These groups were used to create different feature sets with combinations of environmental and physiological variables, for use in a multi-class classification task. These classification models were trained on a feature set that was developed from time-series attributes, environmental and near-body sensors, heart rate, and the historical preferences of both the individual and the comfort group assigned. The most accurate model had multi-class classification F1 micro scores of 64%, 80% and 86% for thermal, light, and noise preference, respectively. The discussion outlines how these models can enhance comfort preference prediction when supplementing data from installed sensors. The approach presented prompts reflection on how the building analysis community evaluates, controls, and designs indoor environments through balancing the measurement of variables with occupant preferences in an intensive longitudinal way.
EdenApp Thermal Comfort: An mobile app for measuring personal thermal comfort	2017	Yiqiang Zhao, Ola Uduku and Dave Murray-Rust	personal thermal comfort recording, Thermal sensation, Adaptive model, PMV	Currently, many researchers focus on how to apply Predicted Mean Vote (PMV) and Adaptive Comfort (AC) models to different climatic zones and types of buildings to study how specific environmental elements or forms of behaviour influence participant's thermal choice. However, most of the studies focus on modelling thermal comfort which was based on average group data statistics and did not localise the thermal difference at individual levels. In addition, expensive professional sensors and closed source data collection tools increased the difficulty for new researchers to develop customized long-term personal data collection systems. As a result, we developed EdenApp-Thermal Comfort, an open-source mobile app which can record participants' individualised thermal comfort responses and local environmental data. These forms of personalised data can be uploaded onto the EdenApp server and used for further research into individual and group thermal comfort analysis. This paper discusses the significant benefits of modelling personal thermal comfort, when compared with traditional methods. It also describes the newly formed EdenApp data collection platform and its use for a pilot study on recording personal thermal comfort amongst students.

CoBi: Bio-Sensing Building Mechanical System Controls for Sustainably Enhancing Individual Thermal Comfort	2010	Joon Ho Choi		<p>Current existing thermal control systems are operated based on thermal comfort models generated by regression formulas averaging the thermal responses over data collected during extensive experiments involving panels of human subjects. These models may not be appropriate for an individual whose physiological characteristics happen to be located outside of the main stream from the experimental sample of occupants. By necessity, existing automatic control systems disregard individual characteristics such as health, age, gender, body mass, etc., which may affect physiological responses. Thereby these systems have serious limitations in ensuring individual thermal satisfaction.</p> <p>While there have been many efforts to overcome the limitations of current technology and to improve individualized control, most of the attempts to make smart controllers for buildings have dealt primarily with optimizing mechanical building components to deliver uniform conditions, largely ignoring whether a generated thermal environment by building systems meet actual users' comfort and satisfaction. Over-cooling and over-heating are common unnecessary results. Thermal control innovations for building mechanical systems are critically needed to demonstrate that meeting the physiological needs of occupants can actually save energy and improve environmental quality while enhancing user satisfaction.</p> <p>The thermoregulation of the human body has a biological mechanism, homeostasis, which enables it to maintain a stable and constant body temperature by changing physiological signals including skin temperatures and heart rate. These signal patterns have the potential to provide information about each individual's current thermal sensation.</p>
Artificial Intelligence for Efficient Thermal Comfort Systems: Requirements, Current Applications and Future Directions	2020	Ali Ghahramani, Parson Galicia, David Lehrer, Zubin Varghese, Zhe Wang and Yogesh Pandit	machine learning, personal thermal comfort, data mining, human building interactions, buildings energy efficiency, intelligent personal comfort systems	<p>In buildings, one or a combination of systems (e.g., central HVAC system, ceiling fan, desk fan, personal heater, and foot warmer) are often responsible for providing thermal comfort to the occupants. While thermal comfort has been shown to differ from person to person and vary over time, these systems are often operated based on prefixed setpoints and schedule of operations or at the request/routine of each individual. This leads to occupants' discomfort and energy wastes. To enable the improvements in both comfort and energy efficiency autonomously, in this paper, we describe the necessity of an integrated system of sensors (e.g., wearable sensors/infrared sensors), infrastructure for enabling system interoperability, learning and control algorithms, and actuators (e.g., HVAC system setpoints, ceiling fans) to work under a governing central intelligent system. To assist readers with little to no exposure to artificial intelligence (AI), we describe the fundamentals of an intelligent entity (rational agent) and components of its problem-solving process (i.e., search algorithms, logic inference, and machine learning) and provide examples from the literature. We then discuss the current application of intelligent personal thermal comfort systems in buildings based on a comprehensive review of the literature. We finally describe future directions for enabling application of fully automated systems to provide comfort in an efficient manner. It is apparent that improvements in all aspects of an intelligent system are needed to better ascertain the correct combination of systems to activate and for how long to increase the overall efficiency of the system and improve comfort.</p>
An IoT Framework for Modeling and Controlling Thermal Comfort in Buildings	2019	Fadi Alsaleem, Mehari K. Tesfay, Mostafa Rafaie, Kevin Sinkar, Dhaman Besarla and Parthiban Arunasalam	machine learning, comfort, HVAC, wearable devices, galvanic skin response, private model, PMV	<p>Humans spend more than 90% of their day in buildings, where their health and productivity are demonstrably linked to thermal comfort. Building thermal comfort systems account for the largest share of U.S energy consumption. Despite this high-energy cost, due to building design complexity and the variety of building occupant needs, addressing thermal comfort in buildings remains a difficult problem. To overcome this challenge, this paper presents an Internet of Things (IoT) approach to efficiently model and control comfort in buildings. In the model phase, a method to access and exploit wearable device data to build a personal thermal comfort model has been presented. Various supervised machine-learning algorithms are evaluated to produce accurate personal thermal comfort models for each building occupant that exhibit superior performance compared to a general model for all occupants. The developed comfort models were used to simulate an intelligent comfort controller that uses the particle swarm optimization(PSO) method to search for optimal control parameter values to achieve maximum comfort. Finally, a framework for experimental validation of the new proposed comfort controller that interactively works with the HVAC element has been introduced.</p>

