Exploring the relationship between the workplace environment, employee wellbeing, and productivity

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Candidate Declaration

I hereby declare that:

1. I have not been enrolled for another award of the University, or other academic or professional organisation, whilst undertaking my research degree.
2. None of the material contained in the thesis has been used in any other submission for an academic award.
3. I am aware of and understand the University's policy on plagiarism and certify that this thesis is my own work. The use of all published or other sources of material consulted have been properly and fully acknowledged.
4. The work undertaken towards the thesis has been conducted in accordance with the SHU Principles of Integrity in research and the SHU Research Ethics Policy.
5. The word count of the thesis is 26,588 (excluding all title pages prior to the Introduction [1.0], published material, references, and appendix, but including tables and figures).

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CONTENTS

ABSTRACT

The 'healthy buildings' movement has emerged in response to increasing recognition that many indoor environments, particularly office spaces, have a negative impact upon the wellbeing and productivity of the building users. However, the move towards healthier working environments is hampered by the fact that the academic workplace literature lacks a suitable theoretical framework for representing the complex and dynamic nature of the relationship between the employee and the workplace environment. Therefore, the major objective of this research project was to develop and validate a theoretical framework to represent the employee-workplace relationship. A programme of primary research conducted within industry followed the initial development of framework, further confirming its utility for both research and practice.

First, a comprehensive multidisciplinary literature review was conducted, leading to the initial development of the novel conceptual framework to represent the ways in which employees are affected by, and act upon, their workplace environment. The Environmental Demands-Resources (ED-R) framework conceptualises the workplace environment as a composite of pathogenic demands (i.e., aspects of the workplace which cause strain and negatively affect employees) and salutogenic resources (i.e., aspects of the workplace which support employee motivation and engagement). A conceptual analysis of the multidisciplinary workplace literature confirms that these concepts are common across seemingly disparate strands of workplace research.

Subsequently, a series of five primary research studies (culminating in six published outputs) was conducted. Two studies explored how requirements for the workplace are moderated by individual differences, finding that what constitutes an environmental demand or resource differs from employee to employee (e.g., noise-sensitive employees are less suited to open-plan offices). Two studies explored the use of environmental sensor data to identify environmental demands and predict employee discomfort, leading to the development of a methodology to combine objective building data with subjective human responses. Finally, one study explored the use of innovative biophilic design as a novel environmental resource, finding that a 'regeneration pod' more effectively facilitated recovery from work stress than an ordinary meeting room.

This thesis presents the results of those studies in full. First, an introduction to the research topics is presented, followed by a description of the key theoretical constructs and a narrative review and conceptual analysis of the multidisciplinary workplace literature. Then, the six research articles comprising the main programme of primary research are summarised and discussed. Finally, the theoretical and practical implications of the research are considered, with a particular focus on the ways in which the research contributes to effective strategies for the creation and maintenance of workplace environments which better support the health, wellbeing, and productivity of their users.

LIST OF PUBLICATIONS

The following six publications (referred to in text by their numbering) have been achieved during the course of the Ph.D., and form the core of this thesis (the full text for each is provided in Appendices B to G). Additionally, four other research outputs were also achieved during the project (provided in Appendices H to K). These are not part of the main body of the thesis, however they are also referred to in the text at certain points.

Paper I

Roskams, M., and Haynes, B. (2019a), "Employee-workplace alignment: Employee characteristics and perceived workplace requirements", *Facilities,* Vol. 38 No. 3/4, pp. 282-297. https://doi.org/10.1108/F-09-2018-0105

Paper II

Roskams, M., Haynes, B., Lee, P. and Park, S. (2019), "Acoustic comfort in open-plan offices: The role of employee characteristics", *Journal of Corporate Real Estate,* Vol. 21 No. 3, pp. 254-270. https://doi.org/10.1108/JCRE-02-2019-0011

Paper III

Roskams, M., and Haynes, B. (2019b), "An experience sampling approach to the workplace environment survey", *Facilities,* Vol. 38 No. 1/2, pp. 72-85. https://doi.org/10.1108/F-04-2019-0050

Paper IV

Roskams, M., and Haynes, B. (2019c), "Predictive analytics in facilities management: A pilot study for predicting environmental comfort using wireless sensors", *Journal of Facilities Management,* Vol. 17 No. 4, pp. 356-370. https://doi.org/10.1108/JFM-03-2019-0008

Paper V

Roskams, M., and Haynes, B. (2020), "Testing the relationship between objective indoor environmental quality and subjective experiences of comfort", *Building Research & Information,* Vol. 49 No. 4, pp. 387-398. https://doi.org/10.1080/09613218.2020.1775065

Paper VI

Roskams, M., and Haynes, B. (2020b), "A randomised field experiment to test the restorative properties of purpose-built biophilic 'regeneration pods'" *Journal of Corporate Real Estate,* Vol. 22 No. 4, pp. 297-312. https://doi.org/10.1108/JCRE-05-2020-0018

Additional Paper I

Roskams, M., and Haynes, B. (2019d), "Salutogenic workplace design: A conceptual framework for supporting sense of coherence through environmental resources" *Journal of Corporate Real Estate,* Vol. 22 No. 2, pp. 139-153. https://doi.org/10.1108/JCRE-01-2019-0001

Additional Paper II

Roskams, M., and Haynes, B. (2021), "Environmental Demands and Resources: A framework for understanding the physical environment for work", *Facilities,* Vol. 39 No 9/10, pp. 652-666. DOI: https://doi.org/10.1108/F-07-2020-0090

Additional Paper III

Park, S., Lee, P., Lee, B., Roskams, M., and Haynes, B. (2020), "Associations between job satisfaction, job characteristics, and acoustic environment in open-plan offices", *Applied Acoustics,* Vol. 168, p. 107425. https://doi.org/10.1016/j.apacoust.2020.107425

Additional Paper IV

Roskams, M., McNeily, E., Węziak-Białowolska, D., and Bialowoski, P. (2021). The Job Demands-Resources Model: Its applicability to the workplace environment and human flourishing. In R. Appel-Meulenbroek & V. Danivska (Eds.), *A Handbook of Theories on Designing Alignment Between People and the Office Environment* (pp. 27-38). Routledge. http://doi.org/10.1201/9781003128830-3

AUTHOR'S CONTRIBUTION

The author's contribution to each paper are noted below, using the CRediT (Contributor Roles Taxonomy) method (for descriptions of each category, see Brand *et al.*, 2015).

For the majority of the research outputs, the author was solely responsible for the conceptualisation, methodology, investigation, formal analysis, data curation, writing (original draft and subsequent editing), visualisation, and project administration. Specifically, the author was responsible for these roles on: Paper I; Paper III; Paper IV; Paper V; Paper VI; Additional Paper I; and Additional Paper II).

For one paper only (Paper II), the author was responsible for the same roles with the exception of investigation; in this study, the data collection was performed by two of the study's co-authors.

The same study also yielded a second research output (Additional Paper III), for which the author's only responsibility was to review and edit the manuscript prior to its submission to the journal.

Finally, for one output (Additional Paper IV), the author shared roles with a second author of the book chapter. Specifically, they shared responsibilities for conceptualisation and writing (original draft and subsequent editing).

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LIST OF ABBREVIATIONS

ASHRAE - American Society of Heating, Refrigerating, and Air-Conditioning Engineers

BREEAM - Building Research Establishment Environmental Assessment Method

CIPD – Chartered Institute for Personnel Development

CO – Carbon monoxide

CO_2 – Carbon dioxide

ED-R framework – Environmental Demands-Resources framework

G7 – Group of Seven

IEQ – Indoor environmental quality

JD-R model –Job Demands-Resources model

LEED - Leadership in Energy and Environmental Design

NO_2 – Nitrogen dioxide

O_3 – Ozone

ONS – Office for National Statistics

PMs – Particulate matter

PMV – Predicted mean vote

SBS – Sick building syndrome

SOC – Sense of coherence

UK – United Kingdom

VOCs – Volatile organic compounds

1.0 INTRODUCTION

1.1 Motivation

1.1.1 Deficits in employee wellbeing

Are employers morally obliged to support the wellbeing of their employees, beyond the provision of secure employment and a relatively safe working environment? Should national governments legislate or otherwise pressurise employers to do more to support the physical and mental health of their employees? These questions could be keenly disputed on philosophical or practical grounds, but on purely economic grounds the answer seems more straightforward. Poor wellbeing amongst workers in the United Kingdom (UK) incurs a significant cost for both individual organisations and the economy as a whole.

One major cost associated with poor wellbeing is *absenteeism* (i.e., staying home from work, for any reason; Stevenson and Farmer, 2017). According to a survey conducted by the Chartered Institute of Personnel Development (CIPD) in 2017, the average employee is absent from work 6.6 days per year, costing their employer an average of £554 each per year (CIPD, 2018). With approximately 30.3 million employees in the UK workforce in 2017 (Office for National Statistics [ONS], 2019), this represents a loss of nearly 200 million working days and an overall cost to the UK economy of almost £17 billion per year. An even higher cost associated with poor wellbeing is *presenteeism* (i.e., working whilst unwell), which is estimated to cost the UK economy between double to triple that of absenteeism (Stevenson and Farmer, 2017).

The most common reasons for absenteeism involve physical health complaints (e.g., minor illnesses, musculoskeletal complaints), however a significant and rising proportion of sickness absence is attributable to stress and mental ill health (CIPD, 2018). Indeed, in

2016/17, more than 12.5 million working days were lost due to work-related stress, depression, and anxiety in the UK (Health and Safety Executive, 2018). Focusing specifically on the costs associated with mental ill health, Stevenson and Farmer (2017) estimate that UK employers lose £8 billion per year from absenteeism and up to £26 billion per year from presenteeism. The wider costs to the UK economy, taking into account lost output and public spending, is estimated to be as high as £99 billion per year.

Additionally, employers may also face more indirect costs associated with staff turnover if their employees are unhappy and/or unwell as a result of their work. These costs relate not only to the recruitment of new employees when somebody else is off sick or leaves the organisation, but also the time required to train the new employee to the requisite standard. Focusing again on the costs directly associated with mental health, Stevenson and Farmer (2017) estimated that UK employers face additional staff turnover of approximately £8 billion per year due to poor employee wellbeing. Overall, it is evident that deficits in employee wellbeing harm employers in various different ways, and therefore it is in their interest to consider how these issues might be redressed.

1.1.2 Deficits in employee productivity

Another issue afflicting the UK workforce is employee productivity, which can be defined in purely economic terms as the economic output per hour worked. Productivity in the UK has effectively stalled since the global economic crisis in 2017/18, whereas comparable nations have been able to rebound more strongly.

For example, the difference between the UK's post-downturn productivity performance and the pre-downturn trend was 15.8% in 2016, which is almost double the average of 8.8% across other Group of Seven (G7) countries (ONS, 2017). Indeed, productivity in UK is approximately 15.1% lower than in comparable G7 countries (ONS, 2017). The stagnation is evident not only in the manufacturing sector, but also in knowledge-intensive industries such as professional services, telecommunications and computing, and finance (Giles *et al.,* 2015). Overall, the state of affairs has variously been referred to as a “productivity puzzle” (ONS, 2015) and a “productivity crisis” (Giles, 2018).

Clearly, it is important to understand the various factors which contribute to comparatively low levels of productivity within the UK, so that remedial interventions can be implemented. Indeed, even small improvements could have a very real impact on the UK’s overall economic prosperity and, consequently, the material wealth of its citizens. Specifically, it has been estimated that even a 1% productivity gain would add £20 billion to the national output, increase annual profits around the country by £3.5 billion, and add £250 to the average wage packet (Weldon, 2016).

1.1.3 The role of the workplace environment

Whilst many possible causes of the productivity crisis have very little to do with the actions of individual employees (e.g., under-investment from companies, low interest rates allowing unproductive companies to survive through loans rather than profits; Tetlow, 2017), it stands to reason that organisations are more productive when their employees are able to work at maximum productivity. As per the ‘marginal gains’ perspective, where small incremental improvements will add up to a significant overall improvement when added together (e.g., Harrell, 2015), these organisation-level strategies could be a crucial part of resolving the overall productivity crisis.

For ‘knowledge workers’ (whose output is primarily a function of mental, rather than physical, processes) in particular, the workplace environment itself has been identified as a significant impediment to productive work. For example, an analysis of almost 300,000 individual responses to the Leesman Index, an industry survey used to measure employee experience, demonstrates that only 58% of respondents believe that their office enables them to work productively (Rothe, 2017). Clearly, many workers arrive at the office each day with the intention of working productively, but find it a challenge due to their working environment. As a result, their employers miss out on harnessing their full potential.

The role of the workplace environment will be discussed in far more depth in the Literature Review (Chapter 3) of this thesis. In this Introduction, it is sufficient to simply note that many of the issues with workplace environments are thought to result from the 'cost reduction' paradigm which pervades workplace practice, whereby organisations seek productivity improvements through the more efficient use of their real estate space (Haynes, 2007a). Given that only 9% of an organisation's operating costs are on real estate rental whereas 90% are on staff salaries and benefits (UK Green Building Council, 2017), it is likely that any cost savings in real estate are dwarfed by the cost of lost productivity amongst employees. Hence, it has been argued that practitioners should instead adopt a 'human contribution' paradigm, characterised by the provision of workplaces which fully support the wellbeing and productivity of their occupants (Haynes, 2007a).

1.2 Industry Context

Increased recognition of the role of the workplace environment in driving organisational performance and decision-making has been mirrored within industry. For example, whereas facilities management has typically been viewed as a cost reduction function limited to a specific number of key responsibilities (e.g., building maintenance, cleaning), it is now recognised that facilities management can have the greatest positive impact when it also adopts broader workplace design and strategy responsibilities, and collaborates with other business functions such as Information Technology and Human Resources to provide the optimal overall working environment to users. This is reflected in the recent decision of the British Institute of Facilities Management to re-brand as the Institute of Workplace and Facilities Management (Institute of Workplace and Facilities Management, 2018).

In particular, with respect to the provision of healthier and more productive working environments, three major developments have recently occurred within the workplace industry. First, there has been the emergence of specialised certifications explicitly focused on supporting occupant health and wellbeing through the built environment. Second, there is the recent technological development of wireless sensors, as part of the wider "smart buildings" movement. Third, there are new approaches to measuring occupant experience within offices being considered, although these remain in a nascent stage at present. Each of these developments are now discussed in turn.

1.2.1 Wellbeing certifications

Within industry, the trend towards healthier buildings was driven initially through specialised modules within sustainability certifications, and more recently through standalone wellbeing certifications. For example, the most popular sustainability certification worldwide, Building Research Establishment Environmental Assessment Method (BREEAM) (achieved by more than 500,000 buildings globally; BREEAM, 2019), contains a category explicitly targeted towards improving human health and wellbeing (BREEAM, 2016). Similarly, the second most popular sustainability certification, Leadership in Energy and Environmental Design (LEED) (achieved by almost 80,000 buildings globally; Tufts, 2016), also contains prescriptions for improving indoor environmental quality (IEQ) in order to improve employee wellbeing (Benjamin, 2018).

The standalone certifications are not yet as widespread, but contain an even more comprehensive list of prescriptions for improving occupant health and wellbeing. The most prominent of these is the WELL Building Standard, which is currently being applied by more than 4,000 buildings globally (WELL Certified, 2020). WELL encourages building owners and developers to better support occupant wellbeing by following more than 100 “Features” across seven key “Concepts”: Air, Water, Nourishment, Light, Fitness, Comfort, and Mind (International WELL Building Institute, 2020a). These prescriptions are broad in scope, encompassing detailed technical specifications for building systems, compliance criteria for key parameters of IEQ and water quality, workplace design recommendations, and even human resources policy recommendations.

Two additional standalone wellbeing certifications are also noteworthy. Fitwel (2020) uses a scorecard-style ranking system to assess the extent to which the building supports the overall health and wellbeing of its users, focusing largely on building amenities and policies rather than detailed technical requirements. The RESET Building Standard (RESET, 2020) is a sensor-based certification focusing on indoor air quality, which does not prescribe any particular routes to compliance as long as air quality standards are met. Neither of these certifications is yet as popular as WELL, however their very existence demonstrates how the industry is rapidly responding to the need for improved wellbeing in the workplace environment.

