Measuring Thriving Experience in Physical Working Spaces

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ABSTRACT

The global pandemic has enforced corporations to shift into new working patterns and design upgrades of the physical working space - from packed desks to long-term modifications design, putting well-being at the heart of workplace planning. This paper hypothesises the use of technologies to revolutionise work practices for monitoring the well-being in a physical space. New human-computer interaction approaches can be introduced to measure psychophysical and physical metrics to gauge occupant thriving in indoor office environments. They offer changes to the working environment, e.g. breaks and lighting to enhance productivity and well-being. This research investigates three domains to measure human thriving indoor: (a) methods used in architecture domain to understand the impact of architecture design on human thriving, (b) current approaches in the sensory domain to evaluate human physiological and psychological states, and (c) non-obtrusive methods of psychophysical data collection.

Author Keywords

physical spaces; health and well-being; video-based physiological measurement; emotional responses; psychophysiological measurement; emotional intelligence; deep learning

INTRODUCTION

The forced shift towards creating new working patterns and design upgrades of the physical working space in the COVID-19 global pandemic has unleashed an unprecedented number of concerns. It may well signal the end of the traditional office design. Companies have long dreaded that this forced culture-change will impact adversely upon worker productivity, engagement and health and well-being. The long-term implications for employees and employers remain far-reaching. Whilst many employees signal newfound delight in flexible working, others suffer from a considerable high degree of worry, fear and concerns, affecting their physical and mental health. Meanwhile, some employees cannot or do not want to work from home and require a physical environment that boosts their creativity and productivity while being in surroundings that signal the brand of their chosen employers. Employers are simultaneously expected to provide emotional support and help maintain the well-being of their employees.

Technology has empowered design of physical remote working spaces - from collaboration tools such as Trello to communication applications such as Slack and Microsoft Teams. However, it does not determine the level of social engagement or capturing employees' emotional states. When working with such technologies, employees often choose their verbal and cognitive level of engagement.

The lock-down period has also been recorded to have created a long-term socioeconomic impact and increased the prevalence of mental health issues. COVID-19 has shown pervasive psychological and social effects on individuals and society, setting out well-being and mental health as immediate priorities [28]. Public health responses include providing advice and recommendations to help individuals cope with their emotional struggles [1] [2]. Although fragmented research responses to COVID-19 include estimating the rate of the mortality [6], discussing the public mental health stress caused by the pandemic [46, 44], there is a little attention paid to the practical implementation of psychological intervention activities for people affected by the COVID-19 epidemic and afterwards [20]- requiring radical adjustments to the new office design on how they are operated and what support services should be provided. For the first time, all organisations have been forced to rethink working space completely and put employees' physical and mental health as a priority.

Productivity, creativity and well-being require serendipity - random moments that spark a collaborative human invention, which only a creative physical space can provide [43]. Creative and highly innovative work including research and branding are more likely to be affected by the well-being inside physical spaces. In this position paper, we argue that organisations play a pivotal role in supporting and augmenting the mental health of their employees, but also the design of the indoor environment, even in a post-pandemic scenario will continue to influence worker well-being. Human emotional responses and room design can already be reliably captured from video footage and thus enable measuring of the physiological and

[1] http://www.euro.who.int/en/health-topics/health-emergencies/coronavirus-covid-19/technical-guidance/mental-health-and-covid-19

[2] https://www.nhs.uk/oneyou/every-mind-matters/coronavirus-covid-19-staying-at-home-tips/

psychological states [26]. So far practical applications of such computer vision techniques on psychophysical states have been limited to the automotive industries. For instance when seeking to gauge driver's emotional states and levels of concentration whilst driving.

We propose that emotional monitoring systems in working spaces could similarly augment a new spectrum of effective interactions for workers, informing the individual of their physiological and psychological states and being alerted and warned to signs of emotional states that may adversely affect productivity, concentration and overall mental well-being. It can also offer activity and design related suggestions, e.g. fresh air breaks, colour and lighting to enhance productivity and well-being. Computer vision can assist employers in guiding employees on office working space environmental improvements to reduce adverse effects on emotional states and enhance work environment suitability for selected work tasks. The new proposed system in a post-pandemic scenario could be embedded into the physical office designs. This approach to proposing a solution is grounded in the principles of human centring design thinking of indoor environments and information systems.

In the sections to follow, we first discuss the future workspace design, then state-of-the-art in human-centric design architecture of indoor environments — specifically, the effect of the internal and external determinants that influence human well-being in an indoor environment. We also review the impact upon the architectural design of physical workspaces that may inadvertently influence human psycho-physical thriving. Our proposed conceptual framework to monitor the well-being of employees at physical working space, including the design of physical office indoor spaces, is then presented. Finally, we conclude the paper with subsequent open challenges that need to be addressed and draw future directions for further research to address these challenges.