Workplace productivity and individual thermal satisfaction	2015	Shin-ichi Tanabe, Masaoki Haneda, Noe Nishihara	Thermal satisfaction Office work performance Workplace productivity Summer season	This study examines the relationship between individual thermal satisfaction and worker performance. Field measurements and a questionnaire survey were conducted within an organization participating in the COOL BIZ energy conservation campaign. A subjective experiment was also conducted in a climate chamber with eleven Japanese male subjects, testing five scenarios combining operative temperature (25.5 C and 28.5 C), clothing (with and without suits), and cooling items (desk fan, air-conditioned shirt, mesh office chair). From the individual analysis, actual air temperature in the COOL BIZ office was poorly correlated with self-estimated performance, whereas perceived thermal satisfaction correlated well with self-estimated performance ($R^2 \text{ } 1/4 \text{ } 0.944$, $p < 0.001$). The results of the subjective experiment indicate that performance during simulated office work (i.e. multiplication and proof reading tasks) increased with greater individual thermal satisfaction ($R^2 \text{ } 1/4 \text{ } 0.403$ and 0.464 , $p < 0.001$). The finding that perceived thermal satisfaction of occupants is reflected in objective measurement of office work performance has practical implications for the evaluation of thermal satisfaction in real offices as a means to boost workplace productivity.
Thermal Comfort - Based Personalized Models with Non-Intrusive Sensing Technique in Office Buildings	2019	Siliang Lu, Weilong Wang, Shihan Wang, Erika Cochran Hameen	adaptive thermal comfort; infrared thermography; support vector machine; random forest; intelligent workplace	Heating, ventilation, and air-conditioning (HVAC) systems play a key role in shaping the built environment. However, centralized HVAC systems cannot guarantee the provision of a comfortable thermal environment for everyone. Therefore, a personalized HVAC system that aims to adapt thermal preferences has drawn much more attention. Meanwhile, occupant-related factors like skin temperature have not had standardized measurement methods. Therefore, this paper proposes to use infrared thermography to develop individual thermal models to predict thermal sensations using three different feature sets with the random forest (RF) and support vector machine (SVM). The results have shown the correlation coefficients between clothing surface temperature and thermal sensation are 11% and 3% higher than those between skin temperature and thermal sensation of two subjects, respectively. With cross-validation, SVM with a linear kernel and penalty number of 1, as well as RF with 50 trees and the maximum tree depth of 3 were selected as the model configurations. As a result, the model trained with the feature set, consisting of indoor air temperature, relative humidity, skin temperature and clothing surface temperature, and with linear kernel SVM has achieved 100% recall score on test data of female subjects and 95% recall score on that of male subjects.
Personalized conditioning and its impact on thermal comfort and energy performance – A review	2014	Michal Vesely, Wim Zeiler	Cooling Energy performance Heating Personalized conditioning Task ambient conditioning Thermal comfort	The building industry nowadays is facing two major challenges – the increased concern for energy reduction and the growing need for comfort improvements. These challenges have led many researchers to develop a personalized conditioning system. Personalized conditioning aims to create a microclimate zone around a single workplace. In this way the energy is deployed only where it is actually needed, and the individual needs for thermal comfort are fulfilled. In recent years personalized conditioning has received a lot of attention in research publications. This paper reviews the impact of different personalized conditioning systems on thermal comfort and building energy performance. In the reviewed publications, it was demonstrated that thermal comfort can be well maintained at ambient temperatures that are 4–5 K higher as well as lower than the temperatures recommended by current standards. Personalized conditioning also allows reduction in energy consumption due to an increased cooling setpoint, a decreased heating setpoint, or a decreased ventilation rate of the background system. Energy simulations show that reductions of up to 60% can be achieved.
Continuous Stress Detection Using Wearable Sensors in Real Life: Algorithmic Programming Contest, Case Study	2019	Yekta Said Can, Niaz Chalabianloo, Deniz Ekiz and Cem Ersoy	stress recognition; machine learning; wearable sensors; smartwatch; photoplethysmography ; electrodermal activity; daily life psychophysiological data; heart rate variability	The negative effects of mental stress on human health has been known for decades. High-level stress must be detected at early stages to prevent these negative effects. After the emergence of wearable devices that could be part of our lives, researchers have started detecting extreme stress of individuals with them during daily routines. Initial experiments were performed in laboratory environments and recently a number of works took a step outside the laboratory environment to the real-life. We developed an automatic stress detection system using physiological signals obtained from unobtrusive smart wearable devices which can be carried during the daily life routines of individuals. This system has modality-specific artifact removal and feature extraction methods for real-life conditions. We further tested our system in a real-life setting with collected physiological data from 21 participants of an algorithmic programming contest for nine days. This event had lectures, contests as well as free time. By using heart activity, skin conductance and accelerometer signals, we successfully discriminated contest stress, relatively higher cognitive load (lecture) and relaxed time activities by using different machine learning methods.