However, due to the recency of these certifications, it remains unclear to what extent the achievement of these certifications actually improves employee wellbeing and productivity. The relatively little empirical evidence indicates that ‘green’ buildings (i.e., those which have achieved sustainability certifications) tend to have better measured and perceived IEQ than ‘non-green’ buildings (i.e., those without sustainability certifications), and that this translates to better self-reported health amongst the building occupants (Allen *et al.,* 2015). However, this review also highlights several case studies which found no improvements in wellbeing in green buildings, and also reports that acoustic comfort in particular actually worsened in many green buildings.

Possibly, the relatively equivocal early research literature may result from the fact that wellbeing certifications are largely delivered in an atheoretical ‘one-size-fits-all’ manner. That is, companies seeking certification often choose to adhere to the prescriptions that will grant them the quickest and/or cheapest route to compliance, with little consideration that individual differences amongst employees might affect which types of workplace environment are most suitable. For example, the optimal working environment (i.e., the workplace which best supports wellbeing and productivity) might differ from employee to employee based upon the type of work that they do, their personality traits, and/or their demographic characteristics.

Indeed, regardless of whether or not the organisation are pursuing a wellbeing certification, workplace researchers recognise that the most effective outcomes will be achieved when the workplace environment aligns with the needs of the individual employees (Gerdenitsch *et al.*, 2018; Haynes, 2012; Heerwagen *et al.*, 1995; Soriano *et al.*, 2018; Vischer, 2008; Wohlers *et al.*, 2019). In practice, however, organisations prioritise cost-saving above concerns for occupant requirements (Haynes, 2007a). Hence, even if an organisation achieves a wellbeing certification, there is no guarantee that employees will find the new workplace healthier or more productive, particularly if it is misaligned to their needs and requirements.

1.2.2 Environmental sensors

In addition to wellbeing certifications, the healthy buildings movement has also recently been supported by the technological development of wireless sensors for monitoring IEQ. The technology holds particular promise as a means of effectively supporting employee comfort and wellbeing within offices. Specifically, sensors can be used to continually ensure that key environmental parameters remain within the best-practice ‘comfort boundaries’ specified in wellbeing certifications such as RESET and WELL. For the present project, the collaboration with a large private-sector facilities management organisation enabled environmental sensors to be a key focus of the research.

Environmental sensors are a particularly notable development within workplace research and practice because previous solutions for measuring the IEQ of real offices were flawed in various ways. Before sensors, the measurement of indoor environment parameters necessitated the use of mobile carts equipped with various different types of meter (Candido *et al.*, 2016; Parkinson *et al.*, 2015). The first limitation of this approach is the high associated material and labour costs, meaning that the majority of workplaces eschewed IEQ measurements entirely or performed brief one-off assessments. This leads to a second limitation, which is the fact that any measurements that *were* performed were limited to a specific location within the office at a specific time. In reality, environmental parameters fluctuate at different times of day and in different places, and so the spot measurements from mobile carts are of limited practical utility when it comes to identifying and addressing specific issues.

The development of wireless environmental sensors enables such limitations to be overcome. Environmental sensors (e.g., uHoo Indoor Air Sensor, uHoo, 2020; Elsys ERS CO_2 Sensor, Elsys, 2020) are relatively cheap to purchase, and can be permanently installed at numerous locations within the workplace to continuously measure key IEQ parameters. As such, they continually provide spatio-temporally specific information (which can be overlaid onto a three-dimensional model of the workplace and visualised in real time) about the IEQ within the office, enabling facilities managers to instigate immediate remedial action in the event of a pre-specified comfort boundary being breached.

As “smart building” technology continues to develop, it is anticipated that environmental sensors and building management systems will be able to automatically communicate with each other to automate building optimisation processes (e.g., Aryal *et al.*, 2019; Foster *et al.*, 2016). For example, a signal that carbon dioxide (CO_2) concentration had exceeded recommended levels due to human respiration in a busy space might automatically trigger an increase in the ventilation rate until the CO_2 had returned to healthier levels. This is particularly beneficial from an energy usage perspective, as it would mean that the more energy-intensive solutions for optimal working environments are only implemented as and when they are needed. However, it should be noted that these ambitions are largely unrealised at present, and the use of environmental sensors within offices remains rare in both research and practice.

Indeed, only two studies have combined objective sensor data with self-reports of employee experience within real offices. In the study by MacNaughton *et al.* (2017), sensors were used to compare IEQ in green-certified and non-green-certified buildings, with the result revealing generally better IEQ and higher environmental satisfaction in the green-certified buildings. However, their analyses did not directly relate specific aspects of IEQ with specific occupant outcomes, and so provided limited insight into the precise causes of discomfort. Romero Herrera *et al.* (2018) also used sensors to measure IEQ within offices, and compared the data against occupants’ subjective responses. However, their analyses were restricted to the relationship between temperature and thermal comfort, and they did not consider the role of specific comfort criteria.

As such, there is a clear need for more sensor-based field research within offices. In particular, there is a need to more rigorously assess the assumptions that underpin the comfort boundaries found in wellbeing certifications (i.e., that compliance with the comfort boundary will optimise subjective comfort amongst employees). In the absence of substantial previous research, a methodology will need to be developed to enable these types of studies to be performed.

1.2.3 Occupant surveys

Just as workplace practitioners have historically lacked a suitable tool to capture spatio-temporal fluctuations in IEQ, so too have they lacked a methodology for capturing building occupants' spatio-temporal fluctuations in subjective experience (i.e., the fact that they feel more or less comfortable in different locations and at different times).

Typically, in order to assess the suitability of a workplace from the perspective of its users, practitioners have used occupant surveys which are sent out to the inhabitants of an office just once, typically six to twelve months after the organisation has moved into the office (e.g., Candido *et al.*, 2016; Leaman, 2010; Oldman and Rothe, 2017; Zagreus *et al.*, 2004). Whilst these surveys can yield useful information about employees' general perceptions of the office environment, there are also two major issues with this approach which limits the usefulness of the data from a practitioner perspective.

First, the fact that employees are asked to report how they feel *in general* whilst in the office means that they must aggregate all of their subjective experiences over time, even if these experiences have fluctuated widely. Consider the employee who feels too cold when she sits by a draughty window on Monday, too warm when she works from stuffy meeting rooms on Tuesday, and then feels comfortable for the rest of the week when sitting at her regular desk. How should she respond to a question asking her about the temperature in the office? Her most sensible option is to average her overall experiences and report that she is "satisfied" overall, but in doing so she would be unable to provide the feedback that she is uncomfortable for almost half of her working week, when working in specific locations.

The second limitation concerns memory bias. When asked to recall their experiences across a six-to-twelve-month period, it is quite possible that respondents will struggle to accurately remember their overall experience within the office. In particular, it is likely that more recent events will be brought to mind more readily than more historic events – an effect termed the recency bias. For example, an employee might remember that the air has felt stuffy for the past two weeks, but forget that he had always been happy with the air quality before then. Hence, when answering a question about air quality he might report that he is "very dissatisfied", even though for the vast majority of his time in the office he experienced no problems with the air.

Overall, therefore, the responses to occupant surveys are of limited utility to practitioners because they fail to provide any of the context around the response which is necessary for the practitioner to devise effective solutions (Deuble and de Dear, 2014). As such, various researchers have advocated that the traditional occupant survey is replaced by, or complemented with, a "right-here-right-now" approach to workplace assessment, which can then be combined with objective IEQ data (Candido *et al.*, 2016; Choi and Lee, 2018; Deuble and de Dear, 2014; Li *et al.*, 2018). This would enable practitioners to understand exactly when and where problems arise.

To address this limitation, a methodology which arose in academic psychology called 'experience sampling' could be usefully adapted. In an experience sampling study, the participant provides repeated assessments of momentary experience across a certain period of time, responding to prompts at specified or random intervals (Fisher and To, 2012). The same approach could be adopted within workplaces using e-mail or smartphone technology; push notifications could be used to request the employee completes a quick survey about their current experience in the workplace, and these responses could capture exactly when and where the survey was completed (providing the contextual information which is useful to practitioners). Through this method, it would be possible to more rigorously test whether the assumptions underpinning the use of environmental sensors (i.e., that subjective comfort will be optimised if objective comfort recommendations are followed) hold true in real offices. Again, however, this methodology has very little precedent in workplace research, and so a methodology for its effective use must be developed.

1.3 Research Questions

As previous sections have demonstrated, the UK workforce is suffering from clear deficits in wellbeing and productivity, and this is at least partially attributable to unsuitable working environments. The workplace industry has responded to poor employee wellbeing and productivity through the development of best-practice wellbeing certifications, as well as the development of new technologies for continually measuring IEQ and occupant experience. However, wellbeing certifications can be costly to achieve and do not guarantee positive outcomes, and the recency of new technologies means that researchers and practitioners lack a clear methodology for their effective use.

In particular, the healthy buildings movement is at present hampered by a limited use of theory, resulting in a tendency to implement interventions in a 'one-size-fits-all' manner, without recognition that different strategies might be appropriate for different types of employee. There is a clear opportunity here for academic research to support the overall trend towards healthier workplace environments, through a more detailed understanding of the various ways in which employees are affected by their working environments, and the development of insights which practitioners can use to ensure that the workplace supports comfort, wellbeing, and productivity.

The current research project was designed to meet this need. Overall, the project was guided by two research questions (RQs):

> *RQ1*: What are the effects of the workplace environment on employee comfort, wellbeing, and productivity?
>
> *RQ2*: What strategies can practitioners use to ensure that the workplace supports comfort, wellbeing, and productivity?

1.4 Research Aim

The two broad research questions each rely upon a more detailed understanding of the way in which the disparate elements of the workplace environment affect the employees' experiences at work. By better understanding the nature of this complex and dynamic employee-workplace relationship, and by recognising both the *pathogenic* (i.e., harm-causing) and *salutogenic* (i.e., health-promoting) potential of the workplace environment, workplace researchers and practitioners will improve their ability to develop strategies for improving comfort, wellbeing, and productivity at work.

In this way, the two research questions can be distilled into a single, more specific, aim for the overall research programme. Namely, the aim of the research project will be to map the effects of the physical workplace environment on the comfort, wellbeing, and productivity of employees.

1.5 Research Objectives

To achieve this research aim, a series of five initial research objectives were specified, corresponding with different research studies. By achieving each of these five objectives, a further objective closely linked to the research aim will also be achieved: to develop and validate a theoretical framework to represent the employee-workplace relationship. This is the major objective underpinning the entire research project, representing the 'golden thread' which links together the different research objectives and research studies. Moreover, the achievement of this final objective will also constitute the major contribution to knowledge of the Ph.D.

The first two objectives are closely aligned to the development and initial validation of the theoretical framework. Specifically, it will first be necessary to assess the existing state of the science by conducting a thorough review of the multidisciplinary workplace environment research literature. Next, it will be necessary to identify common concepts across the disciplines, and to schematically map these into a coherent framework. In this way, the achievement of these two objectives will support the initial development of a framework for the employee-workplace relationship, highlighting the various ways in which employees are affected by environmental forces and the processes by which this can affect overall wellbeing and productivity.

The following three objectives have more of a practical focus, and consider how the framework can be used to guide the provision of healthier working environments. These objectives do not consider every possible workplace intervention that might be used to this purpose, as this would be beyond the scope of a single research project. Rather, in line with the ambitions of the industry partner, the research focuses on more innovative workplace strategies which currently have limited support in the research literature, largely due to their novelty.

Specifically, the programme of primary research comprises three foci aligned with different strands of the framework that was being developed and validated. First, in recognition of the fact that ‘one-size-fits-all’ approaches to workplace practice are often unsuitable, it will be necessary to investigate how requirements for the workplace environment are affected by individual difference characteristics. Next, to support the emergence of environmental sensor technology, it will be necessary to develop a methodology for combining building analytics (i.e., live environmental data) with human analytics (i.e., subjective experience). Finally, moving beyond a narrow focus on the quantifiable parameters of the indoor environment, it will also be valuable to test whether innovative workplace design strategies can further enhance employee wellbeing.

To summarise, five research objectives were specified to correspond with the programme of research, the achievement of which would also constitute the achievement of a sixth objective representing the major contribution to knowledge of the research:

I. Critically appraise the multidisciplinary workplace environment literature to understand which environmental variables affect employee wellbeing and productivity.

II. Identify the common concepts across the workplace environment disciplines, and schematically map these into a coherent framework.

III. Test the extent to which requirements for the workplace environment are moderated by individual difference characteristics.

IV. Develop a methodology for predictive analytics in facilities management, integrating building analytics and human analytics.

V. Identify innovative design strategies for further improving employee wellbeing.

VI. Develop and validate a theoretical framework to represent the employee-workplace relationship.

1.6 Partnership with Industry

Whilst completing the Ph.D., the author was employed within the wellbeing consultancy service of a facilities management organisation, who were tasked with making office environments more conducive to employee health and wellbeing at client sites (see Appendix A for more details). As such, he was well placed to carry out the proposed programme of research, and to work on its translation into the development of ‘products’ (i.e., sellable consultancy services) for the participating organisation.

The partnership with industry was valuable because it provided the researcher with the opportunity to access real office sites for the purposes of conducting the studies, including offices which had environmental sensor technology installed. Indeed, the research programme would not have been possible to achieve without this level of support. However, conducting industry-sponsored research also raises potential risks around objectivity, which needed to be carefully managed. Specifically, given that the partner organisation had a vested interest in carrying out research which helped them to sell their workplace wellbeing consultancy service (grounded in the use of environmental sensors), there was a risk that the researcher may be pressured to produce findings which supported the implementation of that type of service.

To mitigate this, the research held meetings with senior management officials within the organisation at the start of the research process. It was made clear that the research process would be entirely objective, with all results fully and accurately reported to the public. Required sample sizes would be calculated in advance, and data collection would continue until the maximum achievable data had been collected (to avoid the risk of ending data collection early as soon as a significant effect had been detected, sometimes referred to as ‘*p*-hacking’). Additionally, the researcher would maintain a distance from the organisation, and re-assure participants that they could provide data honestly and without fear of any retribution from their organisation, and that their individual data would be anonymous and not accessible by anybody from the organisation (to reduce the risk of participants feeling pressured to respond in a particular way).

As it happened, senior management at the participating organisation fully supported this approach, and re-iterated their commitment to good academic practice. They noted that the wellbeing consultancy was in a nascent stage, and that the research would play an important role in determining exactly how their services should be shaped. In other words, if an unexpected finding emerged, then there would be no pressure to change this or to selectively present this to fit with the fixed group of services, but rather those services could be changed to better reflect the research. This commitment was honoured throughout the research process, and the researcher felt no pressure to his objectivity at any stage.

1.7 Scope of the Research

The collaboration with industry also helped to define the scope of the research. The organisation had a large group of clients across numerous different occupational categories (e.g., manufacturing, healthcare, construction), and it would be unachievable within a scope of a single research project to conduct detailed research into the optimal working environment across all of these categories. As such, a decision needed to be made about exactly which industry should be focused on in the research programme. The researcher discussed this issue with management, and the decision was made to focus on office environments, typically housing knowledge workers.

1.8 Structure of the thesis

This thesis is built upon six research articles, which have been published in peer-reviewed journals. The thesis links the research findings together by highlighting the common thread throughout each piece of research, and relating findings from individual studies back to the aim of the project.

In total, the thesis is divided into six chapters. The first chapter has highlighted the context for the Ph.D. and provided the rationale for its objectives. The second and third chapters present a comprehensive review of the multidisciplinary workplace literature (*Objective I*), culminating in the development of a novel theoretical framework based upon the identification of common concepts across different disciplines (*Objective II*). To aid the reader, these are presented in reverse order: first the theoretical background to the key concepts is presented, followed by an initial specification of the novel framework; then, eight different disciplines of workplace environment research are reviewed and discussed from the perspective of the novel framework. This approach (combining a narrative review and conceptual analysis) serves the dual purpose of elucidating the state of the science whilst validating the framework that has been formulated.

The subsequent chapters discuss the primary research that was conducted during the course of the research project. The fourth section explains the methodological considerations for the overall research programme, and also provides a summary of each individual study that was undertaken. The results of the studies are discussed in relation to theory and practice in the sixth section (*Objectives III, IV and V*). Finally, a conclusion to the thesis is provided in the seventh chapter, in which the overall development and validation of the theoretical framework for the employee-workplace relationship is summarised (*Objective VI*).