FUTURE OF WORKSPACE DESIGN: HUMAN EXPERIENCE OF THRIVING

The architectural design of physical workspaces have been identified to have a profound impact on human psychophysiological thriving. Yet, limited empirical studies exist that have measured psychophysiological implications of building design such as [25]. Human experience of thriving inside architecture has been a scientific category of study as early as the 1960s, but impacts of the human brain in this experience has only been recently introduced since early 2000s [34, 11]. More recently, this particular field of research has been coined as neuro-architecture; a nascent empirical field for measuring how the physical environment surrounding humans can modify brains and consequently, behaviour and even foster increase in creativity and productivity [38].

Fich et al. [24] demonstrated and confirmed in a VR environment that in a closed room design (without windows facing nature) occupants respond with a more pronounced stress reaction than participants that were tested in the open room (with windows facing nature). Such findings, albeit in a virtual environment, confirmed existing studies that demonstrated increased view and access to nature compared to urban scenes have a pronounced influence on the human stress [53, 7]. Yet such studies have overlooked other more delicate nuances of design influencing indoor occupancy thriving and emotional responses, namely through biophilia, quality of lighting, and artificial and natural air ventilation quality. The study paid little attention to the emotional influence of organic forms and geometry; symmetry of objects in interior/exterior spaces, spatial alignment in these objects; shape/layout of areas, and contour of objects; symmetrical layouts; smells and sounds.

Ergan et al. [22] argue that four overarching influences impact human experiences: i) restorativeness; ii) stress/anxiety; iii) aesthetics and pleasure; iv) motivation. However, there have been limited empirical data driven studies considering these categories for measuring human psychophysical impact by design features. The emotional impact of physical spaces and occupant well-being is fundamental to understanding the effects on employee productivity and decision making. Seminal work by Kahneman et al. [31] suggest that according to the dual-process theory; emotional process is one of the two fundamental pathways that shape our thoughts and decisions. In a similar vein, such psychophysiological data could be captured and processed to identify emotional states against surrounding indoor design features, to measure well-being and occupant thriving in an indoor environment.

Of the myriad studies examining architectural the influence over worker behaviour, most have been confined to a commercial office environment. Studies on worker productivity and motivation have been limited to utilitarian interior features such as interior colour coding, texture/material of surfaces, ease of access to spaces, and connectivity of space [27, 22]. Empirical studies on office worker productivity have seen limited measurement of physiological data and most importantly, psychophysical (emotional) analysis of such responses.

HUMAN CENTRIC DESIGN: INDOOR OCCUPANCY

Increased indoor occupancy has shaped the design thinking in architecture towards an emphasis on human well-being affected by the internal and external environment. People in Europe [3] and the US are estimated to spent 80–90% of their time indoors [23], a figure which is now deemed conservative in light of the Covid-19 pandemic. This has led to the movement of human-centric building design, explicitly to tackle impacts of the workplace on human well-being. While architects have implemented such standards on human-centric design, together with developers and building owners and indeed employers of new buildings - it has been rarely extended to measure the well-being impact in a working office. In a post-pandemic scenario, the design of the indoor working environment influences worker well-being. Thus, increased understanding of the impact on human emotional well-being from human-made physical spaces can help in addressing the effects of design on occupants physiological stress responses.

[3] https://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2014/combined-or-multiple-exposure-to-health-stressors-in-indoor-built-environments

WELL Building Standard

A quintessential challenge in the design of buildings is the accumulated knowledge gap and environmental inefficiency emerging from ineffective building performance and its impacts on human health and well-being. One notable standard used to bridge this gap is the measurement of human well-being indoors with the building WELL Standard [4]. The WELL building standard consists of 10 KPI [5] categories (Air, Water, Nourishment, Light, Movement, Thermal Comfort, Sound, Materials, Mind and Community) that are used to capture the impact of design on occupant well-being inside physical spaces/ dwellings. These metrics are monitored with various environmental and external parameters (i.e. acoustics, thermal comfort, furnishings, workspace lighting and quality, odours, and air quality concerns). Previous research in the built environment has highlighted the importance of quality design in the workplace and the correlation with organisational performance [2]. Yet, these models of workplace design have been severely disrupted in an era where previously designed 'productivity inducing' office spaces are now becoming obsolete in the face of post-pandemic trend. The typical time–microenvironment–activity (TMA) already used in an empirical context to measure time and activities spent in indoor environments - becoming an integral part of risk assessment. In the current context, it points to a significant increase in personal exposure to harmful indoor environmental air pollutants based on the established correlation with the amount of time spent in an indoor environment [48].