An Empirical Study Comparing Unobtrusive Physiological Sensors for Stress Detection in Computer Work	2019	Fatema Akbar , Gloria Mark, Ioannis Pavlidis and Ricardo Gutierrez-Osuna	stress; physiology; wearables; unobtrusive sensors; thermal imaging; human- computer interaction; EDA; PPG; ECG	Abstract: Several unobtrusive sensors have been tested in studies to capture physiological reactions to stress in workplace settings. Lab studies tend to focus on assessing sensors during a specific computer task, while in situ studies tend to offer a generalized view of sensors' efficacy for workplace stress monitoring, without discriminating different tasks. Given the variation in workplace computer activities, this study investigates the efficacy of unobtrusive sensors for stress measurement across a variety of tasks. We present a comparison of five physiological measurements obtained in a lab experiment, where participants completed six different computer tasks, while we measured their stress levels using a chest-band (ECG, respiration), a wristband (PPG and EDA), and an emerging thermal imaging method (perinasal perspiration). We found that thermal imaging can detect increased stress for most participants across all tasks, while wrist and chest sensors were less generalizable across tasks and participants. We summarize the costs and benefits of each sensor stream, and show how some computer use scenarios present usability and reliability challenges for stress monitoring with certain physiological sensors. We provide recommendations for researchers and system builders for measuring stress with physiological sensors during workplace computer use.
Detecting work stress in offices by combining unobtrusive sensors	2016	Saskia Koldijk · Mark A. Neerincx · Wessel Kraaij	Machine learning · mental state inference · stress · individual differences · computer logging · facial expressions · posture · physiology	Employees often report the experience of stress at work. In the SWELL project we investigate how new context aware pervasive systems can support knowledge workers to diminish stress. The focus of this paper is on developing automatic classifiers to infer working conditions and stress related mental states from a multimodal set of sensor data (computer logging, facial expressions, posture, and physiology). We address two methodological and applied machine learning challenges: 1) Detecting work stress using several (physically) unobtrusive sensors, and 2) Taking into account individual differences. A comparison of several classification approaches showed that, for our SWELL-KW dataset, neutral and stressful working conditions can be distinguished with 90% accuracy by means of SVM. Posture yields most valuable information, followed by facial expressions. Furthermore, we found that the subjective variable 'mental effort' can be better predicted from sensor data than e.g. 'perceived stress'. A comparison of several regression approaches showed that mental effort can be predicted best by a decision tree (correlation of 0.82). Facial expressions yield most valuable information, followed by posture. We find that especially for estimating mental states it makes sense to address individual differences. When we train models on particular subgroups of similar users, (in almost all cases) a specialized model performs equally well or better than a generic model.
Emotional & physical stress detection and classification using thermal imaging technique		Peter Yuen, Kan Hong, Tong Chen, Aristeidis Tsitiridis, F Kam, James Jackman, David James, Mark Richardson, L Williams, William Oxford, Jonathan Piper, Francis Thomas & Stafford Lightman	remote sensing of intent, stress detection, thermal imaging, thermal signatures of stress, stress classifications	This paper reports how Electro-Optics (EO) technologies such as thermal and hyperspectral [1-3] imaging methods can be used for the detection of stress remotely. Emotional or physical stresses induce a surge of adrenaline in the blood stream under the command of the sympathetic nerve system, which, cannot be suppressed by training. The onset of this alleviated level of adrenaline triggers a number of physiological chain reactions in the body, such as dilation of pupil and an increased feed of blood to muscles etc. The capture of physiological responses, specifically the increase of blood volume to pupil, have been reported by Pavlidis's pioneer thermal imaging work [4-7] who has shown a remarkable increase of skin temperature in the periorbital region at the onset of stress. Our data has shown that other areas such as the forehead, neck and cheek also exhibit alleviated skin temperatures dependent on the types of stressors. Our result has also observed very similar thermal patterns due to physical exercising, to the one that induced by other physical stressors, apparently in contradiction to Pavlidis's work [8]. Furthermore, we have found patches of alleviated temperature regions in the forehead forming patterns characteristic to the types of stressors, dependent on whether they are physical or emotional in origin. These stress induced thermal patterns have been seen to be quite distinct to the one resulting from having high fever.
Enabling Technologies for the Internet of Health Things	2017	Joel J. P. C. Rodrigues, Senior Member, IEEE, Dante B. R. Segundo, Heres A. Junqueira, Murilo H. Sabino, Rafael M. Prince, Jalal	Ambient Assisted Living, Internet of Things, Internet of Health Things, Mobile Health, Remote Healthcare Monitoring, Wearable.	The Internet of Things (IoT) is one of the most promising technologies for the near future. Healthcare and well-being will receive great benefits with the evolution of this technology. This work presents a review of techniques based on IoT for healthcare and ambient assisted living, defined as the Internet of Health Things (IoHT), based on the most recent publications and products available in the market from industry for this segment. Also, this work identifies the technological advances made so far, analyzing the challenges to be overcome and provides an approach of future trends. Though selected works, it is possible notice that further studies are important to improve current techniques and that novel concept and technologies of Internet of Health Things are needed to overcome the identified challenges. The presented results aim to serve as a source of information for