The relationship between the research questions, research aim, research objectives, and the project publications (listed earlier in the "List of Publications" section) is shown below, in Figure 1. The diagram shows that the two broad research questions led to a specific research aim, which could be answered through six research objectives. The first two objectives were more closely aligned to the first research question, and led to the publication of three "additional papers" (the content of which is summarised and re-produced in Chapters 2 and 3 of this thesis). The following three objectives were more closely aligned to the second research question, and led to the six publications which form the core of this thesis, as well as one additional paper. Overall, these ten publications represent a significant contribution to knowledge of the Ph.D. project, which is captured in the final objective: to develop and validate a theoretical framework to represent the employee-workplace relationship.

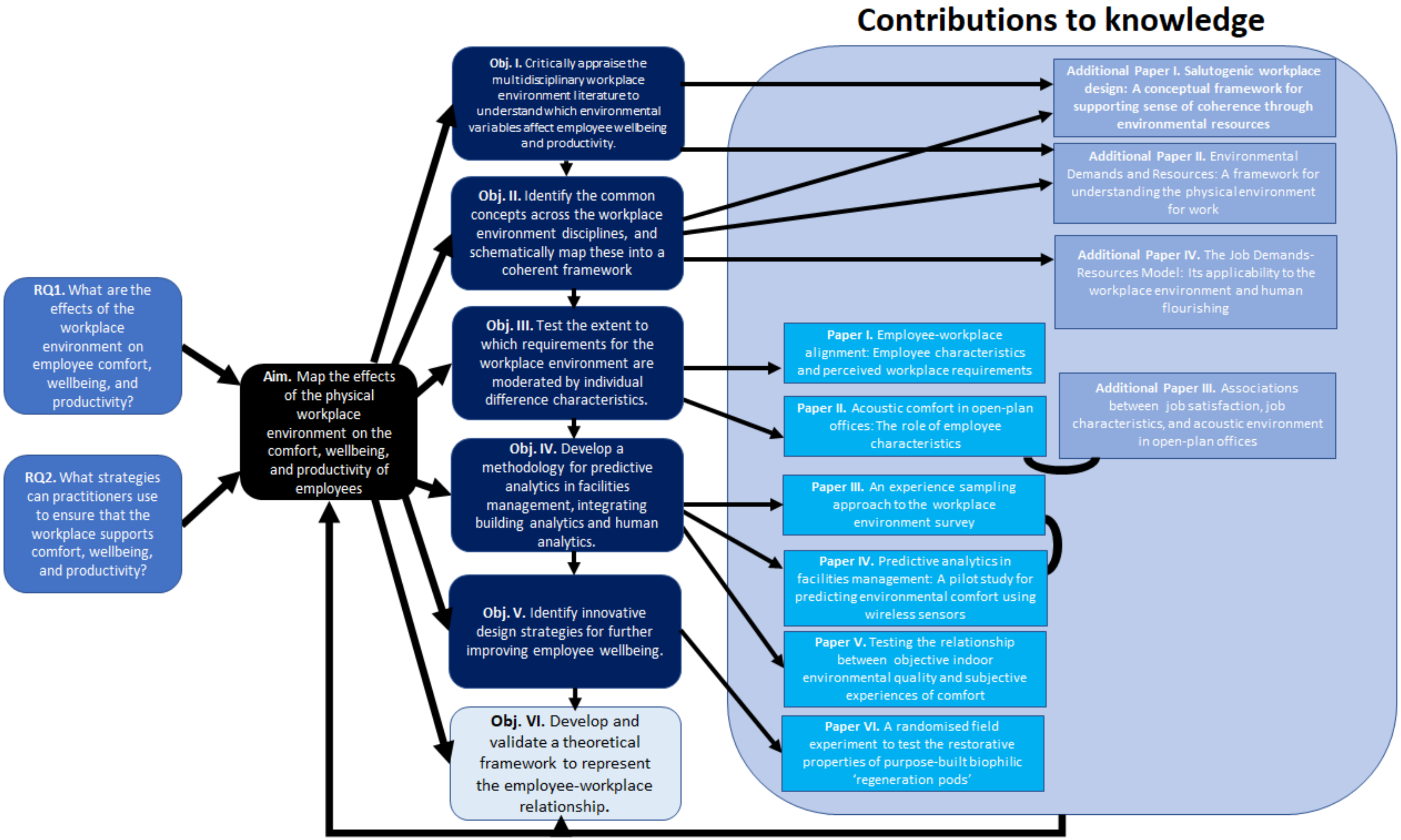

Figure 1. The relationship between the research questions, research aim, research objectives, and publications.

2.0 THEORETICAL BACKGROUND

The overall aim of the research project was to map the effects of the physical workplace environment on the comfort, wellbeing, and productivity of employees. To achieve this, it was proposed that the major objective of the programme of research should be to develop and validate a theoretical framework to represent the complex and dynamic nature of the employee-workplace relationship, as this would help researchers and practitioners to develop more effective strategies for improving office environments.

In this chapter, it is proposed that a novel extension of the Job Demands-Resources (JD-R) model (Demerouti *et al.*, 2001) is suitable for this purpose. Specifically, it is argued that the extension to the JD-R model adequately overcomes the limitations of previous theoretical representations of the employee-workplace relationship, but has been largely unconsidered in relation to the workplace environment in the extant literature. To highlight its utility specifically for this purpose, the domain-specific extension to the model is presented separately as the Environmental Demands-Resources (ED-R) framework.

The development of the ED-R framework took place alongside the literature review, following a reciprocal process in which a more detailed understanding of the workplace literature enabled a better understanding of the key concepts and their interrelations, which in turn enabled a more erudite reading of the literature, and so forth. For the purposes of this thesis, the initial development of the ED-R framework *(Objective II*) will be presented first in this chapter, whereas in the following chapter the literature will be reviewed (*Objective I*) and discussed in relation to the new framework.

These two chapters can essentially be understood as summarised versions of three of the additional outputs from the overall research output: a narrative literature review published in the 'healthy buildings' special issue of the *Journal of Corporate Real Estate* (Roskams and Haynes, 2019d), a conceptual analysis which has been accepted for publication in *Facilities* (Roskams and Haynes, 2021), and a chapter which has been accepted for publication in an upcoming book dedicated to transdisciplinary theories of workplace management (Roskams *et al.*, 2021).

Before the presentation of the new theoretical framework, however, it is necessary to more precisely define the key constructs that are used throughout the research project. Doing so will enable the evaluation of how the constructs were operationalised in prior research, and support the decision-making process for how they should be operationalised in this project. Specifically, it is necessary to consider the following questions: What do we mean by environmental comfort? What do we mean by wellbeing? What do we mean by productivity? What do we mean by the workplace environment? After providing comprehensive responses to each of these questions, the chapter will then turn to a brief review of existing theoretical conceptualisations of the workplace environment, highlight their limitations, and present the new framework as a more suitable alternative.

2.1 Defining and Operationalising Key Constructs

2.1.1 Environmental comfort

Broadly speaking, the word comfort denotes "a state of physical and material well-being, with freedom from pain and trouble" (Oxford English Dictionary, 2020a). With respect to the workplace, environmental comfort therefore implies the state in which the employee is free of pain and trouble caused by environmental forces. To reflect this, an early conceptualisation of environmental comfort included the categories of lighting comfort, acoustic comfort, thermal comfort, and acceptable indoor air quality (Reffat and Harkness, 2000), corresponding with the key parameters of the physical environment.

The concept of environmental comfort was further developed by Vischer (2007, 2008), who viewed comfort as a mediator in the relationship between the workplace environment and job performance. In particular, she considered environmental discomfort to be analogous to workspace stress, which arises due to a misfit between the workspace and the individual, “in which the environment places inappropriate or excessive demands on users, in spite of their adaptation or adjustment behaviours (coping)” (Vischer, 2007, p. 177). It is only in offices with ‘good fit’ that employees are able to apply all their energy and attention to completing their work effectively.

Furthermore, Vischer’s (2007, 2008) conceptualisation of environmental comfort also recognises that the effects of the workplace environment on individuals are not purely physical, and that two other types of comfort (functional and psychological) can also be distinguished. In particular, she argues that these three types of comfort can be hierarchically arranged, such that a lower level should be satisfied before the next stage of comfort can be achieved. Figure 2, taken from Vischer (2008), demonstrates this hierarchical arrangement. Overall, it is predicted that the highest levels of occupant satisfaction and wellbeing are supported when all three types of comfort are achieved.

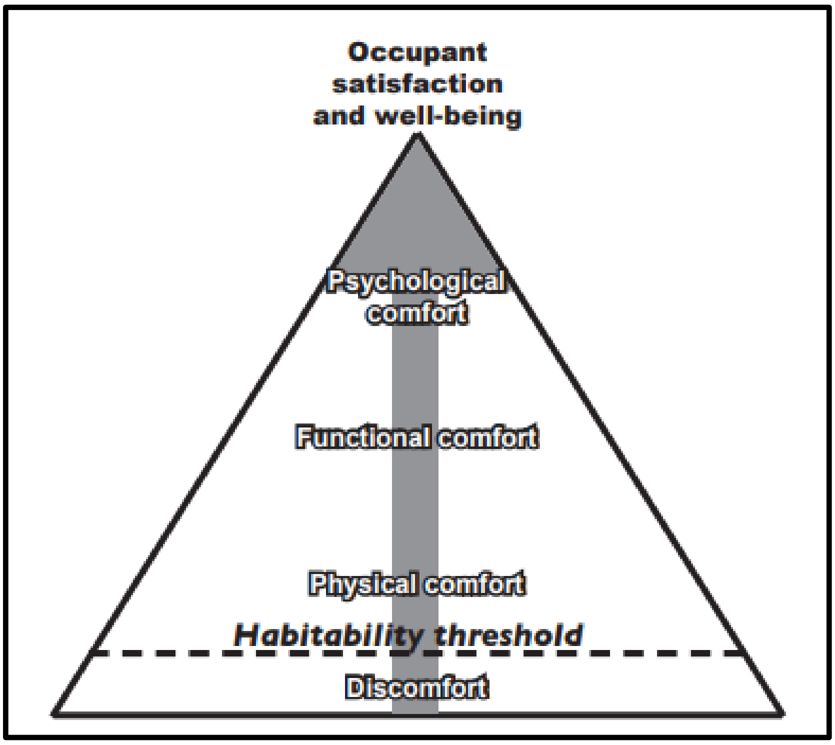

Figure 2: Environmental comfort model of workspace quality (Vischer, 2008)

At the lowest level of the pyramid is the state of *discomfort*, reflecting the situation in which the building does not meet the minimum standards for cleanliness, safety, accessibility, and/or convenience. In such cases, the building is below the 'habitability threshold', and should not be occupied. Conversely, if the standards are met (e.g., through compliance with building codes and occupational health and safety regulations) then a state of *physical comfort* is achieved.

The next level is *functional comfort*, which reflects the extent to which the workplace environment provides support for users' performance of work-related tasks and activities. Given inter-individual variability in the types of tasks that different office workers perform, there will likewise be inter-individual variation in which types of environment are considered to be supportive. Hence, the provision of functional comfort relies on a keen understanding of exactly what type of work is performed in the office, and the design strategies which support this type of work.

Finally, the highest level of the pyramid is *psychological comfort,* referring to the degree to which the occupant experiences feelings of belonging, ownership, and control over the workspace. The primary component of psychological comfort is the sense of territory (over both individual and group spaces). This is often expressed through personalisation and appropriation of space, marking territory and constructing boundaries of social and environmental control.

In support of this conceptualisation, Vischer (2007, 2008) how the disparate disciplines which comprise the multidisciplinary workplace environment literature can all be understood in terms of physical comfort, functional comfort, and/or psychological comfort. Whilst empirical tests linking these concepts to specific aspects of job performance remain rare, the model has proven to be popular in terms of informing the different criteria to consider during a workplace evaluation (e.g., Jaca *et al.,* 2018; Naccarella *et al.,* 2018).

That said, there are also limitations of this conceptualisation of environmental comfort which should be noted. Firstly, evidence in favour of the assumed hierarchical nature of the different types of comfort is limited. Indeed, it is quite possible that a workplace might have polluted indoor air and high noise levels (resulting in low physical and functional comfort), but nonetheless feel homely and familiar (resulting in high psychological comfort). Additionally, there may be other types of comfort influenced by the workplace environment which are not included in the model. For example, the concept of social comfort, defined as "the phenomenon of collective understanding of experienced comfort and the co-development of agency for achieving comfort" (Cole *et al.,* 2008, p. 332), is another form of comfort which could feasibly be positively (e.g., working arrangements which promote useful social contact) or negatively (e.g., segregated working arrangements which prohibit interaction) affected by the workplace environment.

Nonetheless, Vischer's model of environmental comfort remains a useful approach for distinguishing the major types of comfort affected by the workplace environment, and the processes by which they might be associated with wider job outcomes. For the purposes of the present research programme, the focus was largely on physical and functional comfort. In the first two studies (*Papers I and II*), the aim was to explore how requirements for the workplace environment vary between individuals, which indirectly relates to the concept of functional comfort. Then, in the studies which utilised environmental sensors (*Papers III, IV and V),* participants were repeatedly asked how satisfied they were with different aspects of the workplace environment, which can be considered to be a measure of physical comfort.

2.1.2 Wellbeing

Dictionary definitions of wellbeing allude to the complex and multi-dimensional nature of the term, rather than highlighting any clear and simple way that it should be defined in research. For example, the Oxford English Dictionary (2020b) defines wellbeing as "with reference to a person or community: the state of being healthy, happy, or prosperous; physical, psychological or moral welfare". Even with this short definition, we can see that wellbeing is a broad over-arching concept which encompasses health, happiness, and prosperity (which are themselves complex and multi-dimensional concepts), and which can be applied at the level of the individual or the group. Hence, if we make the claim that Office

A is better for employees' wellbeing than Office B, it remains unclear exactly *how* the offices differ with respect to their influence on occupants.

To unpack some of this complexity, Hanc *et al.* (2018) reviewed the various ways in which wellbeing has been operationalised in built environment research. Their findings highlight nine themes and numerous additional sub-themes of wellbeing, indicating considerable heterogeneity in conceptual approaches to wellbeing within the literature. These results are shown in Figure 3, where the size of each circle is proportional to the number of papers that define wellbeing in that manner (the ninth theme, "Unspecified", is not shown).