Subjective Well-being (SWB)

Subjective well-being (SWB) is a personal perception that describes the person's positive and negative emotional responses and overall cognitive evaluations complacency with life. In principle, SWB consists of three main components: positive affect (PA) (e.g. happiness, joy) and negative affect (NA) (e.g. sadness, fear and concerns), and life satisfaction - an assessment of the one's whole life (e.g. how happy) [17].

Most recent commercial advances of subjective well-being of the office environment have paved the way for smart environmental control services in office buildings. These services incorporate occupants' lighting and thermal preferences; however, they have all been designed to improve on-going building energy management systems operations to offer reduced energy consumption. The services are also designed for Building Management Systems (BMS) suppliers. They do not necessarily provide the much-needed learning for architects and designers who remain the most disconnected from the real human experience of the spaces they design - most importantly, the psychophysical experiences of their designs. A notable issue (both ethical and functional) with such commercial personalised services in buildings, lies in the confines of occupant privacy debates and the disconnect of knowledge on how building design itself affects human emotional state through changes in psychophysical states.

A human-centric approach for designing buildings has fuelled computerisation of design vision to leverage the strengths of data and machine learning. This has resulted in augmenting the outdated building post-occupancy evaluations which monitor human experiences in spaces and predict building management specific dependencies (e.g. utility cost, environmental control settings and overall building sustenance measures like carbon footprint). The design industries have witnessed unprecedented digitisation of design processes and building connectivity over the last three decades. This is coupled with the built environment sector, contributing to ever-increasing levels of global pollution as demonstrated by its continuous decline in meeting actual building performance and human health and well-being targets. Against this backdrop, the WELL building standard has utility for building owners, designers and occupants to assess the impact of design on human well-being.

The WELL building standard assesses the environmental impact on well-being from two dichotomous groups, namely the internal (directly related to physical space) and external (indirectly related to physical space) elements. These elements have immediate and protracted effects on human health and well-being. Table 1 and Table 2 summarise the internal and external WELL standard features, and their key measurements (i.e. standard threshold values for human wellness).

Internal Impact: Measuring Air, Light, Sound and Biophilia

Many of the internal measures (such as thermal comfort, air, light and sound) used in the building WELL standard would point to the need for SWB measurement of occupants. Personality tends to be a dominant predictor of SWB. Individual level of subjective well-being is influenced by internal factors such as their social relationships and external factors such as community they interact with and society they live in [16]. Accordingly, individuals with high SWB seem to be healthier and productive at work and thereby having a positive effect on people surrounding them, compared to the ones who are stressed and anxious. Studies measuring SWB against the indoor air quality, lighting and thermal comfort sometimes view this as the psychophysical measurement through human physiological responses. Design strategies of WELL building standards play a pivotal role in protecting against the psychological maladjustment based on key internal design features such as thermal comfort, air quality, natural and artificial lighting conditions and soundproofing. These internal design features can be measured unobtrusively - without specialised indoor or body sensors. Our proposed system will only be able to make inferences of impact on air, light, sound, and biophilia through audio and video data.

A plethora of studies have sought to understand the effect of indoor environmental quality (IEQ) measures such as air, sound, light, thermal comfort on occupant well-being [2, 41, 40, 1, 55, 56, 35]. For instance, positive linear correlations have been established empirically between occupant productivity and lighting (proximity to windows); natural ventilation and air (presence of operable windows); thermal comfort (circa. 19-28 degrees Celsius); sufficient artificial lighting levels (light

[4]WELL is a well known tool for advancing health and well-being in buildings globally (https://www.wellcertified.com/certification/v2/)
[5]Key Performance Indicator (KPI)

intensity of > 215 lux at > 0.76 m above the floor); noise level (outside noise intrusion < 50 dBA)[52, 3].

Air Quality

Air quality, both indoor and outdoor, is linked to health impacts as well as emotional responses [3] on productivity and comfort. Built environment field has conducted myriad empirical studies to measure air quality in indoor environments, largely with occupant surveys and environmental sensors [58, 12, 29, 10, 47, 4, 51, 37, 18]. Empirical examples of SWB emotional responses used to assess air pollution directly was conducted in a study by Li et al. [36]. In the study, the effect on SWB from viewing air pollution images has been measured against six emotional effects (i.e., expectations for the future, happiness, stressed, depressed, worry, irritation).