		Al-Muhtadi, and Victor Hugo C. de Albuquerque		healthcare providers, researchers, technology specialists, and the general population to improve the Internet of Health Things.
Human Acute Stress Detection via Integration of Physiological Signals and Thermal Imaging	2016	Mohamed Abouelenien, Mihai Burzo, Rada Mihalcea	acute stress; thermal ; physiological; modality	Daily pressure, work load, and family responsibilities among other factors impose increasing levels of stress on different individuals. Hence, detecting stress as early as possible can potentially reduce the severe consequences and risks that someone may experience. In this paper, we develop a novel dataset to detect acute stress using 50 subjects. We additionally analyze different features extracted automatically from the thermal and physiological modalities. Furthermore, we develop a system that integrates both thermal and physiological features for improved stress detection rates. Our system achieves promising results exceeding 75% accuracy and has the potential to be further improved by adding additional modalities, which can provide a useful and reliable approach in early detection of stress.
Unobtrusive stress detection on the basis of smartphone usage data	2017	Elena Vildjiounaite & Johanna Kallio & Vesa Kyllönen & Mikko Nieminen & Ilmari Määttä & Mikko Lindholm & Jani Mäntyjärvi & Georgy Gimel'far	Mobile phone data analysis. Stress detection. Personalisation · Unsupervised learning. Hidden Markov models	Stress has become an important health problem, but existing stress detectors are inconvenient in long-term real-life use because users either have to wear dedicated devices or expend notable interaction efforts in system adaptation to specifics of each person. Adaptation is necessary because individuals significantly differ in their perception of stress and stress responses, but typical adaptation employs supervised learning methods and hence requires fairly large sets of labelled data (i.e. information on whether each reporting period was stressful or not) from every user. To address these problems, we propose a novel unsupervised stress detector, based on using a smartphone as the only device and using discrete hidden Markov models (HMM) with maximum posterior marginal (MPM) decisions for analysis of phone data. Our detector requires neither additional hardware nor data labelling and hence is truly unobtrusive and suitable for lifelong use. Its accuracy was evaluated using two real-life datasets: in the first case, adaptation was based on very short (a few days) phone interaction histories of each individual, and in the second case—on longer histories. In these tests, the proposed HMM-MPM achieved 59 and 70% accuracies, respectively, which is comparable with results of fully supervised methods, reported by other works.
Towards an automatic early stress recognition system for office environments based on multimodal measurements: A review	2016	Ane Alberdi, Asier Aztiria, Adrian Basarab	Stress, Early detection, Multimodality, Behaviour, Physiology	Stress is a major problem of our society, as it is the cause of many health problems and huge economic losses in companies. Continuous high mental workloads and non-stop technological development, which leads to constant change and need for adaptation, makes the problem increasingly serious for office workers. To prevent stress from becoming chronic and provoking irreversible damages, it is necessary to detect it in its early stages. Unfortunately, an automatic, continuous, and unobtrusive early stress detection method does not exist yet. The multimodal nature of stress and the research conducted in this area suggest that the developed method will depend on several modalities. Thus, this work reviews and brings together the recent works carried out in the automatic stress detection looking over the measurements executed along the three main modalities, namely, psychological, physiological, and behavioural modalities, along with contextual measurements, in order to give hints about the most appropriate techniques to be used and thereby, to facilitate the development of such a holistic system.