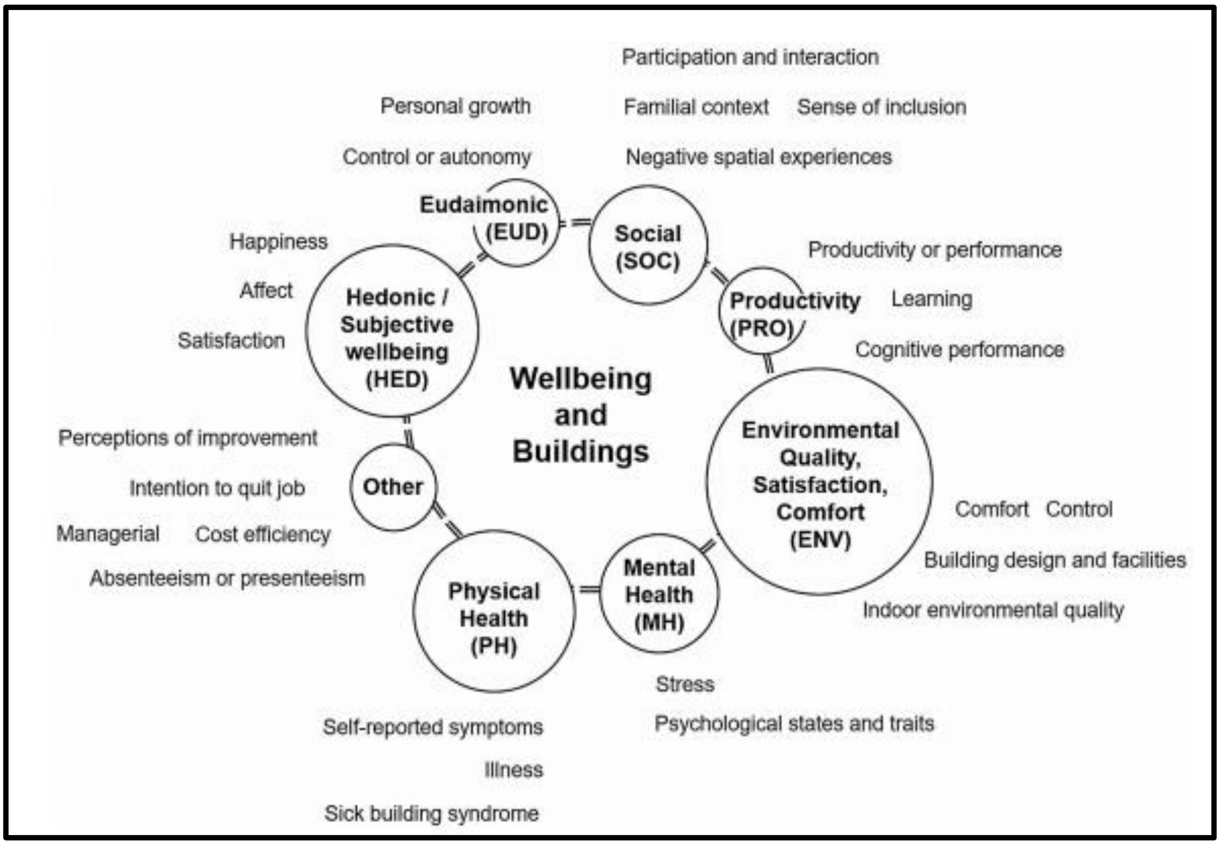

Figure 3: Wellbeing and buildings, conceptual themes and subthemes (Hanc *et al.*, 2018)

Across the different studies in this programme of research, various measures of wellbeing were used, generally corresponding with the 'mental health' category from Hanc *et al.* (2018). In particular, given the centrality of the concept of workspace stress in relation to environmental comfort, the decision was made to focus on self-reports of stress and associated psychological phenomena (e.g., anxiety, depression, workload). It was expected that, when there is a misfit between environmental conditions and the employee's needs, the employee would need to exert additional energy to overcome these demands. In the short term this may be unproblematic, however a period of prolonged exertion is likely to lead to the accumulation of stress and, eventually, exhaustion (Vischer, 2007, 2008).

In turn, higher levels of stress at work result increase the risk of both psychological illness (e.g., clinical depression, anxiety) and physical illness (e.g., cardiovascular disease, type 2 diabetes) for employees (Ganster and Rosen, 2013). Work stress is also associated with higher levels of absenteeism and presenteeism (Schmidt et al., 2019), and increases the likelihood that the employee will express an intention to quit the organisation (Jha, 2009). Hence, it can be reasonably assumed that studying the effects of the workplace environment upon stress, and devising strategies that workplace practitioners can use to mitigate environmental sources of stress, will be a valuable strategy for helping to reduce the overall deficits in employee wellbeing and the associated costs to the economy.

Thus, stress and its associated symptoms were determined to be the most important measures of wellbeing upon which to focus for the purposes of the research. Specifically, in the first study (*Paper I*), participants were simply asked to indicate the type of workplace environment which would help them to work in a stress-free manner. Self-reported stress was measured directly in the second study (*Paper II*), alongside more specific environmental complaints. In the third study, measures of anxiety-comfort and depression-enthusiasm were taken (*Paper III*), alongside measures of physical comfort. However, to reduce survey length, these were dropped from the fourth study (*Paper V*) and only the measures of physical comfort were taken. Finally, in the fifth study (*Paper VI)*, anxiety-comfort and self-reported stress were measured alongside ratings of perceived workload.

2.1.3 Productivity

For jobs in which a clear output per individual can be defined (e.g., products handled per hour, calls made per hour), productivity can be defined and calculated in a relatively straightforward manner. However, in the modern "knowledge economy", the majority of office-based employees produce outputs which are intangible and difficult to quantify, making it more complex to operationalise the construct.

In the academic literature, there is no clear consensus on the best way to resolve this complexity, and so a variety of different strategies have been used by researchers to measure knowledge worker productivity. Ramírez and Nembhard (2004) provide a taxonomy of the methods that have been used, including organisational metrics collected as part of normal operational practice (e.g., profitability, customer satisfaction), quantity-based metrics (e.g., the number of 'units' of work that are completed), and quality-based metrics (e.g., self-ratings of productivity, manager's ratings of productivity). Additionally, other researchers have also adopted a slightly more indirect way of measuring productivity, through quantifiable tests designed to mimic typical office work (e.g., reading comprehension, proofreading; Venetjoki *et al.,* 2006) and/or tests designed to replicate specific cognitive functions (e.g., tests of higher-order decision-making; Allen *et al.,* 2016; Satish *et al.,* 2012).

Each method has its own strengths and limitations. Organisational metrics relate most closely to the outcomes that employers are most interested in, but the relationship between organisational profitability and the productivity of a particular employee is complex and imprecise. Surrogate tests provide an objective measure of individual task performance, however the extent to which this relates to the employee's actual day-to-day work may be relatively low.

The approach taken for the purposes of the present research was to primarily use a subjective measure of self-rated productivity, but to complement this with an objective surrogate measure in certain cases. Specifically, in all but two studies (*Papers II, III, IV and V*) participants were asked to rate the extent to which they had been able to work productively, aligning with Kämpf-Dern and Konkol's (2017) conceptualisation of knowledge worker as "the degree to which stated objectives are being achieved… the relationship between forecast and executed work".

This approach was deemed to be the most appropriate because it recognises that the employees themselves are best placed to understand exactly what their work consists of, and to assess their own progress towards salient goals and sub-goals. Whilst this does raise the risk that employees' subjective responses might be biased in some way (e.g., unwillingness to report low productivity in case these responses are seen by their supervisor), this can be mitigated by ensuring employees that all responses are completely anonymous and stressing that accurate data is necessary to help the researchers understand how to help people to work in a more stress-free and productive manner.

In the other two studies, the research method used made it appropriate to use different measures of productivity. Because the first study *(Paper I)* concerned perceived requirements rather than actual requirements, participants were asked to indicate what sort of workplace environment would enable them to work most productively. Whilst this does not provide a direct measure of productivity, the insight gained using this approach can lead to the formulation of hypotheses about the types of workplace which are likely to be most and least conducive for different employees.

Lastly, in the final study (*Paper VI)* an experimental research design was adopted, in which the relative benefits of two working environments were contrasted. This made it possible to include within the experimental protocol the completion of tasks designed to mimic office work (proofreading and arithmetic) as a surrogate measure for productivity. A small limitation of this approach is the possibility that the surrogate tasks used are dissimilar to the type of office work that people actually do, however a unique benefit of using surrogate tasks is that it enables performance to be quantified and contrasted between different employees, free from the possibility of subjective bias. Overall, therefore, the use of both subjective and objective measures of productivity across the entire research programme can be considered a strength of the research.

2.1.4 The workplace environment

Simple definitions for the word environment include “the physical surroundings or conditions in which a person or other organism lives, develops, etc.” and “a particular set of surroundings or conditions which something or someone exists in or interacts with” (Oxford English Dictionary, 2020c). Elaborating upon this slightly, a publication by the U.S Department of Health and Human Services highlights the role of sensory experience, and defines the physical environment as “that which can be seen, touched, heard, smelled, and tasted… [and] also contains less tangible elements, such as radiation and ozone” (U.S.

Department of Health and Human Services, 2010, p. 19). Hence, a conceptualisation of the workplace environment should involve aspects of each definition.

The conceptualisation of the workplace by Forooraghi *et al.* (2020) meets this requirement, describing the workplace environment in terms of various environmental features arranged into three higher-order categories: (1) Indoor environmental quality (indoor air quality, thermal environment, luminous environment, acoustic environment); (2) Spatial factors (interior design, spatial layout); and (3) Socio-spatial factors (perceived privacy, perceived territoriality, perceived autonomy). Here, the workplace can be understood as both the physical surroundings or conditions in which a person works, as well as the ways in which they respond to and interact with those objective properties.

2.2 Theoretical Conceptualisations of the Workplace Environment

Clear definitions have now been established for environmental comfort, wellbeing, productivity, and the workplace environment, but how do all of those concepts fit together? The employee-workplace relationship is highly complex, and a theoretical framework is therefore important for unpacking this complexity and demonstrating how key concepts relate to one another. Conversely, limited use of theory raises the risk of iatrogenesis (i.e., unanticipated negative effects of well-intentioned interventions), due to limited understanding of the likely effects of a specific action on the wider employee-workplace ecosystem.

Whilst some theoretical frameworks for the workplace environment have been proposed, it has been noted that the majority of workplace studies tend to be unconnected to any underlying theoretical framework, and also remain segmented by discipline (Ashkanasy *et al.*, 2014; Sander *et al.*, 2018). Clearly, the literature still lacks a compelling theoretical framework within which to contextualise workplace research and practice. To address this gap, the purpose of this section is to briefly review previous theoretical frameworks for the workplace environment, highlight their limitations, and then propose a novel framework which addresses those limitations by identifying and mapping common concepts across different strands of the extant workplace environment literature (*Objectives I and II, leading into Objective VI*).

2.2.1 Previous theoretical frameworks for the workplace environment

Haynes (2007b) developed one of the earliest theoretical frameworks to represent the workplace environment, focusing in particular on the effects of the office on productivity. His factor analysis revealed that different attributes of office environments could be divided into four impactful factors. Comfort (e.g., IEQ, cleanliness) and office layout (e.g., informal meeting areas, privacy) were the important elements which characterised the physical environment, whereas interaction (e.g., social interaction, work interaction) and distraction (e.g., interruptions, crowding) were the important elements of the behavioural environment.

Other theoretical frameworks for the workplace environment have largely focused on the various ways in which the physical office environment can affect occupants. For example, as previously described in Section 2.1.1, the tri-partite model of environmental comfort proposed by Vischer (2008) considers that environmental forces can affect physical comfort (the influences on health and safety), functional comfort (the influence on the ability to complete work tasks effectively), and psychological comfort (the influence on perceptions of belonging, ownership, and control).

Similarly, Sander *et al.* (2019) developed a framework focusing on the effects of the workplace environment on psychological perceptions in particular. Following a scale validation process, they arrived at a three-dimensional framework consisting of focus (the influences on the ability to concentrate), sense of beauty (the influences on the aesthetic appreciation of the environment), and connectedness (the influences on perceptions of social connections within the organisation). The concept of focus corresponds with Vischer's (2008) concept of functional comfort, whereas sense of beauty and connectedness can be seen as distinct elements of psychological comfort.

Heerwagen *et al.* (1995) also considered comfort in their framework, essentially considering it to be a function of person-environment congruence (in line with more general theories of person-environment fit, e.g., Edwards and Billsberry, 2010). According to the person-environment congruence framework, the most effective workplace environments are those which support the idiosyncratic needs of their users. Whilst some employee needs are universal (e.g., belongingness, self-esteem, self-actualisation), others are significantly moderated by personal factors or task requirements. Hence, it is argued that workplace practitioners must recognise that different strategies will be required to achieve congruence (and therefore higher satisfaction and work performance) for different groups of users. Only in this way can a truly salutogenic (i.e., health-promoting) workplace be achieved.

Whilst each of these frameworks is valuable, they share in common a limitation that they do not explicitly represent the pathway between the physical environment, the occupants' perceptions, and work outcomes. Furthermore, they also share the limitation that they do not explicitly represent the complex and dynamic process by which the occupants and physical environment act upon one another.

2.2.2 The Job Demands-Resources Model

The limitations of previous theoretical representations of the employee-workplace relationships can be overcome by a domain-specific extension of a popular and influential model of work stress termed the Job Demands-Resources (JD-R) model, which was originally proposed by Demerouti *et al.* (2001) as an attempt to understand the antecedents of burnout through the accumulation of stress.

Influential models of psychological stress, such as the homeostatic model of stress (McGrath, 1970) and the conservation of resources theory (Hobfoll, 1989), posit that stress arises due to an imbalance between external demands and the resources of an organism. Adopting these concepts in the context of the workplace, a meta-analysis by Lee and Ashforth (1996) identified eight "job demands" and thirteen "job resources" as possible causes of burnout. Demerouti *et al.* (2001) went one step further by positing links between job demands and exhaustion and between job resources and engagement, and also by offering clear definitions for each of these concepts. A later revision of the model widened the scope beyond burnout to job performance more generally, and also added in the concept of job crafting to reflect the employee's ability to alter the demands and resources they experience at work (revised JD-R model shown below, in Figure 4; Bakker and Demerouti, 2014).

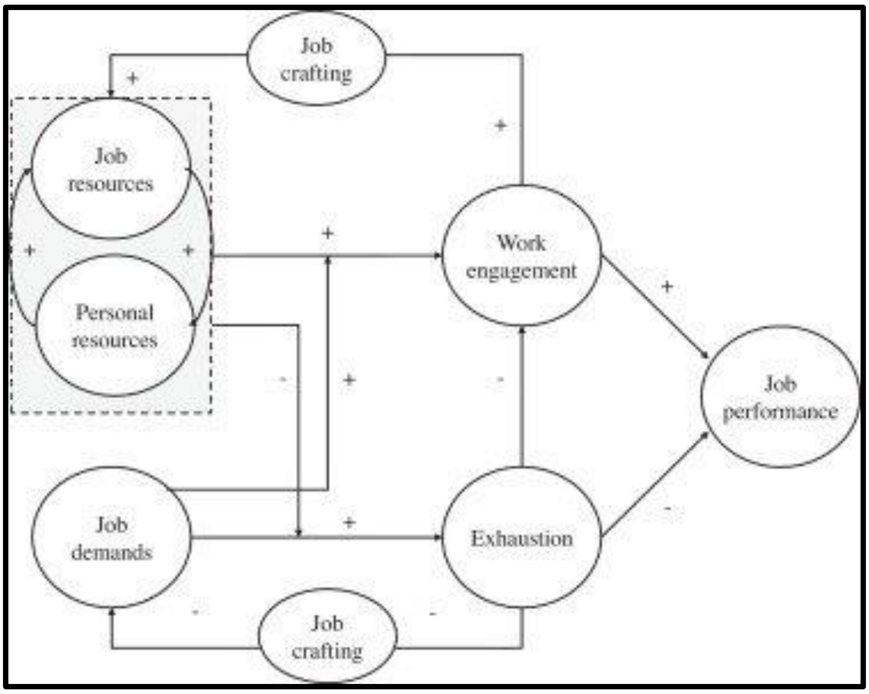

Figure 4: The Job Demands-Resources Model (Bakker and Demerouti, 2014)

The core propositions of the model can be outlined as follows. According to JD-R theory, every job shares in common certain risk factors (*job demands*) and opportunities (*job resources*) for impaired or enhanced wellbeing and functioning. Job demands are defined as "those physical, social, or organizational aspects of the job that require sustained physical or mental effort and are therefore associated with certain physiological and psychological costs" (Demerouti *et al.,* 2001, p. 501). To be considered a demand, the characteristic in question should be perceived negatively by the employee (as opposed to characteristics which are difficult but valued positively, and seen as providing an opportunity for personal growth and mastery; Schaufeli and Taris, 2014). Examples of job demands might include high workload, long working hours, and time pressure, amongst others.

Job resources, on the other hand, are defined as "those physical, social, or organizational aspects of the job that may do any of the following: (a) be functional in achieving work goals; (b) reduce job demands and the associated physiological and psychological costs; (c) stimulate personal growth and development" (Demerouti *et al.,* 2001, p. 501). Examples here might include organisational factors such as supervisor support and goal clarity, and can also be widened to include personal resources such as resilience and interpersonal skills (Xanthopoulou *et al.,* 2007).

Job demands and resources influence a variety of work outcomes through two mediating processes. First, the process of *exhaustion* can arise as a result of high demands and few resources. Repeated exposure to job demands requires the employee to expend high levels of energy to achieve work-related goals, with insufficient time for recovery, leading to a state of exhaustion. Similarly, a lack of job resources leads to a state of disengagement in which the employee is no longer motivated to expend effort to complete work. This combination (exhaustion and disengagement) is characteristic of burnout, which is in turn associated with a host of negative outcomes (e.g., higher absenteeism, higher turnover intentions, impaired physical and mental health).

Although the absence of job resources results in de-motivation, their presence triggers a separate pathway termed *work engagement.* Job resources satisfy universal human needs, leading to an intrinsically-motivated state of mind characterised by vigour (i.e., higher levels of energy and mental resilience whilst working), dedication (i.e., a sense of significance, enthusiasm, and challenge), and absorption (i.e., high levels of focus and feeling engrossed in one's work). In this way, work engagement is associated with a host of positive outcomes (e.g., higher productivity, positive affect at work, extra-role performance).