Lighting Effect

Light is a quintessential architectural design element with well-studied impacts on mental well-being. It is evidenced that natural and artificial light creates a better indoor experience and significantly improves the health and well-being benefits for office workers. For instance, artificial light treatments are used as a treatment for winter depression [21]. Other areas of artificial light measurement include melanopic light intensity in work areas; lamp shielding; glare minimisation from surfaces; and daylight management. Although intelligent lights in offices have been designed to improve the building energy management and to offer reduced energy consumption, it has a potential impact on addressing lower mood. Researches have shown that light has a direct and positive influence on human physiology [25]. Proper lighting can potentially improve the individuals quality of life. Research studies underline the significant association between good light and wellness of employees in working spaces. Detecting the light in the physical workspace can be one of the crucial measurement of the quality of the workspace at the office. Advancements in sensing and actuation devices are also key enablers to capture environmental data, including lux levels, noise levels, and air quality measurements.

Sound Level

Acoustics of indoor environment has been shown to have a linear correlation with acoustic comfort of occupants in a multitude of environments (i.e. office [30], home, classrooms [39] and hospitals [62]) and being a multi-sensory experience for occupants[8]. Indeed, some studies point to the objective influence of one factor affecting the other such as sound thresholds affecting thermal comfort of occupants [8, 52].

Biophilia - connecting with nature

Biophilia (or biophilic design) is based on the premise design - a hypothesis that contact, visibility and access to nature influence human well-being, particularly in an indoor environment [54]. Biophilia is considered a more human-centric approach to indoor environmental design factors affecting occupant experience and green building design [59]. This has been interpreted to include indoor planting according to WELL building standard.

Object Recognition in Physical Working Spaces

Object recognition is a general term for finding and identifying objects in an image or a video. It has been widely studied in computer vision domains. In physical workplaces, recognising diverse floor plan elements including doors, windows, presence of indoor plants and natural light, and the type of room is crucial for studying the impact of office environments on the employees. Some existing methods such as [19, 14] locate room elements such as doors, windows, walls, and room type by recognising their graphical and geometric shapes (e.g. line, arc) in the room layout. Other approaches rely on using Computer-Aided Design (CAD)-based geometry recognition. A new CAD-based method has been proposed in [5] for modelling inter-relationships between objects-to-objects and objects-to-layout from 3D environments captured by RGB-D cameras. Xiang et al. [57] have built ObjectNet3D method. It can identify a variety of object categories such as lighter, keyboard, desk lamp, chair, door, among others. This enables building and training a powerful and efficient DNN to detect these environmental features from a physical space.

A recent deep neural network framework: room-boundary-guided attention has been proposed [61]. In principle, it is a deep multi-task neural network based on a labelling hierarchy for floor plan elements using VGG network [49]. The approach aims at capturing the spatial relations between existing elements to identify the type of a room as well as the room elements, e.g. doors, walls and closets. Thus, we hypothesise that non-verbal communications such as facial expressions captured from video offer a potential conduit for measurement of well-being and human psychophysical thriving in an indoor environment. In particular, when these non-verbal cues are coupled with measurable indoor features taken from the WELL building standards, new findings can emanate in the scientific field of neuro-architecture where the study of architectural experience itself can potentially expand neuroscientific research.

Overall, many of the object categories of indoor environment and external features discussed in the WELL building standard (i.e. mind, biophilia, light, sound) can already be captured from image and audio data. Table 1 presents only the categories from WELL standard that can be recognised from video data combined with environmental measurements using deep learning. 'Video Data Feature‘ column refers to the indicators from WELL standard that can be captured from video data and sensory devices.

External Impact: Measuring the Mind

Human emotions are inextricably linked to the brain and experiences of the entire body through physiological changes [13]. Empirical researches from the last decade reveal a strong association between emotions and well-being [60]. Emotional states can already be assessed to some degree of accuracy by measurement of facial expression variability, body language, and attitudes which trigger changes in behaviour, physical and mental well-being [31, 13].