Thermal spatio-temporal data for stress recognition	2014	Nandita Sharma, Abhinav Dhall Tom Gedeon and Roland Goecke	Stress classification; Temporal stress; Thermal imaging; Support vector machines; Genetic algorithms; Watching films	Stress is a serious concern facing our world today, motivating the development of a better objective understanding through the use of non-intrusive means for stress recognition by reducing restrictions to natural human behavior. As an initial step in computer vision-based stress detection, this paper proposes a temporal thermal spectrum (TS) and visible spectrum (VS) video database ANUStressDB - a major contribution to stress research. The database contains videos of 35 subjects watching stressed and not-stressed film clips validated by the subjects. We present the experiment and the process conducted to acquire videos of subjects' faces while they watched the films for the ANUStressDB. Further, a baseline model based on computing local binary patterns on three orthogonal planes (LBP-TOP) descriptor on VS and TS videos for stress detection is presented. A LBP-TOP-inspired descriptor was used to capture dynamic thermal patterns in histograms (HDTP) which exploited spatio-temporal characteristics in TS videos. Support vector machines were used for our stress detection model. A genetic algorithm was used to select salient facial block divisions for stress classification and to determine whether certain regions of the face of subjects showed better stress patterns. Results showed that a fusion of facial patterns from VS and TS videos produced statistically significantly better stress recognition rates than patterns from VS or TS videos used in isolation. Moreover, the genetic algorithm selection method led to statistically significantly better stress detection rates than classifiers that used all the facial block divisions. In addition, the best stress recognition rate was obtained from HDTP features fused with LBP-TOP features for TS and VS videos using a hybrid of a genetic algorithm and a support vector machine stress detection model. The model produced an accuracy of 86%.
A Presence-Based Context-Aware Chronic Stress Recognition System	2012	Klemen Peternel, Matevž Pogačnik, Rudi Tavčar and Andrej Kos	presence; chronic stress; context awareness; embedded sensors; Hidden Markov models; health monitoring	Stressors encountered in daily life may play an important role in personal well-being. Chronic stress can have a serious long-term impact on our physical as well as our psychological health, due to ongoing increased levels of the chemicals released in the 'fight or flight' response. The currently available stress assessment methods are usually not suitable for daily chronic stress measurement. The paper presents a context-aware chronic stress recognition system that addresses this problem. The proposed system obtains contextual data from various mobile sensors and other external sources in order to calculate the impact of ongoing stress. By identifying and visualizing ongoing stress situations of an individual user, he/she is able to modify his/her behavior in order to successfully avoid them. Clinical evaluation of the proposed methodology has been made in parallel by using electrodermal activity sensor. To the best of our knowledge, the system presented herein is the first one that enables recognition of chronic stress situations on the basis of user context.
Review on psychological stress detection using biosignals		Giorgos Giannakakis, Member, IEEE, Dimitris Grigoriadis, Katerina Giannakaki, Olympia Simantiraki, Alexandros Roniotis and Manolis Tsiknakis, Member	stress, biosignals, physiological measures, EEG, ECG, EDA, HRV, stress response	This review investigates the effects of psychological stress on the human body measured through biosignals. When a potentially threatening stimulus is perceived, a cascade of physiological processes occurs mobilizing the body and nervous system to confront the imminent threat and ensure effective adaptation. Biosignals that can be measured reliably in relation to such stressors include physiological (EEG, ECG, EDA, EMG) and physical measures (respiratory rate, speech, skin temperature, pupil size, eye activity). A fundamental objective in this area of psychophysiological research is to establish reliable biosignal indices that reveal the underlying physiological mechanisms of the stress response. Motivated by the lack of comprehensive guidelines on the relationship between the multitude of biosignal features used in the literature and their corresponding behaviour during stress, in this paper, the impact of stress to multiple bodily responses is surveyed. Emphasis is put on the efficiency, robustness, and consistency of biosignal data features across the current state of knowledge in stress detection. It is also explored multimodal biosignal analysis and modelling methods for deriving accurate stress correlates. This paper aims to provide a comprehensive review on biosignal patterns caused during stress conditions and reliable practical guidelines towards more efficient detection of stress.

Remote heart rate monitoring - Assessment of the Facereader rPPG by Noldus	2019	Simone Benedetto, Christian Caldato, Darren C. Greenwood, Nicola Bartoli ¹ , Virginia Pensabene, Paolo Actis		Remote photoplethysmography (rPPG) allows contactless monitoring of human cardiac activity through a video camera. In this study, we assessed the accuracy and precision for heart rate measurements of the only consumer product available on the market, namely the Facereader TM rPPG by Noldus, with respect to a gold standard electrocardiograph. Twenty- four healthy participants were asked to sit in front of a computer screen and alternate two periods of rest with two stress tests (i.e. Go/No-Go task), while their heart rate was simultaneously acquired for 20 minutes using the ECG criterion measure and the Facereader TM rPPG. Results show that the Facereader TM rPPG tends to overestimate lower heart rates and underestimate higher heart rates compared to the ECG. The Facereader TM rPPG revealed a mean bias of 9.8 bpm, the 95% limits of agreement (LoA) ranged from almost -30 up to +50 bpm. These results suggest that whilst the rPPG Facereader TM technology has potential for contactless heart rate monitoring, its predictions are inaccurate for higher heart rates, with unacceptable precision across the entire range, rendering its estimates unreliable for monitoring individuals.
One-Lead Electrocardiogram for Biometric Authentication using Time Series Analysis and Support Vector Machine	2019	Sugondo Hadiyoso, Suci Aulia, Achmad Rizal	ECG; biometric; Hjorth; sample entropy; SVM	In this research, a person identification system has been simulated using electrocardiogram (ECG) signals as biometrics. Ten adult people were participated as the subjects in this research taken from their signal ECG using the one-lead ECG machine. A total of 65 raw ECG waves from the 10 subjects were analyzed. This raw signal is then processed using the Hjorth Descriptor and Sample Entropy (SampEn) to get the signal features. Support Vector Machine (SVM) algorithm was used as the classifier for the subject authentication based upon the record of ECG signal. The results of the research showed that the highest accuracy value of 93.8% was found in Hjorth Descriptor. Compared to SampEn, this method is quite promising to be implemented for having a good performance and fewer features.
Thermal imaging to detect physiological indicators of stress in humans	2013	Carl B. Cross, Julie A. Skipper, Douglas T. Petkie	thermal imaging, stress detection, physiological monitoring, stand-off detection, image processing	Real-time, stand-off sensing of human subjects to detect emotional state would be valuable in many defense, security and medical scenarios. We are developing a multimodal sensor platform that incorporates high-resolution electro-optical and mid-wave infrared (MWIR) cameras and a millimeter-wave radar system to identify individuals who are psychologically stressed. Recent experiments have aimed to: 1) assess responses to physical versus psychological stressors; 2) examine the impact of topical skin products on thermal signatures; and 3) evaluate the fidelity of vital signs extracted from thermal imagery and radar signatures. Registered image and sensor data were collected as subjects (n=32) performed mental and physical tasks. In each image, the face was segmented into 29 non-overlapping segments based on fiducial points automatically output by our facial feature tracker. Image features were defined that facilitated discrimination between psychological and physical stress states. To test the ability to intentionally mask thermal responses indicative of anxiety or fear, subjects applied one of four topical skin products to one half of their face before performing tasks. Finally, we evaluated the performance of two non-contact techniques to detect respiration and heart rate: chest displacement extracted from the radar signal and temperature fluctuations at the nose tip and regions near superficial arteries to detect respiration and heart rates, respectively, extracted from the MWIR imagery. Our results are very satisfactory: classification of physical versus psychological stressors is repeatedly greater than 90%, thermal masking was almost always ineffective, and accurate heart and respiration rates are detectable in both thermal and radar signatures.
Wearable Physiological Sensors Reflect Mental Stress State in Office-Like Situations	2013	Jacqueline Wijnsman, Bernard Grundlehner, Hermie Hermens		Timely mental stress detection can help to prevent stress-related health problems. The aim of this study was to identify those physiological signals and features suitable for detecting mental stress in office-like situations. Electrocardiogram (ECG), respiration, skin conductance and surface electromyogram (sEMG) of the upper trapezius muscle were measured with a wearable system during three distinctive stress tests. The protocol contained stress tests that were designed to represent office-like situations. Generalized Estimating Equations were used to classify the data into rest and stress conditions. We reached an average classification rate of 74.5%. This approach may be used for continuous stress measurement in daily office life to detect mental stress at an early stage.