Whilst demands and resources are often fixed attributes of the jobs, it is also possible for employees to proactively reduce demands and increase resources through *job crafting* strategies. This term encompasses strategies aimed at altering the nature of the work being completed (*task crafting*), the subjective appraisal of the work being completed (*cognitive* *crafting*), and the relationships with clients and colleagues (*relationship crafting*) (Wrzesniewski and Dutton, 2001). In these ways, the employee may be able to make their work more enjoyable and meaningful.

Overall, the JD-R model has become one of the most popular and influential models of work stress in the literature. For example, a Google Scholar search conducted in April 2021 reveals that the original Demerouti *et al.* (2001) article has been cited more than 10,500 times. The model has an abundance of empirical support in the literature, having directly inspired hundreds of empirical articles which have tested and validated its core propositions, (Demerouti *et al.,* 2019).

For example, meta-analyses have been used to synthesise the large evidence base, and have confirmed the positive associations between job resources and work engagement (Christian *et al.,* 2010; Crawford *et al.,* 2010; Halbesleben, 2010), between job demands and burnout (Alarcon, 2011; Crawford *et al.,* 2010), and that outcomes such as dedication and commitment are positively associated with work engagement and negatively associated with burnout (Alarcon, 2011; Halbesleben, 2010; Christian *et al.,* 2010). The majority of the work has been cross-sectional, however a recent meta-analysis including only longitudinal studies also found support for the core propositions of the JD-R model (Lesener *et al.,* 2018), providing more rigorous evidence that the concepts are causally related to one another.

The authors also claim that the model has also been directly applied within thousands of organisations worldwide (Demerouti *et al.,* 2019). Indeed, as a result of its broadness and generalisability, it has been found to be equally applicable across a range of ostensibly disparate professions and different cultures. For example, similar support for the model is found amongst different samples of blue-collar and white-collar workers from Austria (Korunka *et al.,* 2009), Belgium (Hansez and Chmiel, 2010), and China (Hu *et al.,* 2011).

Thus, the conclusion that the JD-R model is a universal framework for describing conditions at work has merit.

Having said that, certain limitations of the JD-R model have also been noted. At the conceptual level, the distinction between a demand and a resource is not always clear (i.e., a lack of resources might be considered a demand), and similarly the distinction between engagement and strain is not always clear (i.e., an absence of engagement might be symptomatic of high strain). Additionally, the open nature of the model means that it does not have a clear and well-defined set of demands, resources, and psychological outcomes. Finally, there is a lack of specificity in the theory, meaning that additional models will be needed to describe specific relationships in more detail and with better predictive power (Schaufeli and Taris, 2014).

Whilst these limitations are certainly valid, and constrain the application of the JD-R model for certain purposes, the abundant evidence in support of the model demonstrates that JD-R theory remains highly valuable as a simultaneously simple yet comprehensive framework through which to view jobs and their expected outcomes. It may not be appropriate for making specific predictions about the effects of specific stimuli, but it describes the relationship between key concepts which are universally applicable across all job types. In practical terms, three broad strategies for enhancing employee wellbeing and productivity are suggested: (i) the mitigation of job demands; (ii) the enhancement of job resources; and (iii) the facilitation of job crafting.

2.2.3 The Environmental Demands-Resources Framework

Although the very first conceptualisation of the JD-R model highlighted an unfavourable working environment as a potential job demand (Demerouti *et al.,* 2001), the empirical JD-R literature has largely neglected the role of the physical environment (for exceptions, see Hakanen *et al.*, 2005; Morrison and Macky, 2017). Instead, job demands and resources have been understood almost entirely as personal, social, or organisational factors.

In recognition of this fact, as well as the fact that the workplace literature lacks a suitable framework for representing the complex and dynamic nature of the employee-workplace relationship, a novel extension of the JD-R model termed the Environmental Demands-Resources (ED-R) framework (Figure 5) has been proposed (Roskams and Haynes, 2019d, 2021; Roskams *et al.*, 2021). The term 'framework' is preferred to 'model' as it better captures the higher-order arrangement of key concepts, within which more detailed models can be specified.

Specifically, it is argued that many aspects of the workplace environment have the same effects as other job demands and resources, and that many common behaviours within the workplace can be considered as examples of crafting.

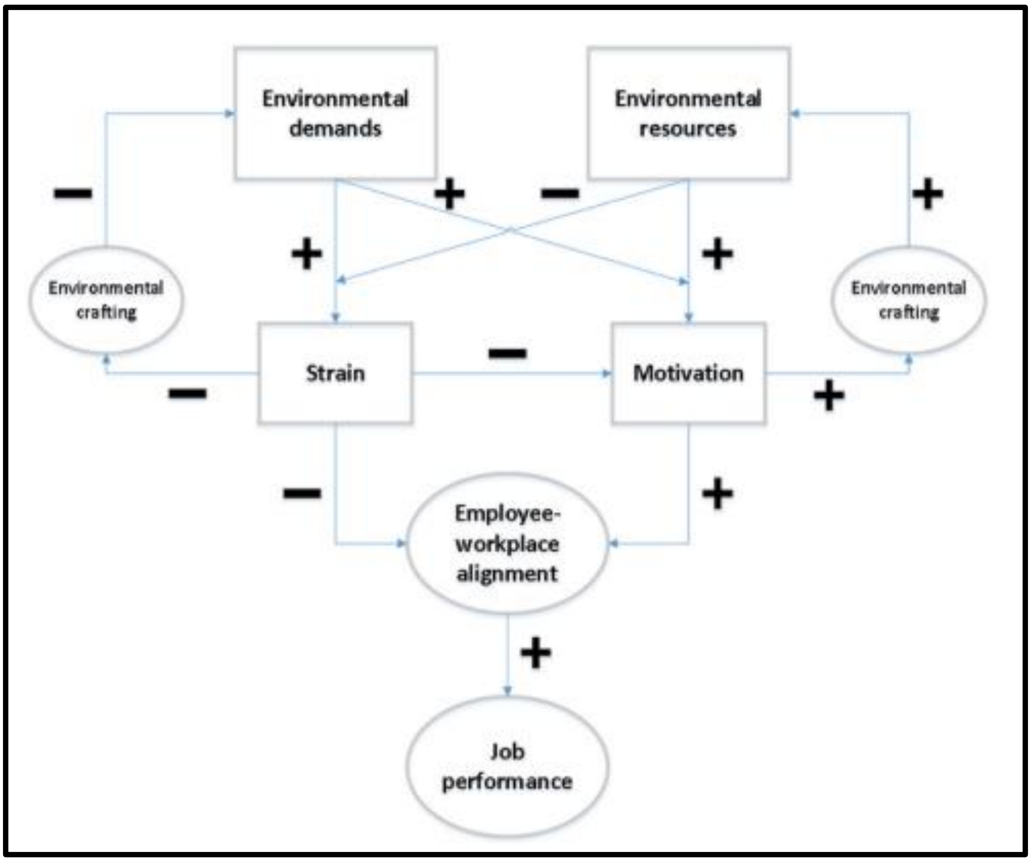

Figure 5: The Environmental Demands-Resources framework (Roskams and Haynes, 2019d)

Environmental demands can be defined as the pathogenic aspects of the workplace environment, whose presence requires the additional and sustained exertion of physical and/or mental effort. This corresponds with Vischer's (2007) concept of workspace stress, which can be understood as the degree to which employees must expend additional energy to compensate for adverse environmental conditions in the pursuit of work-related goals. This stress is brought about by those environmental characteristics which cause physical and/or functional discomfort (Vischer, 2008). In this way, chronic exposure to environmental demands is positively associated with the development of physical and/or psychological strain.

Environmental resources can be defined as the salutogenic aspects of the workplace environment, whose presence is associated with an enhanced ability to cope with demands and higher levels of work engagement. Here, there is overlap with Vischer's (2008) concept of psychological comfort, which is brought about by aspects of the environment which support feelings of belonging, territoriality, and ownership in the workplace. The concept can be further extended to other psychological needs too, in particular the sense of coherence (SOC; consisting of *comprehensibility, manageability,* and *meaningfulness*) proposed by Antonovsky (1987) as being critical for explaining why some individuals are better than others at coping with ubiquitous stressors and remaining healthy. In this way, aspects of the environment which contribute to comprehensibility (i.e., aiding understanding), manageability (i.e., enhancing the ability to cope), and meaningfulness (i.e., enhancing the feeling that the situation is worthy of investment) may also be crucial resources, positively associated with motivation and engagement (Roskams and Haynes, 2019d).

Environmental crafting refers to workplace behaviours which are directly motivated by a desire to improve the working environment (i.e., by reducing environmental demands and/or enhancing environmental resources). This is important because if the autonomy to mitigate sources of environmental stress is restricted, 'learned helplessness' can occur; that is, the individual simply succumbs to adverse environmental conditions instead of trying to improve them, leading to depressive symptoms and poorer work performance (Evans and Stecker, 2004). As such, it is important to consider the ways in which employees can effectively improve their working conditions. This might include choosing to work at a particular location (*spatial crafting*) or from a given location at a time of day when conditions are most suitable (*time crafting*) (Wessels *et al.,* 2019). Additionally, the term also encompasses strategies aimed at reducing demands and enhancing resources at the primary workspace (*local environment crafting*) (Roskams and Haynes, 2021).

Overall, the relative presence of demands and resources (relative to the idiosyncratic needs of each employee) determines the overall level of *employee-workplace alignment,* essentially reflecting the combination of physical, functional, and psychological comfort (Vischer, 2008). This is a similar concept to what has previously been termed ‘functional and psychosocial congruence’ (Heerwagen *et al.,* 1995), ‘need-supply fit’ (Gerdenitsch *et al.,* 2018; Wohlers *et al.,* 2019), ‘work pattern office-type (mis)fit’ (Soriano *et al.,* 2018), and as one component of the broader term ‘person-environment fit’ (Edwards and Billsberry, 2010). Essentially, each of these terms describes the extent to which the characteristics of the workplace environment (*place*) are aligned to the task requirements (*processes*) and personal preferences of the employee (*people*) (Haynes, 2012). Workplaces promoting strain will result in a perception of misalignment, whereas those supporting motivation will result in a perception of alignment.

It is predicted that higher employee-workplace alignment will lead to improved employee wellbeing and productivity, combined in the model using the more general term *job performance*. Mirroring the practical implications from the JD-R model, the ED-R framework leads naturally to three broad approaches for the optimisation of workplace environments: (i) the mitigation of environmental demands; (ii) the enhancement of environmental resources; and (iii) the facilitation of environmental crafting.

2.3 Summary

The workplace literature to date has been often limited by vague and imprecise uses of key terms, as well as by a lack of a suitable conceptual framework to represent the complex relationship between the employee and the workplace environment. In response to these limitations, this section has provided clear definitions of environmental comfort, wellbeing, productivity, and the workplace environment. The existing conceptual frameworks for the workplace environment were reviewed, and then the ED-R framework was presented as a framework which is capable of overcoming the limitations of previous approaches. In the next section, a review and conceptual analysis of the multidisciplinary workplace literature is undertaken (*Objectives I and II)* to validate the core propositions of the ED-R framework.

3.0 LITERATURE REVIEW

To achieve Objective I, this chapter presents the results of a comprehensive review of the multidisciplinary workplace literature, which is a slight adaptation of the results presented in Additional Paper II (Roskams and Haynes, 2021). The literature review serves two major functions. First, it enables a narrative review of the evidence base to be performed. This is a non-systematic form of literature review, the purpose of which is to simply use indicative studies to inform the reader about the current state of the science by summarising the extant research (Ferrari, 2015). In doing so, the review will highlight existing recommendations for workplace wellbeing, and also highlight the gaps in the research and the most important topic areas for future study. The results will be presented separately by discipline, focusing on different aspects of IEQ, spatial design, and socio-spatial factors.

Second, to achieve Objective II, the literature review also enables a conceptual analysis of the ED-R framework to be performed. A conceptual framework analysis is a technique which treats the extant literature as a data source which can be interpreted in order to "generate, identify, and trace a phenomenon's major concept, which together constitute its theoretical framework" (Jabareen, 2009, p. 53). Hence, whilst the narrative review of the workplace environment literature is performed, a secondary focus will be to identify common concepts across the different disciplines, and explore the extent to which the concepts of environmental demands, environmental resources, and environmental crafting are consistent with the results of existing studies.

By taking this approach, it will be possible not only to synthesise the research base to elucidate what is currently known about the impact of the workplace environment on wellbeing and productivity, but also to rigorously assess whether the ED-R framework is an appropriate lens through which to view the "phenomenon" of the employee-workplace relationship. In this way, the literature review makes a significant contribution to the development of the theoretical framework, which will subsequently underpin the programme of primary research.

3.1 Literature Review Methodology

The conceptual analysis was guided by the phases Jabareen (2009) proposed for the development of conceptual frameworks, with one small adaptation. Jabareen proposes that concepts are 'discovered' after an extensive reading of the relevant literature, whereas the process for developing the ED-R framework was slightly more cyclical. That is, the JD-R model had already provided *a priori* assumptions about the nature of the concepts (i.e., demands, resources, and crafting) and their interrelationships. As such, the purpose of the conceptual analysis was to evaluate the extent to which the workplace environment literature supports the existence of environmental demands, environmental resources, and environmental crafting behaviours. Hence, the three-phase approach to the conceptual analysis was as follows: (i) Map the disciplines comprising the multidisciplinary workplace environment literature; (ii) Extensively read and categorise the literature; and (iii) Evaluate the logical consistency of the proposed concepts.

The mapping of the workplace environment was largely achieved in Section 2.1.4 of the previous chapter, in which the various different components of the workplace environment were distinguished by Forooraghi *et al.* (2020). For the purposes of this section, these categories will be altered slightly to include an additional section on 'ergonomic quality' into the spatial factors category. This provides a conceptualisation of the workplace environment in terms of eight broad disciplines in three higher-order categories: (1) Indoor environmental quality (indoor air quality; thermal comfort; lighting and daylighting; noise and acoustics); (2) Spatial factors (spatial layout; interior design; ergonomic quality); and (iii) Socio-spatial factors (territoriality and autonomy). These categories will be used to structure the results of the literature review.

In line with the second phase proposed by Jabareen (2009), the aim was to understand how each environmental factor related to occupants' health, wellbeing, and/or productivity within offices. Given the breadth of scope of the review, comprising numerous subject areas which could each be considered separate disciplines of research in themselves, it was decided that it would not be plausible to systematically review every relevant piece of research. Rather, the purpose would be to use indicative reviews and studies to elucidate the current state of the science and to assess the propositions of the ED-R framework. Systematic review papers published in the last decade would be prioritised where possible, however if these did not exist for a particular discipline, the review could also include field studies and laboratory studies where the findings were generalisable to real office environments. Following this approach, the relevant literature was identified using a targeted keyword search in the Scopus database. The titles and abstracts of all identified articles were reviewed for relevance, and were passed on to full-text evaluation if they met the key inclusion criteria. To identify suitable papers which may have been missed by the initial searches, the reference lists and citations of each article were scanned to identify additional articles.

Finally, the third phase was addressed by identifying, categorising, and integrating common concepts across the disciplines. Specifically, the process of conceptual analysis involved assessing the extent to which the content of the papers aligned to the proposed conceptual framework of environmental demands, resources, and crafting behaviours. The results are expounded in the following sections of the review, considering evidence for the existence of environmental demands, environmental resources, and/or environmental crafting behaviours (referring back to the definitions introduced in Chapter 2) within each category of workplace environment research.

Overall, the review process yielded an initial typology of environmental demands, environmental resources, and environmental crafting strategies (showed in Table 1 at the end of the chapter, alongside the search terms used in the literature review).

3.2 The Findings of the Literature Review

3.2.1 Indoor air quality

The review highlighted numerous airborne pollutants within offices which clearly contribute towards physical and/or functional discomfort, and which can therefore be conceptualised as environmental demands. In indoor environments, airborne pollutants might be introduced from external sources (e.g., vehicular pollution entering through open windows), from internal sources (e.g., from cleaning products or building materials), and/or from human activity (e.g., human respiration, smoking tobacco). In many mechanically-ventilated office spaces the ventilation rate is too low to effectively remove these pollutants, contributing to a phenomenon known as “sick building syndrome” (SBS), referring to a set of symptoms (e.g., headaches, respiratory difficulties, tiredness) which occur when spending time in a specific building, typically a workplace (Burge, 2004). The development of SBS impairs physical health, and attempting to work whilst experiencing SBS symptoms also harms productivity.