Table 1: WELL Standards: Internal Impact Features

	WELL Standard Feature	Description	Video Data Feature	Key Measurement
AIR	Ventilation effectiveness	To ensure adequate ventilation and indoor air quality	WINDOW	Window presence
	Operable windows	To increase supply of high quality outdoor air and promote a connection to the outdoor environment by encouraging occupants to open windows when outdoor air quality is acceptable	WINDOW	Window presence
	Microbe and mold control	To reduce mold and bacteria growth within buildings, particularly from water damage or condensation on cooling coils	WALLS	Discoloration of wall/ceiling
LIGHTING	Visual lighting design	To support visual acuity by setting a threshold for adequate light levels and requiring luminance to be balanced within and across indoor spaces.	LIGHT LEVEL	Average light intensity of $>$ 215 lux at least 0.76m above finished floor
	Circadian lighting design	To support circadian health by setting a minimum threshold for daytime light intensity.	LIGHT FIXTURE and WINDOW	>250 equivalent melanopic lux at >75% workstations at 1.2m above finished floor for 4 hours per day
	Solar glare control	To avoid glare from the sun by blocking or reflecting direct sunlight away from occupants.	WINDOW BLINDS	Presence of interior window shading / blinds controllable by occupier
	Right to light	To promote exposure to daylight and views of varying distances by limiting the distance workstations can be from a window or atrium.	WINDOW	Area of regularly occupied space is within 7.5m of view windows
	Surface design	To increase overall room brightness through reflected light from room surfaces and avoiding glare.	WALLS and CEILING	• Ceilings have average LRV of > 0.8 (80%) for > 80% of surface area in regularly occupied area. • Walls have average LRV of > 0.7 (70%) for > 50% of surface area directly visible from regularly occupied spaces
SOUND	Internally generated noise	To reduce acoustic disruptions from internal noise sources and increase speech privacy	AUDIO	• Open office spaces which contain workstations noise criteria (NC) <40 • Enclosed offices - noise criteria (NC) $<$ 35 • Conference rooms - noise criteria (NC) $<$ 30 (25 recommended)
	Exterior noise intrusion	To reduce acoustic disruptions by limiting external noise intrusion.	AUDIO	Average sound pressure level from outside noise intrusion < 50 dBA, measured when space / adjacent spaces are unoccupied/within 1 hour of normal business hours
	Reverberation time	To help maintain comfortable sound levels by limiting reverberation times.	AUDIO	• Conference rooms: 0.6 seconds • Open workspaces: 0.5 seconds
	Sound masking	To reduce sound transmission and acoustic disruptions through sound barriers.	AUDIO	• Open workspaces: 45 – 48 dBA • Enclosed offices : 4 – 042 dBA

Psychophysical Measurements

Human-centric data can be collected with an eclectic mix of sensors and data sources such as image-based, threshold and mechanical, motion sensing, radio-based, human-in-the-loop, consumption sensing, among others. Changes to the autonomic nervous system (ANS) are widely recognised as reliable indicators of emotional stress. Multiple physiological signals have been used for detecting associated stress activities such as the electrical activity of the heart on the skin's surface with an electrocardiogram (ECG), muscle activity with Electromyography (EMG), and increases in skin temperature, and body temperature. Other parasympathetic activities of the ANS measured by heart rate variability, blood volume pulse (BVP), respiration rate (RESP), and galvanic skin response (GSR) can also capture stress responses. In particular, Electrocardiogram (ECG), galvanic skin response (GSR), temperature and respiration have been measured during a laboratory stress test. The study also highlights that GSR-based features, together with the mHR (mean heart rate), are the most dominant features for detecting the stress level in a controlled environment. Many of these psychophysical measurements rely on specialist equipment and wearable sensors to capture such data and track individuals emotional states. Albeit to date, experiments with body sensors have been limited to a laboratory or artificial setting. Using the body sensors mentioned above can be deemed as invasive technologies, requiring the user to wear intrusive sensors and wearable devices. However, emotional states can be captured unobtrusively merely from facial video cameras.

Emotion Recognition

Recent advances in deep learning with video applications show promising results in capturing some of the psychophysical measures used to assess emotional states. Chen et al. [9] have demonstrated video-based physiological measurement of blood volume pulse, heart and breathing rates. It is based on a 'DeepPhys' – a convolutional neural network video-based physiological measurement. Successful physiological measures have been obtained from respiratory signals using colour and motion-based analyses. This study potentially demonstrates that supervised deep learning techniques can be generalised to occupants based on, skin types and illumination conditions (which vary based on internal space, location of glazing and lighting fixtures). Other recent research studies, such as [32] classify efficiently human emotions using a new hybrid deep learning approach. The proposed Convolutional Neural Network and Long Short-term Memory Recurrent Neural Network (CNN-LSTM) outperforms the traditional fully connected deep neural network (DNN) on EnvBodySens dataset [33] with 20% increase in the accuracy and F-Measure. Another study by Smets et al. [50] detects psychophysiological stress. The study compares different machine learning algorithms such as Support Vector Machines (SVM), Decision Trees (DT) and Bayesian Networks (BN). However, the data was collected in a very controlled environment.

Facial expression recognition (FER) is a sentiment analysis technique for automatically detecting emotional states (e.g. attention, distraction, happy) from facial expressions such as happiness, sadness, anger, and fear. There has been extensive research for FER applications. Recent deep FER systems have been developed to improve automated facial recognition technology. In the traditional FER methods, feature extraction and classifications are two independent steps. In contrast, deep FER involves deep feature learning and deep feature classification that perform FER in an end-to-end way. DNN architectures, including deep auto-encoder (DAE) and CNN, among others, aim at learning an efficient representation of face image through non-linear transformation.