Appendix B — Literature review criteria

Table 6. Study Sources and Results

Operations	Search strings 2000-2020	Google Scholar	Science Direct	IEEEXplore
All in title	Allintitle: personalized smart workplace environment	0	0	0
	allintitle: smart workplace well-being	1	0	0
	allintitle: thermal comfort workplace	25	4	1
	allintitle: personalized thermal comfort	104	26	8
	allintitle: indoor environmental stressors	2	3	0
	allintitle: human stress detection	88	6	15
	allintitle: personal thermal model sensors	0	1	0
Anywhere in the article	smart workplace environment OR "personalized workplace"	63	1	887
	smart workplace OR wellbeing OR "personalized workplace"	27	130	82
	smart workplace OR indoor environment OR "personalized workplace"	59	198	174
	smart workplace OR wellbeing OR "stress detection"	582	105	57

	personalized workplace OR wellbeing OR "stress detection"	627	82	37
	personalized smart workplace OR "indoor environment"	2370	198	170
	personalized thermal comfort OR "smart workplace"	45	97	69
Total:		3993	771	1500

Appendix C — Online Questionnaire

1. Age

- 18-24
- 25-34
- 35-44
- 45-54
- 55-64
- 65 or older
- Prefer not to answer

2. Gender

- Male
- Female
- Other

3. Which best describes your workplace?

- Home office
- Private room office
- Co-working space
- Open space / hot-desking
- Cubicle space
- Open space / desk sharing
- Open space / fixed desk
- None of the above

4. How do you feel about lighting on the desk for pre-based tasks (reading & writing)?

- | | | | | | | |
|--------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|-----------|
| Very | 1 | 2 | 3 | 4 | 5 | Very |
| Dissatisfied | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | Satisfied |

5. How do you feel about the overall air quality in your work area?

Very	1	2	3	4	5	Very
Dissatisfied	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Satisfied

6. How do you feel about the odors in your work area?

Very	1	2	3	4	5	Very
Dissatisfied	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Satisfied

7. How do you feel about the temperature in your work area?

Very	1	2	3	4	5	Very
Dissatisfied	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Satisfied

8. Temperature in your work area during the Winter?

- Cold
- Cool
- Neutral
- Warm
- Hot

9. Temperature in your work area during the Summer?

- Cold
- Cool
- Neutral
- Warm
- Hot

10. How do you feel about the amount of noise from other people's conversations while you are at your workplace?

Very Dissatisfied 1 2 3 4 5 Very Satisfied

11. How do you feel about the amount of noise from mechanical or office equipment you hear at your workplace?

Very Dissatisfied 1 2 3 4 5 Very Satisfied

12. How do you feel about the air movement in your work area?

Very Dissatisfied 1 2 3 4 5 Very Satisfied

13. If dissatisfied, what are the current air movement conditions?

- Stuffy
- Drafty
- Both
- N/A

14. Rank from 1 to 7 what should be improved to support your well-being at work. 1st is the most important and 7th is the at least important.

	1	2	3	4	5	6	7
Temperature	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Noise	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Air Movement	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Window Access	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Lighting	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Privacy	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Workplace Aesthetic	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