To address these issues, workplace practitioners are tasked with periodically assessing the concentrations of airborne pollutants and ensuring that these comply with specified limits for health, safety, and wellbeing. Because it is complex and costly to measure every possible pollutant, CO_2 is commonly used as a surrogate measure for overall indoor air quality (Hui *et* *al*., 2008). In general, good indoor air quality is assumed when CO_2 is maintained at approximately 600-800 parts per million (ppm). For example, it has been demonstrated that the risk of experiencing SBS symptoms increases progressively as CO_2 rises above 800 ppm (Seppänen *et al.,* 1999). Lower concentrations of CO_2 also appear to support higher productivity; in one study, participants' cognitive performance was 101% higher at 600 ppm than at 1,400 ppm (Allen *et al.*, 2016).

However, the assumption that good air quality is always achieved when CO_2 is maintained below 800 ppm is flawed. Correlations show that the association between CO_2 and other pollutants tends to be significant but relatively weak (r^2 values < 0.4), and can be moderated by various seasonal, building-related, and occupant-related factors (Ramalho *et al.,* 2015). As such, it is perfectly possible for the indoor air to contain CO_2 below 800 ppm but still contain other pollutants contributing to SBS. For this reason, when it is possible to do so (e.g., when more advanced sensor technology is available), practitioners should seek to perform more comprehensive evaluations of indoor air quality instead of focusing solely on CO_2.

For example, other pollutants which have been linked to SBS include microscopic solid or liquid particles suspended in the air, which are collectively termed particulate matter (PMs) (Nezis *et al.*, 2019), as well as a group of organic chemicals collectively termed volatile organic compounds (VOCs) (Tsai, 2018). Additionally, compounds including nitrogen dioxide (NO_2), carbon monoxide (CO), and ozone (O_3) have also been linked to poorer health outcomes (International WELL Building Institute, 2020b), and should therefore also be included in a comprehensive indoor air quality assessment. Practitioners may also wish to assess humidity, as SBS symptoms tend to be exacerbated at low humidity (Wolkoff, 2018).

Finally, the olfactory environment (i.e., the presence or absence of fragrances in the air) can also be considered as a component of overall indoor air quality. Clearly, an unpleasant odour could be distracting and cause significant discomfort for building occupants, and can therefore be conceptualised as an environmental demand. However, it is also possible that more pleasant smells could function as resources by engendering desirable states of mind. For example, it has been demonstrated that exposure to pleasant fragrances induces positive affect, which can in turn lead to more optimistic goal-setting, more cooperative conflict resolution, and higher task performance (Baron and Bronfen, 1994; Baron and Thomley, 1994).

3.2.2 Thermal comfort

Thermal comfort is defined as "a state of mind which expresses satisfaction with the thermal environment", and is typically measured using a 7-point rating of thermal sensation from -3 ("Cold") to 3 ("Hot") (The American Society of Heating, Refrigerating, and Air-Conditioning Engineers [ASHRAE], 2004, p. 4). The opposite, thermal discomfort, is therefore a state of dissatisfaction (i.e., feeling too cold or too hot) which is unpleasant and distracts from work, resulting in lower productivity (Rupp *et al.*, 2015). Therefore, thermal conditions which result in dissatisfaction can also be considered as environmental demands.

According to ASHRAE (2004), occupant thermal comfort should be supported using one of two methods. In mechanically-ventilated buildings, the Predicted Mean Vote (PMV) method (Fanger, 1970) should be used. Based upon decades of research conducted with mannequins and human participants in climate-controlled laboratories, the PMV method uses three environmental inputs (mean radiant temperature, air velocity, and relative humidity) and two occupant-related inputs (clothing insulation and metabolic rate) to calculate an ambient temperature which ostensibly leads to thermal comfort amongst 95% of occupants. However, numerous studies have demonstrated that actual thermal comfort (i.e., occupants' self-reported thermal sensation) tends to be significantly poorer than that predicted by PMV (e.g., Beizaee *et al.*, 2012; Cheung *et al.*, 2019; Deuble and de Dear, 2012; Oseland, 1995; Rupp and Ghisi, 2017), indicating that the method may not generalise well outside of laboratory environments.

In naturally-ventilated buildings, ASHRAE (2004) recommend that the Adaptive Comfort Model (de Dear and Brager, 1998) should be used. This model recognises that wider contextual factors also affect thermal comfort, highlighting the role of the prevailing outdoor climate in particular. The adaptive comfort chart can be used for defining a thermal comfort zone within which 80% (wider zone) or 90% (narrower zone) of occupants should be satisfied. As the mean outdoor temperature increases, so too do the lower and upper bounds for the acceptable indoor temperature. However, the adaptive comfort model has also been criticised for its poor predictive performance when applied to individuals within real offices, and the fact that the model is unable to adapt or re-learn in response to occupant feedback (Kim *et al.,* 2018).

Due to the limitations of existing methods, thermal comfort is increasingly exploring a new paradigm of personal comfort models (Kim *et al.,* 2018). These models recognise that thermal comfort preferences can vary from individual to individual due to both biological factors (gender, weight, and age) and cultural factors (reflecting thermal history) (Karjalainen, 2011; Rupp *et al.,* 2015). Therefore, optimal thermal comfort can only be achieved when occupants are able to adjust local temperature conditions to their own preferences. This temperature adjustment can be seen as an obvious but effective example of environmental crafting. With individual control over temperature, occupants may be able to experience pleasurable sensations beyond just thermal neutrality (termed 'thermal alliesthesia'; Parkinson and de Dear, 2014) by directing pleasant warmth or cooling to different regions of the body. Research is still in an early stage, but one field study adopting the personal comfort approach found that thermal comfort votes increased to 96% by using desk chairs with controllable built-in heating and cooling mechanisms (Kim *et al.,* 2019).

3.2.3 Lighting and daylighting

Veitch (2001) highlights three different ways in which lighting quality can influence employee wellbeing and productivity: (i) through visual processes; (ii) through non-visual processes; and (iii) through psychological processes.

With respect to visual processes, the aim is simply to ensure that there is sufficient illumination to support visual acuity for office-based tasks (e.g., using computers, filling out paperwork). Here, an environmental demand would be the situation in which visual discomfort and eyestrain is caused by insufficient light and/or the sensation of glare (Carlucci *et al.,* 2015). To reduce the risk of this occurring, the Society for Light and Lighting (2015) recommend that illumination should be maintained at 300 lux or higher, combined with a contrast management strategy to reduce glare. This recommended ambient illumination level accords with the light intensity that people typically choose when they have individual control over task lighting (Veitch and Newsham, 2000a).

The effects of non-visual processes are largely centred around the extent to which the overall lighting environment represents (or mimics) natural daylight. Limited access to daylight causes diminished alertness and cognitive response (Aries *et al.*, 2013), because the regulation of circadian rhythms (which govern the sleep-wake cycle) is dependent on the stimulation of a photoreceptor which is maximally sensitive to wavelengths that are found in natural but not artificial light (Lucas *et al.,* 2014; Vandewalle *et al.,* 2009). Indeed, it has been demonstrated that access to daylight is consistently rated as one of the most important features of offices by occupants (Galasiu and Veitch, 2005), and that employees are more satisfied and alert under natural daylight (Edwards and Tocellini, 2002; Jamrozik *et al.,* 2019), or 'blue-enriched' light designed to artificially mimic natural daylight (Mills *et al.,* 2007; Viola *et al.,* 2008), compared to ordinary artificial light. Hence, limited access to natural daylight can also be classified as a potential environmental demand within offices.

Finally, there is also some suggestion that the luminous environment could also function as a resource. In her review, Veitch (2001) identifies two relevant psychological processes in particular which appear to be most promising. First, providing occupants with individual control over task lighting may be an effective way of accommodating changing demands and variations in daylight availability, although this may not be necessary in spaces with good lighting design. Second, specific lighting strategies (e.g., non-uniform light distribution) might be effective in terms of promoting interest and positive affect (thereby positively influencing motivation and work performance), although limited research has been conducted to test this claim.

3.2.4 Noise and acoustics

Noisy offices are an inevitable part of working life for many modern employees. This noise, typically in the form of conversations between staff members, often functions as a valuable resource; after all, it is typical means by which colleagues share knowledge, solve problems, and socialise with one another. However, noise is also perhaps the most oft-recognised environmental demand within offices (particularly open-plan offices), with acoustic comfort consistently rated the lowest aspect of environmental satisfaction by employees (Bodin Danielsson and Bodin, 2008, 2009; Jensen *et al.,* 2005). For any particular sound, the capacity for annoyance and work disturbance can be described as a function of both its measurable and subjective characteristics.

In terms of the measurable physical characteristics, researchers have explored how the loudness and pitch of a sound affects its propensity for discomfort. Generally, it has been demonstrated that individuals' self-reported annoyance tends to increase as the sound's loudness increases (Ayr *et al.*, 2001; Landstrom *et al.*, 1991), and that higher-frequency noises are typically judged to be more annoying than lower-frequency noises (Landstrom *et al.*, 1995; Veitch *et al.*, 2002). As a general rule, it has therefore been suggested that office noise levels should not regularly exceed 48 decibels (Bradley and Gover, 2004).

However, subjective characteristics, particularly the sound's intelligibility, are generally understood to have a larger impact (e.g., Job, 1988; Smith and Jones, 1992). Intelligible background speech can be particularly pernicious because it automatically draws attention and interferes with the articulatory rehearsal process in working memory (Gathercole and Baddeley, 1993). As such, any form of cognitive work which involves reading or writing becomes disrupted by the presence of background speech (e.g., Haapakangas *et al.*, 2014; Haka *et al.*, 2009; Liebl *et al.*, 2012). Indeed, background speech is frequently cited as the most annoying aspect of open-plan offices (Haapakangas *et al.*, 2008; Jensen *et al.*, 2005; Mak and Lui, 2012), resulting in an approximate tenfold increase in acoustic complaints (Pejtersen *et al.*, 2006) and an estimated doubling in the amount of time wasted due to noise (Kaarlela-Tuomaala *et al.*, 2009) in open-plan offices relative to enclosed offices.

Context-appropriateness and predictability have also been highlighted as being important determinants of noise annoyance. When a sound is deemed to be inappropriate for the context or unpredictable, it is more likely to cause annoyance (Emberson *et al.*, 2010;

Glass and Singer, 1972; Graeven, 1973). However, annoyance in the face of unpredictable sounds can be mitigated by providing individuals with control over the noise source (even if that control is not actually exercised) (Carton and Aiello, 2009; Glass and Singer, 1972). This implies that it is of crucial importance to ensure that open-plan office occupants are able to escape annoying noises if they need to, for example by having the freedom to work from a different location (spatial crafting), arriving early or staying late to avoid the busiest periods (time crafting), and/or being permitted to use noise-cancelling headphones (local environment crafting).

Finally, it should be recognised that employees may vary considerably in their responses to the same noises, as a result of individual difference factors. For example, characteristics associated with greater disturbance by background noise include higher introversion (Belojevic *et al.*, 2001; Cassidy and MacDonald, 2007; Dobbs *et al.*, 2011; Geen, 1984; Oseland and Hodsman, 2018), higher noise sensitivity (Haapakangas *et al.*, 2014; Kaarlela-Tuomaala *et al.*, 2009; Park *et al.*, 2018), and a greater need for concentration due to difficult work tasks (Fried *et al.*, 2001; Seddigh *et al.*, 2014). This suggests that the appropriate strategies to enhance acoustic comfort within a workplace will depend on the specific characteristics of the office occupants.

3.2.5 Spatial layout

The interior architecture of an office can significantly alter the demands and resources to which the occupants are exposed. Historically, it was more common for employees to work in private offices (i.e., private rooms with closable doors) before a gradual transition was made towards various different forms of open-plan office (where the desks of numerous employees are within the same room, often with few or no partitions between individual workstations) (van Meel, 2000). Although advocates of open design highlight increased opportunities for knowledge-sharing and collaboration, it should be noted that the transition is at least partially motivated by cost reduction; the removal of interior walls and the use of shared desks enables a higher number of employees to be accommodated within the same space (Brennan *et al.*, 2002; Hedge, 1982).

Overall, the research evidence suggests that this space efficiency comes at the cost of the wellbeing and productivity of the workforce. Compared with employees in enclosed offices, open-plan office employees score lower in terms of overall environmental satisfaction, job satisfaction, perceived productivity, perceived privacy, and quality of sleep, whilst reporting higher perceptions of crowding, emotional exhaustion, and absenteeism (Bodin Danielsson and Bodin, 2008, 2009; de Been and Beijer, 2014; de Croon *et al.*, 2005; Kim and de Dear, 2013; Sundstrom *et al.*, 1980; Laurence *et al.*, 2013).

Furthermore, the purported benefits of open-plan offices do not typically arise; a growing body of cross-sectional and longitudinal research indicates that communication actually tends to worsen in open-plan offices (Bernstein and Turban, 2018; Kaarlela-Tuomaala *et al.*, 2009; Kim and de Dear, 2013; Pejtersen *et al.*, 2006). Hence, the overall picture of open-plan offices is one of increased environmental demands, with no compensatory increase in resources.

However, it is worth acknowledging that not all open-plan offices are necessarily low-quality workplaces. For example, in the Leesman Index's database of more than 2,000 workplaces, nine out of the top ten highest-performing offices were predominantly open-plan (Oldman and Rothe, 2017). Relatedly, certain employees may be better suited to open-plan than private offices, particularly if their job necessitates collaborative rather than individual work (Haynes, 2008). Therefore, open-plan offices may still be effective workplaces, provided that the employees who work within them are those who require more interaction at work, and provided that the most common environmental demands within this type of office (e.g., noise, crowding, lack of privacy) are mitigated.

3.2.6 Interior design

Research into interior design highlights that certain objects within the workplace environment can function as environmental resources, by reducing the impact of stress and by giving rise to positive states of mind. In particular, the majority of relevant research here has concerned the impact of *biophilic* design, which essentially describes the integration of nature and natural analogues into the indoor built environment (Ryan *et al.*, 2014).

In line with the evolutionary hypothesis that humans possess an innate affinity for life and lifelike processes (Wilson, 1984), research has consistently demonstrated that exposure to nature instigates a restorative process characterised by reductions in psychophysiological stress, the recovery of depleted attentional resources, and general improvements in health (Hartig *et al.,* 2014; Kaplan and Kaplan, 1989; Norwood *et al.,* 2019; Park *et al.,* 2010; Ulrich, 1983, 1984).

Accordingly, biophilic design within offices (typically involving interior plants and window views of nature) has been associated with numerous benefits, including lower subjective stress, better self-reported health and job satisfaction, improved information process and management, greater attention capacity, and higher self-rated productivity amongst employees (Gillis and Gatersleben, 2015; Lohr *et al.*, 1995; Kaplan, 1993, 1995; Nieuwenhuis *et al.,* 2014; Raanaas *et al.,* 2011; Smith and Pitt, 2005).

It has also been demonstrated that indoor plants engender an *instorative* effect (i.e., intrinsic benefits to attention and cognitive processing which arise even when cognitive resources were not previously depleted), suggesting the benefits of biophilic design extend beyond just restoration (Beute and de Kort, 2014). In these ways, biophilic design clearly functions as an environmental resource which serves to improve the manageability of the oft-demanding workplace environment.

Relatedly, it is possible that similar benefits may be derived from the aesthetic quality of the interior design, which can be understood as the sensory experience it elicits with respect to the perception of beauty (Elsbach and Pratt, 2007; Vilnai-Yavetz *et al.,* 2005). Philosophers of architecture recognise that the aesthetic appreciation of architectural objects gives rise to an extended range of psychological states (Fisher, 2016), suggesting an indirect pathway by which employee wellbeing and productivity might be enhanced by aesthetically-pleasing design.