Emotional expressions involve encoding information from different perspectives. Although face images have been successful in recognising human emotions, some other office design influences further improve the emotional prediction and can also detect the level of engagements automatically from video cameras installed at working space [15].

In the section to follow, we will provide an overview of our proposed framework for monitoring the wellness at physical workspaces.

CULTIVATING WORKPLACE WELL-BEING: ASSESSING PHYSICAL SPACES OF THE HOME

Deep learning techniques have been successfully applied in different applications for detecting human activity and emotions. However, extant literature has paid little attention to environmental effect (e.g. office design and elements), and psychophysical (e.g. emotions and cognitive states) [32]. Limited practical experiments have been conducted beyond human and physiological recognition. While progress has been made, accurate (automatic) detection of human emotions is still a very challenging task [45, 32].

Commercially available tools include Affectiva (in-cabin sensing emotion and cognitive state detector) used for detecting emotional states of car drivers and passengers using face and voice data [6]. To the best of our knowledge, there is no practical deployment and application to augment emotions at the physical workplace from video data and from the architectural design perspective.

We summarise our conceptual framework in Figure 1. The framework emphasises on human well-being affected by the internal and external influences shown in red and green boxes, respectively. Details of these influences are explained in previous sections. A subjective-well-being (SWB) score measures the wellness level - incorporating the impact of both influences on individual wellness in physical working spaces.

Interpreting Emotional States from Internal Influences: Indoor work environments shape employee health. Internal influences include data captured from the video (i.e. room design) and environmental sensory devices (e.g. light, noise levels, air quality) to measure the individual well-being. This includes recognising diverse room elements including doors, windows, and their features (e.g. colour, shape), presence of indoor plants and natural light.

[6] https://www.affectiva.com/

Table 2: WELL Standards: External Impact Features

	WELL Standard Feature	Description	Video Data Feature	Key Measurement
MIND	Beauty and design	Thoughtful unique and culturally-rich spaces.	• FACIAL EXPRESSION, AUDIO VOICE TONE • ROOM BACKGROUND • CEILING HEIGHT	• Expressions of human delight and joy • Artwork in all regularly occupied space > 28 m^2 • Rooms of 9m width or less have ceiling height of at least 2.7 m
	Biophilia	To support occupant emotional and psychological well-being by including the natural environment in interior and exterior design.	ROOM BACKGROUND	Presence of indoor plants. A plant wall per floor, covering a wall area equal or greater than 2% of the floor area, or covering the largest of the available walls, whichever is greater
	Stress treatment	To avoid or mitigate stress issues	FACIAL EXPRESSION, AUDIO VOICE TONE	Signs of stress, depression or anxiety

Interpreting Emotional States from External Influences: Humans have a plethora of non-verbal cues such as facial expressions and gestures which point to the emotional state of being. Artificial emotional intelligence can provide a richer understanding of human well-being. The external influence data, includes facial expressions (e.g. happy, sad, tired) which can be captured from video footage data.

Subjective Well-being (SWB): SWB score fuses and estimates the effect of internal and external influences. The score can range from 1 to 10 with higher scores indicating higher SWB. The SWB combined score is then classified into risk levels; *high*: 1–4, *medium*: 5–6, and *low*: 7–10. The score typically relies on how the captured internal and external influences are compliant with the recommended fundamental measurements, including their standard threshold values for human wellness in Tables 1 and 2. Based on the SWB score, the framework could detect the warning signs or offer suggestions and modifications to the working environment, e.g. fresh-air breaks, colour and lighting to enhance well-being score and reduce the stress and burnout.

Our framework could be offered as a service for employees for self-care and well-being or employers for improving the working environments to boost productivity. The framework also could help in improving the current existing working spaces by highlighting critical issues in the working environments that cause adverse effects - having a low value of SWB.

Overall, an employee who experiences a more significant positive effect and the less negative effect would be deemed to have a high level of SWB. Emotional responses, environmental quality measures (e.g. light, air quality) and room features and design can be reliably captured from a video camera and sensory devices, and thus enable measuring the physiological and psychological states. However, there are some open challenges for adopting the proposed framework. We will discuss some of these challenges briefly, however addressing these challenges is out of scope for this early conceptualisation of the proposed framework and will instead form a pathway for future research.

Open Challenges

Our framework demonstrates that there are multiple channels to measure the SWB; however, there are some challenges associated with employees' data collection and usage and how deep learning models will make decisions and offer recommendations.