15. Do you feel stressed at work?

- Extremely often
- Very often
- Moderately often
- Slightly often
- Not at all

16. What will you do when you feel stressed?

17. What are your needs when you are under high stress?

18. Do you use any methods to relieve your stress?

19. Do you use mobile apps for stress relief?

20. What kind of design style do you like the most in the stress relief app?

21. Do you feel that the workplace environment affects your well-being?

- Yes
- No
- Maybe

22. Would you like to work in a safe and healthy workplace environment?

- Yes
- No
- Maybe

Appendix D — Card Sorting Online Questionnaire

Card Sorting Questionnaire – Reverse category description survey

1. Which of the following categories would you go on first to *edit your preferences*?

- Dashboard
- Building
- Places
- Your profile
- Help center

2. Which of the following categories would you go on first to *book meeting room*?

- Building
- Home
- Dashboard
- Places
- Access

3. Which of the following categories would you go on first to *check the temperature at your workplace*?

- Heatmap
- Sensors
- Panel control
- Dashboard
- Places

4. Which of the following categories would you go on first to *find the bathrooms*?

- Access

- Indoor navigation
- Dashboard
- Find facilities
- Search

5. Which of the following categories would you go on first to *view the floor occupancy*?

- Panel control
- Sensors
- Indoor navigation
- Reports & analytics
- Access

6. During the test did you have any difficulty to understand the terms of the category?

7. Have you used a similar application before?

8. What was your overall impression about this experience?

Appendix E — Expert Review Test

Introduction

Welcome, you have been invited to participate in a usability test as a part of a master's research of designing the mobile application for the personalized smart workplace environment. The system that you will test is called CalmSmart, the study aims to evaluate the low-fidelity prototype of the application. The system is capable of monitoring and processing the indoor workplace environment (such as temperature, humidity, lighting, air quality, and air velocity), and predicting stress by measuring the physiological signals (heart rate, skin temperature, activity) of the occupants by using biometric sensors. You will be asked to perform certain tasks on a computer and later fill the survey regarding the tasks you performed.

Your contribution is fundamental to this study, as we can explore new solutions to improve the usability and interaction of the system and promote a healthier workplace environment.

Consent Form: Remote Usability Test

Please read and sign this form.

During this usability test, I agree to participate in an online session using my computer. During the session, I will be interviewed about the site, asked to find information or complete tasks using the site, and asked to complete an online questionnaire about the experience.

I understand that the information and recording are for research purposes only and that my name and image will not be used for any other purpose. I understand that participation is voluntary, and I agree to immediately raise any concerns I might have.

If you have any questions after today, please contact Galina Dzhambinova at galina.dnova@gmail.com

Please sign below to indicate you have read and understand the information on this form and that any questions you might have about the session have been answered.

Please sign your name: _____

Date: _____

Task Test:

T1— Go through the onboarding process and complete the registration form.

<https://www.figma.com/proto/cjK7R6q68WlUx4SDBiZk2p/Low-Fidelity---Task-1?page-id=0%3A1&node-id=2%3A517&viewport=241%2C48%2C0.25&scaling=scale-down&starting-point-node-id=2%3A517&show-proto-sidebar=1>

T2 — Go and check your Health status, and find your body activity.

<https://www.figma.com/proto/ID8UceYck8eq9vyewWqF9t/Low-Fidelity---Task-2?page-id=0%3A1&node-id=1%3A50&viewport=241%2C48%2C0.5&scaling=scale-down&starting-point-node-id=1%3A50>

T3 — Find and book a workplace room so you can work quietly.

<https://www.figma.com/proto/5s7KQ5QMG0w0BZ93JArtlj/Low-Fidelity---Task-3?page-id=0%3A1&node-id=1%3A50&viewport=241%2C48%2C0.5&scaling=scale-down&starting-point-node-id=1%3A50&show-proto-sidebar=1>

T4 — Your health status has changed, find the notifications.

<https://www.figma.com/proto/4PPZalAAc29SD6BTHqdrsI/Low-Fidelity---Task-4?page-id=0%3A1&node-id=1%3A70&viewport=241%2C48%2C0.5&scaling=scale-down&starting-point-node-id=1%3A70>

T5 — View your current workplace temperature and air quality.

<https://www.figma.com/proto/DYWoSqVc4RcHECIXTeoEMH/Low-Fidelity---Task-5?page-id=0%3A1&node-id=1%3A56&viewport=241%2C48%2C0.25&scaling=scale-down&starting-point-node-id=1%3A56>

T6 — [Respond to the following Expert Review Questionnaire.](#)

Appendix F — User Testing

You have been invited to participate in a usability test as a part of a master's research of designing the mobile application for the personalized smart workplace environment.

The system that you will test is called CalmSmart, the study aims to evaluate the high-fidelity prototype of the application. The system is capable of monitoring and processing the indoor workplace environment (such as temperature, humidity, lighting, air quality, and air velocity), and predicting stress by measuring the physiological signals (heart rate, skin temperature, activity) of the occupants by using biometric sensors.

You will be asked to perform certain tasks on a computer and later fill the survey regarding the tasks you performed.

Your contribution is fundamental to this study, as we can explore new solutions to improve the usability and interaction of the system and promote a healthier workplace environment.

Consent Form: Remote Usability Test

Please read and sign this form.

During this usability test, I agree to participate in an online session using my computer. During the session, I will be interviewed about the site, asked to find information or complete tasks using the site, and asked to complete an online questionnaire about the experience.

I understand that the information and recording are for research purposes only and that my name and image will not be used for any other purpose. I understand that participation is voluntary, and I agree to immediately raise any concerns I might have.

If you have any questions after today, please contact Galina Dzhambinova at galina.dnova@gmail.com

Task Test:

T1— Go through the onboarding process and complete the registration form.

<https://www.figma.com/proto/OqYLYKeKAyIWnKKiAS9Ff6/High-Fidelity---Task-1?page-id=0%3A1&node-id=101%3A179&viewport=241%2C48%2C0.16&scaling=scale-down&starting-point-node-id=101%3A179>

T2 — Go and check your Health status, run a diagnosis, and see your body activity.