Research into the effects of workplace aesthetics on employee wellbeing and productivity remains rare, although it has been found that aesthetic appreciation of the office contributes to overall workplace satisfaction (Bodin Danielsson, 2015) and that aesthetic quality remains one of the most crucial considerations for workplace designers in practice (Appel-Meulenbroek *et al.,* 2018). Possibly, the fact that the elicitation of awe promotes creative thinking (Chirico *et al.,* 2018; McCoy and Evans, 2002) might suggest that certain design features could inspire states of mind conducive to more effective work, however this is speculative and has not yet been tested in the workplace domain.

3.2.7 Ergonomic quality

The interior furnishings of an office can also exert an influence on employee wellbeing and productivity through their ergonomic quality. In particular, chairs, desks, and computer arrangements which do not adhere to ergonomic guidelines raise the risk of physical discomfort, thereby constituting an environmental demand. For example, the development of musculoskeletal symptoms in the spine and neck has been associated with non-adjustable seating arrangements, poor posture, and a close keyboard position to the body (Jun *et al.,* 2017). Over time, this could result in chronic pain for office occupants, resulting in increased presenteeism and absenteeism.

A related concern is that of sedentary behaviour, which in this context would arise from the requirement for prolonged periods of sitting down whilst at work. High sedentary behaviour also contributes to musculoskeletal pain, and has been associated with the development of even more serious health impairments such as type 2 diabetes, cardiovascular diseases, and certain types of cancer (Owen *et al.,* 2008). To reduce this risk, practitioners can ensure that employees have the ability to switch between seated and standing positions throughout the working day (e.g., through adjustable sit-stand desks or non-adjustable standing desks in addition to regular seated desks).

3.2.8 Socio-spatial factors

The socio-spatial dimension of an office reflects the interaction between its physical characteristics and the users' actions, in particular with respect to the users' perceptions of territoriality, control, and privacy (Forooraghi *et al.,* 2020). The effects of the workplace environment on privacy were discussed in the discussion regarding spatial layout (section 3.2.5), so this section will focus on territoriality and control.

Territoriality is defined as a behaviour by a person or group which stems from a feeling of ownership of a place or object (Brown *et al.,* 2005). In the context of the workplace, territoriality is frequently observed at the level of the individual workspace, and desk personalisation (e.g., with photos of loved ones, artwork) is very common. Not only does this define personal territory, it also serves to accelerate personal identity expression and imbue the workplace with a sense of meaning and comfort, and buffer the impact of low privacy (Ashkanasy *et al.*, 2014; Brunia and Hartjes-Gosselink, 2009; Greene and Myerson, 2011; Laurence *et al.*, 2010; Wells, 2000). In this way, the objects of personalisation function as environmental resources, whereas the process of personalisation is a valuable form of environmental crafting.

However, a recent major transition in the nature of work has significantly affected the potential for territoriality within offices. Historically, it has been common for offices to employ a 'fixed' concept, in which each employee had their own desk. More recently, however, developments in work technology have afforded the possibility for non-territorial or 'activity-based' forms of working, in which employees have no fixed desk but are instead provided with the autonomy to work from the most appropriate location for the task at hand (Veldhoen, 2008). Depending on the precise policies employed by the organisation, this may or may not include potential workspaces outside the office building (e.g., working from home, cafés, libraries). In this way, activity-based working supports the psychological need for control, but may do so at the expense of territoriality.

Overall, the evidence base for activity-based working is mixed (Engelen *et al.*, 2019). It is likely that its effectiveness is highly variable because it depends on both the implementation procedure and the characteristics of the workplace users. It appears to be least effective amongst employees who perceive no benefit in switching workstations regularly, who have been found to resist the concept and persist with territorial behaviour (Appel-Meulenbroek *et al.*, 2011; Hoendervanger *et al.*, 2016; Skogland, 2017). The persistence of territoriality in offices where it is explicitly discouraged raises the likelihood of territorial infringement, which may result in negative affect, anger, and a mistrustful interpersonal environment (Ayoko and Härtel, 2003; Brown and Robinson, 2011; Monaghan and Ayoko, 2019).

However, in line with the assumption that the enhancement of environmental crafting is typically desirable because it enhances control, successful implementations of activity-based working have also been noted. Importantly, the implementation process should ensure that employees are involved in the co-creation of explicit rules for using the activity-based workplace (Babapour Chafi and Rolfö, 2019; Rolfö, 2018), which can effectively ensure the implemented policies are aligned with the users' needs. Indeed, those who are most satisfied and productive in activity-based offices are those who have the highest perceived alignment with the concept (Gerdenitsch *et al.*, 2018; Hoendervanger *et al.*, 2019). Overall, therefore, the implementation of activity-based working can be an effective way of facilitating environmental crafting and thereby enhancing the perception of autonomy.

3.3 Summary

The review of the multidisciplinary workplace environment literature showed that the core propositions of the ED-R framework are logically coherent and have good support in the research literature. The findings revealed that disparate aspects of the environment are similar in that they contribute to physical and/or psychological strain and have an overall negative impact on job performance (and can therefore be classified as environmental demands), whereas others have a more positive impact by facilitating stress recovery and/or improving work engagement (and can therefore be classified as environmental resources). Many behaviours within the workplace are directly motivated by reducing these demands and/or enhancing these resources, and can therefore be considered as examples of environmental crafting. Overall, the workplaces which are most supportive of wellbeing and productivity appear to be those which are most aligned to the needs of the users. Hence, the ED-R framework can be accepted as an appropriate conceptual framework within which to situate the programme of primary research.

Table 1. The results of the conceptual analysis of the multidisciplinary workplace environment literature. The three right-hand columns present an initial typology of environmental demands, environmental resources, and examples of environmental crafting.

Workplace Environment Factor	**Keyword Search**[1]	**Environmental Demands**	**Environmental Resources**	**Environmental Crafting**
Indoor Air Quality	"indoor air quality" OR "indoor air pollutants" OR "ventilation rate" OR "air quality"	CO_2; CO; O_3; VOCs; PMs; NO_2; Humidity; Unpleasant odours	Pleasant fragrances	
Thermal Environment	"thermal comfort" OR "temperature" OR "thermal sensation" OR "thermal satisfaction"	Thermal discomfort (too cold); Thermal discomfort (too warm)	Thermal alliesthesia	Cooling fan; Personal heater
Acoustic Environment	"acoustic comfort" OR "noise" OR "background speech" OR "irrelevant speech" OR “speech distraction” OR “psychoacoustics”	Too loud; Too quiet; Annoying non-speech sounds; Annoying speech	Valuable speech (work-related); Valuable speech (non-work-related)	Headphones; Time crafting; Spatial crafting
Luminous Environment	“lighting" OR "light quality" OR "daylighting" OR "access to daylight" OR "natural light" OR "access to natural light"	Insufficient light; Glare; Insufficient access to daylight	Interest-evoking lighting	
Spatial Layout	"office layout" OR "office design" OR "workplace layout" OR "workplace design" OR "workspace layout" OR "workspace design")	Perceived crowding; Lack of privacy; Auditory distractions; Visual distractions; Isolation	Valuable social interactions (work-related); Valuable social interactions (non-work-related)	Time crafting; Spatial crafting
Biophilic Design	"biophilic design" OR "biophilia" OR "interior plants" OR "indoor plants" OR "nature-based design" OR "nature views" OR "views of nature"		Interior plants; Interior water features; Design which evokes nature	

Aesthetic Design	"aesthetic design" OR "aesthetics" OR "beauty"		Aesthetically-pleasing design	
Ergonomic Design	"ergonomics" OR "ergonomic quality" OR "furniture"	Uncomfortable furniture; Requirement for prolonged period of sitting		
Privacy / Crowding	"privacy" OR "crowding" OR "density"	Lack of visual privacy; Lack of auditory privacy; Perception of crowding		
Autonomy / Control	"autonomy" OR "individual environmental control" OR "local environmental control" OR "personal comfort system" OR "personal comfort device" OR "activity-based working" OR "non-territorial office" OR "flexi office" OR "flexible working" OR "agile working"	Lack of autonomy; Lack of control		Cooling fan; Personal heater; Headphones; Time crafting; Spatial crafting
Territoriality / Ownership	"psychological comfort" OR "territoriality" OR "appropriation" OR "ownership" OR "personalisation" OR "personalization"		Perceptions of ownership; Perceptions of belonginess	

1. The titles, abstracts, and keywords of research articles were searched with the keywords. All factor-specific search strings were followed by "AND TITLE-ABS-KEY ("wellbeing" OR "well-being" OR "health" OR "productivity" OR "job performance") AND TITLE-ABS-KEY ("workplace" OR "office" OR "workspace"))". To prioritise review papers published since 2010, we added "AND DOCTYPE (re) AND PUBYEAR > 2009" to the search string in a second round of searches.

4.0 RESEARCH METHODOLOGY

A programme of primary research was conducted to investigate Objectives III to V. The purpose of this chapter is to outline the research methodology that was adopted in this programme. This includes a comment on the epistemological position that was adopted, a general summary of the specific research designs and methodologies that were adopted in each study (more detailed descriptions are provided in the studies themselves), and a comment on the ethical considerations of the research.

4.1 Epistemological Considerations

A research paradigm can be defined as “a cluster of beliefs and dictates which for scientists in a particular discipline influence what should be studied, how research should be done, and how results should be interpreted” (Bryman, 1988, p. 4). A researcher’s paradigm is directly informed by ontological assumptions (answers to questions concerning the nature of reality, e.g., ‘What is there?’, ‘What constitutes reality?’) and epistemological assumptions (answers to questions concerning the nature of knowledge, e.g., ‘What constitutes valid knowledge?’, ‘How can we obtain it?’), and subsequently informs the research methodologies that are used to access knowledge.

The current research programme was informed by the *pragmatist* paradigm. Pragmatism is a recent development in research philosophy, which sought to occupy the middle ground between the two prevailing paradigms which preceded it: *positivism* (based on an objectivist ontology, in which reality is considered to be independent of social actors) and *interpretivism* (based on a constructionist ontology, in which social phenomena and their meanings are considered to be continually created by social actors) (Bryman and Bell, 2011; Mentzer and Kahn, 1995).

Whereas positivism and interpretivism are typically held to be exclusive, pragmatism rejects the traditional assumption that social research inquiry can access reality though a single scientific method alone. Rather, it adopts an inherently dualistic approach, and argues that both hypothetico-deductive quantitative methods (traditionally aligned with positivism) and inducive qualitative methods (traditionally aligned with interpretivism) are equally valid for addressing different types of research question (Morgan, 2014).

4.2 Research Approach

In accordance with a pragmatist research paradigm, this research project uses the most appropriate research method for the precise topic of investigation. The aim of the research was to make *predictions* about the nature of the employee-workplace relationship, which could subsequently be translated into recommendations for improving the workplace environment. As such, it was decided that quantitative methods would be most appropriate for answering these types of research question, based upon an objectivist ontology and hypothetico-deductive reasoning.

The research approach for each primary research study was therefore broadly similar. First, the relevant literature was reviewed in order to derive logically-coherent predictions (*hypotheses*) about the nature of reality. Then, quantitative data were collected and statistical tests were performed to test these hypotheses. Finally, the strength of the evidence against the hypotheses was assessed, before the theoretical and practical implications of the research were considered.

4.3 Sampling Approach

The main aim of the research was to develop a more detailed understanding of the impacts of the physical workplace environment on the comfort, wellbeing, and productivity of office-based employees. As such, the inclusion criteria were the same for each study: participants must simply be “knowledge workers” (i.e., employees whose work output consists of mental, rather than physical, processes) above the age of 18.

Given that the author completed the research in partnership with a facilities management organisation, the decision was made to utilise the existing networks of this organisation for the purpose of recruiting appropriate samples for the research. Originally, it had been intended to conduct the research at the sites of external clients who had a contract with the facilities management organisation. However, early discussions with senior management at the host organisation indicated that this would not in fact be possible, and so it was suggested that the research could be conducted at different internal office sites instead.

This early difficulty, combined with the more typical challenges associated with conducting research in real organisations (e.g., difficulties in recruitment due to employees being too busy to participate in research), raised the risk of small sample sizes. In turn, a small sample size would have led to low statistical power, reducing the chance of detecting statistically significant effects and also reducing the chance that a significant finding reflects a ‘true’ effect in the population (Button *et al.,* 2013). As such, the decision was made to use a convenience sampling method in which the researcher would simply aim to recruit the maximum number of participants from the available sites for research.

A small limitation of this non-probabilistic sampling method is that it increases the risk that the sample will not be stratified by important characteristics (e.g., age, sex), which would affect the generalisability of the findings to the overall population (Etikan *et al.*, 2016).

However, the benefits in terms of increasing the likelihood of achieving a sufficient sample size were deemed to outweigh this minor risk, and all research conclusions were appropriately caveated with a discussion on the potential limitations to generalisability.

4.4 Description of Study Methodologies

In total, five primary research studies (resulting in six research outputs, *Papers I* to *VI*) were conducted to achieve Objectives III to V (the relationship between specific objectives and specific publications was shown earlier, in Figure 1). Given that these objectives were broad in scope and each had different foci, a variety of different research methodologies were used throughout the programme of research.

As noted in the previous section, the decision had been made to conduct the research at office sites belonging to the collaborating organisation. Across the course of the project, five regional offices from the organisation were used as sites for different studies. This collaboration opened up the possibility of various different types of research. One possibility that was considered early in the research process was to take a case study approach, and conduct a detailed contextual analysis of the organisation itself (e.g., Yin, 1994). However, upon reflection, it was decided that the aim of the research should be to generate an understanding of the employee-workplace relationships which could generalise beyond a single organisation, and be equally applicable to all knowledge workers, regardless of the specific organisation or industry. Hence, although the participants in all of the research studies were employees of the organisation who were co-funding the research, the focus was not on the organisation itself, but rather on the associations between key environmental data and subjective responses, so that broad conclusions could be generated about the effects of the workplace environment on employees.

4.4.1 Exploring the role of individual differences

To explore the ways in which requirements for the workplace environment are moderated by individual difference characteristics (*Objective III*), two research studies were conducted.

The first study (*Paper I*) explored the extent to which specific demographic characteristics, personality traits, and task characteristics were associated with differences in perceived requirements for the workplace environment. To this end, a questionnaire was developed to measure the employee characteristics of interest, as well as perceived requirements for four aspects of the workplace environment: workspace segregation (i.e., the extent to which the workspace is in an enclosed or open location within the office), workspace territoriality (the extent to which the employee is permitted to personalise their workspace), individual environmental control (the extent to which the employee is able to control local environmental conditions at wok), and aesthetic quality (the extent to which care and attention has been paid to the 'look and feel' of the workspace). The questionnaire was then distributed to employees at 11 office sites nationwide (approximately 2,500 employees) using e-mail mailing lists and the organisation's intranet. In total, it was completed by 384 employees. Multiple regression analyses were used to explore the associations between the variables of interest.

The second study (*Paper II*) followed on from this research, and aimed to determine the extent to which individual difference characteristics predicted employees' experiences of acoustic comfort, well-being, and productivity in open-plan offices. This research was conducted at three open-plan office sites, at which surveys were completed by a combined total of 166 employees. Multiple regression analyses were again used to explore the associations between the variables of interest, with controls added to mitigate the effects of any between-site variance. This study was conducted in partnership with collaborators from the University of Liverpool, who also performed measurements of physical acoustic factors (e.g., active noise levels, reverberation time) at each site and tested the extent to which these predicted subjective responses, before reporting these results in a separate publication (*Additional Paper III*).

Both of these studies utilised a cross-sectional research design, in which a questionnaire was utilised to collect data at one time only. The purpose of the research was primarily analytic rather than descriptive; the use of multiple regression analyses enabled hypotheses about the assumed associations between input variables (i.e., employee characteristics) and output variables (i.e., perceived workplace requirements or experiences within open-plan offices) to be tested. The ability to perform this type of analysis in an effective yet relatively inexpensive manner is the major benefit of analytic cross-sectional research (Weng and Chang, 2020).

A limitation of cross-sectional research is the fact that measuring inputs and outputs simultaneously does not enable causal inferences to be made. However, it is nonetheless a valid tool for generating tentative assumptions about causality which can be further investigated using different research methods in subsequent studies (Weng and Chang, 2020). Moreover, in the present context, the ‘reverse causality’ explanation for a significant association (e.g., that higher levels of productivity in open-plan offices causes higher extraversion) is logically incoherent, given that the employee characteristics were either wholly or partially biologically determined (e.g., gender, age, noise sensitivity), or determined by job design (e.g., task complexity, need for interactivity). Thus, the inability to prove causality was not a major limitation for this research, and the analytic cross-sectional method was deemed appropriate for testing hypotheses in which causal relationships could be assumed.