Accountability

According to the Management of Health and Safety at Work Regulations (NI) 2000, organisations must comply with the Health and Safety at Work (Northern Ireland) Order 1978. The legal responsibility of employers has been set out as: *"All employers have legal responsibility under the Health and Safety at Work (Northern Ireland) Order 1978 and Management of Health and Safety at Work Regulations (Northern Ireland) 2000 to ensure the health safety and welfare at work of their employees. This includes minimising the risk of stress-related illness or injury to employees"* [7]

During the global COVID-19 pandemic, employers are increasingly being asked to support their employees' well-being and safety. Managers are accountable for the safety, health and well-being of the employees they direct. If an employee has mental health or well-being issues, their employer must take it very seriously. In a post-pandemic scenario, the well-being of the employees will be at the heart of workplace planning. This reinforces the accountability of managers. This would require a new level of accountability/responsibility for supporting employees, especially the ones already suffering from mental

[7] https://www.hseni.gov.uk/articles/roles-and-responsibilities-mental-well-being-who-should-take-action

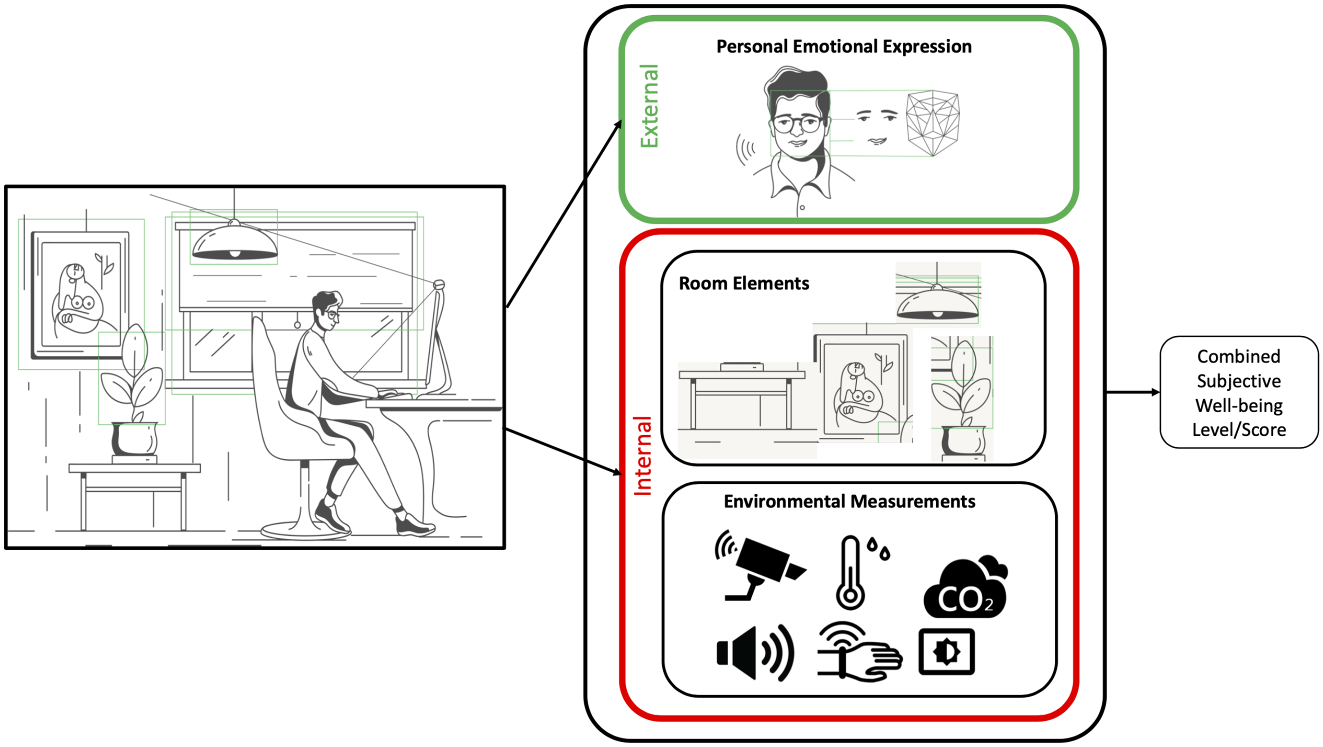

Figure 1: Well-being Framework - top green box is external influences and bottom red box is internal influences

health and well-being issues, to remain in and thrive at work. The new level of accountability should implement emergency legislation to address specific issues raised by pandemic, e.g. the COVID 19 outbreak. This new level can be further split into three risk levels: low, medium and severe. At each level, an action should be taken to provide support and ensure the safety and well-being of the employees. This new accountable level can be integrated into our proposed framework such that each risk level of SWB scores has corresponding accountable actions.