<https://www.figma.com/proto/4taHa5kUfVc6Daw7wyEVpQ/High-Fidelity---Task-2?page-id=0%3A1&node-id=101%3A138&viewport=241%2C48%2C0.5&scaling=scale-down&starting-point-node-id=101%3A138>

T3 — Go and book a workplace room so you can work quietly.

<https://www.figma.com/proto/Akzep3r3nP5S1q7vrJxsQH/High-Fidelity---Task-3?page-id=0%3A1&node-id=102%3A1247&viewport=241%2C48%2C0.25&scaling=scale-down&starting-point-node-id=102%3A1247&show-proto-sidebar=1>

T4 — On your homepage, you receive two notifications. Find and read about them.

<https://www.figma.com/proto/IxLwAeeAz1DOBUw2Qjrx1p/High-Fidelity---Task-4?page-id=0%3A1&node-id=101%3A211&viewport=241%2C48%2C0.25&scaling=scale-down&starting-point-node-id=101%3A211>

T5 — View your current workplace temperature and air quality.

<https://www.figma.com/proto/r7ayiD69RYhEL3gbOGneh5/High-Fidelity---Task-5?page-id=0%3A1&node-id=101%3A1095&viewport=241%2C48%2C0.13&scaling=scale-down&starting-point-node-id=101%3A1095>

Appendix G — Card Sorting Results

Table 7. Card Sorting Results

Card Name	Category 1 — Login page and welcome screen	Category 2 — My preferences	Category 3 — Places	Category 4 — Dashboard	Category 5 — Building	Category 6 — My profile	Other — Accessibility	Other — Interaction with other	Other — Navigation	Other — Room temperature, air quality...	Other — Room reservation	Other — Top to right corner	Other — Maps and find where	Other — Smart Office	Other — Report / Status	Other — Filter / Search	Other — Booking seat / room	Other — Help	Other — Toolbar / Recommendations	Other — Healthcare	Other — Regulation
"Forgot password?, Log in and Sign Up"	69,2%			7,7%				7,7%										7,7%	7,7%		
"Indoor air temperature (Feeling / preference)", "Indoor air velocity (Feeling / preference)", "My metabolic rate", "Clothing insulation", "Find workplace (Booking the room)", "Find room meeting (Booking the room)", "Find people (Search for colleagues)", "Heatmap (occupancy room and cleanliness visualization)", "Find facilities (WC, lounge area, lockers)", "Search (by a floor, from A to Z, by a name)", "Filter (amenities, capacity room)", "Temperature and Radiant Temperature (adjust and real-time monitoring)", "Humidity (adjust and real-time monitoring)", "Lighting and Brightness (adjust and real-time monitoring)", "Air velocity and Air quality (real-time monitoring)", "Window shades (adjust manually)", "Noise pollution (real-time monitoring)", "Aromas diffuser (Adjust manually)", "Indoor navigation (3D map, wayfinding)", "Reports and Analytics (energy consumption, occupation, capacity)", "en": "Access (parking lot, elevators, rooms, visitors)", "Smart cleaning (air filtration and surface sanitizer)", "Sensors (presence sensor, gesture detection, social distancing sensor, pre-entry wellness check)", "View account and edit account", "Edit my preferences", "Help center (notifications, informations, lost and found, health check)", "Sign out",		53,8%		7,7%	23,1%				7,7%												7,7%
		53,8%		7,7%	23,1%					7,7%											7,7%
				15,4%	61,5%										7,7%					7,7%	
		7,7%	30,8%	7,7%	7,7%		7,7%				7,7%					7,7%	7,7%		7,7%		
		7,7%	30,8%	7,7%	7,7%		7,7%				7,7%					15,4%	7,7%		7,7%		
		7,7%	23,1%	7,7%	7,7%	7,7%		7,7%					7,7%			23,1%	7,7%		7,7%		
	7,7%	7,7%	7,7%	23,1%	30,8%			7,7%		7,7%											7,7%
		7,7%	30,8%		15,4%		7,7%						7,7%			23,1%			7,7%		
	7,7%	7,7%	15,4%	23,1%	38,5%			7,7%			7,7%					23,1%				7,7%	
		7,7%	7,7%	15,4%	38,5%						7,7%					7,7%					7,7%
		15,4%		46,2%	23,1%					7,7%											7,7%
		15,4%	7,7%	46,2%	15,4%					7,7%											7,7%
		15,4%	15,4%	38,5%	15,4%					7,7%											7,7%
	7,7%	15,4%		38,5%	23,1%					7,7%											7,7%
		15,4%	15,4%	30,8%	23,1%					7,7%											7,7%
	7,7%	7,7%		46,2%	23,1%					7,7%				7,7%							7,7%
	7,7%		7,7%	46,2%			7,7%		7,7%				7,7%			7,7%					7,7%
		23,1%	7,7%	23,1%	30,8%									7,7%							7,7%
		15,4%	7,7%	23,1%	30,8%				7,7%					7,7%							7,7%
		7,7%		7,7%	53,8%			7,7%				7,7%						7,7%	7,7%		
		46,2%			23,1%			7,7%				7,7%							7,7%	7,7%	
				23,1%	7,7%	23,1%		7,7%										23,1%		7,7%	
	23,1%			15,4%		30,8%		7,7%					7,7%					7,7%	7,7%		