Transparency

Deep neural networks (DNN) are successfully used for object and face recognition and detecting facial emotional expressions. Despite their recent success, they are heavily criticised for their inability to explain decision making in a human-understandable format. It is often challenging to get real insights into DNN models - and are most often referred to as black boxes. Models cannot explain to users why they make a particular decision or which features are considered while making a decision. The decision must not be 'biased' by irrelevant features. For instance, the facial expression models should not be biased against age, race, gender and ethnicity. Bias can be reduced by using a more diverse set of training data (e.g with diverse set of face images).

As we move forward with training complex DNN models for building automatic and intelligent AI systems, we need to transition from 'black-box' into 'glass box' models that reinforce accountability, transparency, explainability, and trustworthiness of ML without sacrificing learning performance.

Privacy and Data Protection

Although employers might collect and analyse data at the working space for boosting productivity, employees are increasingly concerned over the invasion of their privacy as corporate surveillance technology expands to monitor their activities and interactions. For instance, some employees turn-off 'My Analytics' - Microsoft service for analysing and reporting activities as they feel uneasy being continuously watched. Although, the service is based on information pulls from individual email and calendar and can only be viewed by individuals. Employees should be at the centre of the process and have control over their data and choose what to share. The trade-off between what employers should access (within the well-being context) without an invasion of employee privacy still remains an open to debate. Another challenge is in the keeping of a long history of well-being records about employees. As this could potentially be misused - making decisions about promotions and rewards. Employees should be protected against mistreatment at the working space.

Innovative uses of technology play a critical part as a response to the pandemic. However, the General Data Protection Regulation (GDPR) might not be well suited to individual data collection (privacy) [42] and regulators have to balance between the value and the necessity of using technologies after the pandemic. Visual data recording qualifies as "personal data" [8] under the Regulation (EU) 2018/1725. Recording video data that will be used for monitoring the physiological, well-being and mental health statuses are perceived as health data processing. This requires obtaining explicit consent for video recording and informing the employees a specific and detailed privacy statement about how long the data will be stored at the organisation and who should have access to the data.

No one-size-fits-all

The main aim of this framework is to have a positive impact on the well-being of individuals in indoor physical working spaces; however, it could potentially be misused. Call centre workers are assessed on their voice tone, spoken words and their attitudes with customers. Typically, supervisors regularly listen to their calls to ensure the quality of the provided services. Adopting our framework in its current form might have a negative impact on some workers' jobs, where their performance is judged on the basis of their emotional responses by employers. To this end, our framework has to be adaptive to the possibility of tailoring it to purely for employees own well-being needs.

CONCLUSIONS AND FUTURE WORK

Employees are often unwilling to open up about their mental health. Organisations are increasingly boosting their workers' well-being by offering a wide range of well-being support services during the pandemic. Mental health and well-being lie within the broader of understanding emotions by identifying and spotting the warning signs. Emotions play a crucial role in human-to-human interaction, allowing people to express themselves beyond the spoken words.

Human emotions manifest in different ways, including their faces but may also be influenced by their surrounding environments. (Automatic) emotion recognition is still a challenging problem, and it has vast implications on understanding human interactions and emotional states. The recent advancements in AI and deep learning fuel our deep understanding of peoples emotions - capturing the emotional states from facial expressions and the physical environmental design (i.e. spatial alignment, shape/layout of areas, and contour of objects in room offices), among others.

We believe that there is an urgent need for research communities to come together to tackle the challenges related to psychophysical or emotional responses and well-being influenced by the design of physical working spaces. In this paper, we have discussed our proposed measurement to monitor the well-being and emotional states of employees in the physical workspace. In particular, a higher-level framework that is capable of automatically recognising emotional states from multiple perspectives: face expression, physical environment features (e.g. room features) is presented. The output of our model is a human thrive score value which can be further classified into a risk level, and an accountable action should be taken based on the risk assessment. This framework could be offered as a service for employees for (self) well-being or employers for improving the working environments to boost productivity - identifying critical issues in the working environments that cause adverse effects and result at having a lower value of SWB. We have also briefly discussed the open challenges on privacy, transparency and accountability related issues.

Future work will be required to solely study the implications of privacy and accountability of such systems in the future of role of employer and employee responsibility in managing health and well-being. A future extension of this work will focus on deploying video cameras and sensory data for collecting video data, including requesting consent from participants to be compliant with EU GDPR (Regulation (EU) 2016/679). The work will seek to develop a prototype to evaluate well-being scoring metric in a physical workspace.

[8] https://ec.europa.eu/info/sites/info/files/trad19_consent_form_en_0.pdf

ACKNOWLEDGMENTS

We would like to thank Chetwoods Architects for their support and guidance on the WELL building standards and environmental measures of well-being.

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