4.4.2 Predictive analytics in facilities management

The purpose of the next phase of the research was to develop a methodology for predictive analytics in facilities management (*Objective IV*). Previous approaches had tended to only perform spot measurements of IEQ or to eschew IEQ measurement entirely, due to the high costs associated with measurement. As a result, the data often lacked practical utility, as it failed to capture spatio-temporal specificity in environmental conditions (i.e., the fact that IEQ might vary at different parts of the workplace and at different times of day). There are also limitations in the previous approach for capturing subjective data, which is typically done using an occupant survey completed at one time only, typically 6-12 months after occupying a new workplace. These responses also lack spatio-temporal specificity, and may be biased by various forms of bias (see Introduction sections of Papers III, IV and V for a more detailed discussion of the limitations of previous approaches). As such, the new methodology needed to meet a growing call for research which combines 'right-here-right-now' assessments of the workplace environment with local IEQ data captured at the same time (e.g., Candido *et al.*, 2016; Choi and Lee, 2018; Deuble and de Dear, 2014; Li *et al.*, 2018).

To meet this objective, two studies were conducted. The aim of the first study, which was the third of the overall research programme, was to conduct a pilot investigation into the use of environmental sensor data to predict momentary subjective assessments of the workplace environment. The study was conducted within one office site which had permanently-installed environmental sensors. In total, 15 employees from this office were repeatedly sampled across an 11-day study period, providing 78 survey responses in total. The respondent provided their current location in each survey, enabling their responses to be combined with the average IEQ measurements from the nearest environmental sensor in the half hour preceding the survey responses. This made it possible for the effects of IEQ on subjective comfort, wellbeing, and self-reported productivity to be tested, using multilevel regression models.

These analyses were separated into two published outputs (*Papers III* and *IV*), as they focused on different topic areas. In Paper III, the analyses focused purely on the subjective responses, exploring the associations between environmental comfort, wellbeing and productivity, and testing whether repeated assessments were more valid than the more typical 'one-time-only' questionnaire. In Paper IV, the analyses focused on exploring the extent to which environmental sensor data could be used to predict occupants' subjective comfort.

The next study, which was the fourth of the research programme (*Paper V*), built upon this pilot study, and aimed to approximately replicate the methodology with a larger sample. The methodology was slightly adapted (e.g., by using smartphone reminders rather than e-mail reminders, reducing the length of the survey) in a bid to achieve a higher response rate. Two office sites participated in the research, one of which had environmental sensors permanently installed and one which installed sensors temporarily. In total, 45 employees from these offices were repeatedly sampled across a two- or four-week period, and together provided 536 completed surveys. Again, multilevel regression models were used to test the extent to which environmental sensor data could be used to predict occupants' experiences of comfort.

The method adopted in these studies is known as the 'experience sampling' methodology (Fisher and To, 2012). The most obvious advantage of using the experience sampling approach in this context is that it enables the measurement of momentary perceptions (i.e., an employee's perception of comfort, wellbeing, or productivity 'right-here-right-now). This is considered advantageous because, just as IEQ can change on a moment-by-moment basis, so too can the individual's response to environmental conditions. For example, across any given week, an employee might have experienced a range of comfort-related sensations (e.g., too hot, too cold, comfortable). This diversity of sensation cannot be captured using a general question asking the respondent to report comfort across a prolonged period of time (as per previous methods), but can be adequately captured using experience sampling.

One limitation of the method is that repeatedly completing surveys places a higher response burden on participants, potentially leading to low initial up-take and high drop-out across the course of the study (Fisher and To, 2012). To mitigate this, a relatively short survey was used for Papers III and IV (~5 minutes to complete), followed by an even shorter survey for Paper V (~2 minutes to complete) in which single items were used to measure only the key variables. Whilst the use of single-item measures can be viewed as a slight limitation in that it does not enable the same level of detail to be captured, previous research has in fact indicated that single-item measures of a construct tend to yield similar responses to their multi-item equivalents (Gardner *et al.*, 1998). As such, the use of single-item measurements within the experience sampling method was not considered a major limitation of the present research.

4.4.3 Stress recovery in the workplace environment

Finally, to explore innovative design strategies for improving employee wellbeing through the workplace environment (*Objective V*), one additional study was conducted (*Paper VI*). The opportunity for this study arose following the host organisation's decision to construct two 'regeneration pods' at their head office, which provided a unique opportunity for a research study. These biomorphic bamboo pods, which had been commissioned as part of a wider workplace wellbeing initiative, were designed so that employees would have a secluded space for relaxation or meditation within the office. Additionally, users were also able to initiate an acoustic soundscape from overhead speakers featuring calming nature sounds, designed to further enhance the relaxation experience.

Hence, the aim of the study was to explore the extent to which the biophilic regeneration pods effectively enhanced the benefits of a short break from work. A randomised field experiment design was adopted, in which participants completed stressful tasks before being randomly allocated to either an intervention condition (the regeneration pods) or a control condition (an ordinary meeting room) for a short break. At four separate timepoints during the protocol, participants completed measures of perceived stress, anxiety, and task-load, and also completed tasks to measure productivity. In total, 32 employees completed this experimental procedure.

The use of the randomised experimental protocol had several benefits. By randomly assigning participants to either the treatment or control group, the risk of systematic differences between the two groups is reduced, increasing the confidence that any observed effect really is a result of the experimental manipulation. Similarly, adopting an experimental design enables the researcher to have tight control over study conditions, ensuring that participants in both groups experience exactly the same protocol except for the experimental manipulation. Again, this reduces the likelihood that an observed effect is the result of an unmeasured confounding variable. Finally, a benefit of conducting these experiments directly within the location of interest (i.e., within real workplace environments, in the present research) is that the context is more similar to typical working conditions for participants, reducing threats to external validity and further improving the confidence in the research findings. For these reasons, randomised field experiments have been dubbed the 'gold standard' of organisational research methods (Eden, 2017).

However, one slight limitation of the experimental approach is that the completion of the experimental protocol still constitutes an unusual experience for participants, despite the fact that it occurred in their regular workplace. In order to achieve comparability between participants, standardised measures and performance tests needed to be created. These tests were designed to be as similar to office work as possible, but nonetheless they may have been different to the type of work an employee typically completed on a day-to-day basis. So, while the threat to external validity was reduced, it was not eliminated entirely, and it remains possible that the findings would not generalise perfectly to the actual productivity levels of employees. This was an unavoidable consequence of achieving higher levels of experimental control, and is therefore not regarded as a major limitation.

4.5 Ethical Considerations

Various ethical considerations had to be taken in account during the course of the research, in order to ensure that the key goals of the project (i.e., conducting important research, making a valuable contribution to knowledge) were not achieved at the expense of the dignity and/or integrity of the participants. Creating a clear plan for ethical research practice was key to ensuring that nobody was harmed by participating in the research.

The first potential ethical issue related to the fact that the researcher was employed by the organisation in which the research was conducted, posing a risk of a potential conflict of interest. To manage this risk, stakeholders at the organisation were forewarned that the findings of the research might not match their expectations, and the researcher ensured that he remained independent and objective at all times. The partnership with the organisation was clearly noted in the ‘Declaration of Competing Interest’ statement on all published outputs, in the interests of honest and transparent science.

The second ethical consideration related to the use of research incentives. In Paper II only, employees received entry into a prize draw to win a £20 Amazon gift voucher in exchange for their participation in the research, which was considered to be sufficiently high as a reward for the time spent completing the survey, but low enough to not pressure employees into participation. In the other studies, participation was completely voluntary and employees were not reimbursed in any way for their participation in the research.

The next set of ethical considerations relate to informed consent, anonymity, and the right to withdraw. Each study followed the same broad ethical principles to ensure that these ethical standards were met. Prior to providing any data, participants were asked to read a participant information sheet providing detailed information about the study, and to sign a consent form indicating that they agreed to the terms of the study. It was made clear that participation would be completely anonymous, and that any information which could possibly be used to identify an individual participant would be stored separately from the main responses. Participants had the right to withdraw their data from the research without incurring any penalty, although it was also made clear that this request would need to be made before the data had been analysed and submitted for publication.

Finally, there were also ethical considerations surrounding the storage of the data after it had been analysed. Following the completion of each study, data were stored on a secure cloud-based storage drive managed by Sheffield Hallam University. All data (raw and analysed) were deposited in the Sheffield Hallam University Research Data Archive, and can be made available (in anonymised form) upon request to other researchers seeking to re-analyse the data. These data will be retained for a period of 10 years since the last time any third party has requested access to the data.

As a result of this plan, all of the individual studies within this research programme were approved by Sheffield Hallam University's institutional ethics committee. As evidence of this ethical compliance, an example participant information sheet, consent form, and debriefing sheet is provided in Appendix L. The examples are taken from the study reported in Paper VI, and clearly demonstrate adherence to good ethical practice in data collection and storage. Similar documents were also prepared for each of the other primary research studies.

4.6 Summary

In this chapter, the methodology that was used in the research programme has been explained in detail. Pragmatism was adopted as the overall research paradigm, however the specific aims and objectives of the research programme were best answered using solely quantitative methods. From this general approach, five primary research studies were planned and conducted. Two studies were conducted to test the extent to which individual difference characteristics (demographics, personality, and task characteristics) moderated requirements for the office environment. Two studies were conducted to develop a methodology for effectively using environmental sensors in workplace research and practice, overcoming the limitations of previous methodologies. Finally, one study was conducted to test the extent to which biophilic regeneration pods facilitated recovery from work stress.

5.0 DISCUSSION

In this chapter, the results of the five primary research studies (*Papers I* to *VI*) will be discussed. First, the results from each study will be summarised (for a full presentation of the results, please see the papers themselves), before being discussed with respect to the overall objectives of the research programme and workplace theory in general. Next, the practical implications of the research will be discussed, including a discussion of how the insight gained is already being used in the development of consultancy 'products' to support employee comfort, wellbeing, and productivity within real offices. Finally, the most salient areas for future research will be highlighted.

5.1 Summary and Discussion of the Results

5.1.1 Exploring the role of individual differences

Workplace practice often commences as though there were a 'one-size-fits-all' approach to the workplace environment, implying that there is a single hypothetical perfect office (i.e., one which best supports stress-free and productive work) for all knowledge workers. Whilst it is true that certain environmental stimuli can be universally regarded as demands or resources (e.g., polluted indoor air is always harmful to building occupants), it is also true that other environmental stimuli are more variable, and can have a markedly different impact depending upon the characteristics of the employee in question.

Hence, one objective of the research programme was to test the extent to which requirements for the workplace environment are moderated by individual difference characteristics (*Objective III*). Specifically, the aim of Paper I was to investigate whether specific demographic characteristics, personality traits, and task characteristics affected perceived requirements for different aspects of the workplace environment (workspace segregation, workspace territoriality, individual environmental control, and aesthetic quality). Then, in Paper II, the aim was to explore whether a similar set of individual difference characteristics could be used to predict actual employees' acoustic comfort, wellbeing, and productivity at real open-plan office sites.

The first set of results relate to the extent to which the employee requires a workspace which is segregated from distraction, contributing to the ongoing development around the relative merits of enclosed and open-plan office space. In Paper I, the results showed that the perceived requirement for a segregated workspace was significantly predicted by higher distraction-susceptibility and higher introversion. Male respondents were also significantly more likely than female respondents to prefer a segregated workspace. Hence, from these results, certain traits (i.e., distraction-susceptibility, introversion, and being male) can be identified as 'risk factors' for greater dissatisfaction with real open-plan offices.

This assumption was tested in Paper II. In partial support of our predictions, it was found that noise sensitivity (a general trait which encompasses distraction-susceptibility) was strongly associated with more negative ratings of acoustic quality within the open-plan office, greater disturbance by background speech, more difficulties in concentration, higher stress, and lower self-rated productivity. However, although there was a small effect to indicate that extraverts reported higher productivity in open-plan offices, the majority of tests regarding introversion-extraversion in Paper II were non-significant. Similarly, gender did not emerge as a significant predictor in Paper II.

In summary, noise sensitivity emerged as the most important individual difference characteristic for determining the requirement for workspace segregation. Papers I and II both led to the conclusion that noise sensitive employees are more likely to view the open-plan office as being rife with environmental demands. As the ED-R framework predicts, a more demanding working environment was also associated with higher self-rated stress and lower self-rated productivity. Therefore, those with high noise sensitivity may therefore require more private working areas, shielded from auditory and visual distraction, to work effectively.

The finding that more noise sensitive employees report higher stress in open-plan offices is supported by previous research. It has been shown that noise sensitivity heightens the response to auditory stimuli, triggering a psychophysiological stress response (higher respiratory rate, higher galvanic skin response, slower return to baseline) (Park *et al.,* 2018). In offices, this leads to involuntary attention to background noise and more difficulty re-focusing following a disruption, leading to greater disturbance and time wasted due to noise (Kaarlela-Tuomaala *et al.,* 2009). Hence, a background conversation might be relatively easy for one employee to ignore, but represent a pernicious environmental demand for another.

Paper I also explored perceived requirements for other aspects of the workplace requirement, beyond just workspace segregation. With respect to workspace territoriality, it was found that employees who perceived a higher need for territoriality were those with low internal mobility (i.e., only needing the use of one workspace within the office) and less positive perceptions regarding the impact of flexible working on work effectiveness. There was also a significant effect of gender, such that female respondents were more likely than male respondents to endorse a need for territoriality.

These results are important when it comes to considering which types of employee are more or less suited to flexible or activity-base working initiatives. The significant effects of internal mobility and perceptions regarding flexible working are in accordance with previous research indicating that more location-dependent employees have a higher need for familiar and homely working environments (Greene and Myerson, 2011), and may explain why many employees in activity-based offices resist the new concept and persist with territorial behaviours (Appel-Meulenbroek *et al.*, 2011; Hoendervanger *et al.*, 2016; Skogland, 2017).

Interestingly, Paper I also showed that the same three characteristics (lower internal mobility, less positive perceptions regarding the impact of flexible working on work effectiveness, and being female) predicted the perceived requirement for increased individual environmental control at the workspace (e.g., over the temperature, task lighting). This re-iterates that employees who tend to complete all their work from a single location (either because they are required to or because they see no benefit in moving) place a high priority on physical as well as psychological comfort at that workspace, in line with previous research (Greene and Myerson, 2011). Possibly, the effect of gender here may also reflect the fact that female employees tend to be more dissatisfied with office temperatures than male employees due to higher thermal sensitivity (Karjalainen, 2007), suggesting a higher need for crafting control over the thermal environment in particular.

Overall, the results regarding workspace territoriality and individual environmental control allude to a trade-off in environmental crafting strategies. For some employees, the ability to craft the primary workspace to personal preferences is paramount, whereas for others the ability to move freely between workspaces is more important. Hence, it is crucial to ensure that all workplace interventions are informed by an extensive consultation with the workplace end users, and also to ensure that employees are empowered to use environmental crafting strategies in order to co-create the working environment which will help them to work most effectively.

Finally, Paper I also considered whether any characteristics predicted non-uniformity in perceived aesthetic quality requirements. Two significant effects emerged. Perhaps intuitively, respondents with higher aesthetic sensitivity (i.e., those who are more naturally attuned to the look and feel of the world around them) tended to rate the aesthetic quality of the office as being more important. Additionally, aesthetic quality requirements were also stronger amongst those who had less positive perceptions about the impact of flexible working on work effectiveness, which can also be interpreted in line with the suggestion that those who more frequently work from a single workspace place a high priority on psychological comfort at that workspace (Greene and Myerson, 2011). These results imply that strategies aimed at making the office more aesthetically-pleasing will be more effective within some organisations than others, because employees differ with respect to the extent that they consider workplace aesthetics to be a resource.

5.1.2 Predictive analytics in facilities management

New workplace technology has the potential to significantly improve the identification of environmental demands. For example, environmental sensors can continually monitor key parameters of the indoor environment, and highlight any deviation from best-practice comfort boundaries. Technology can also be harnessed to capture momentary assessments of subjective human experience, which can then be combined with objective IEQ data to enable even more detailed insight into the conditions which affect comfort, wellbeing, and productivity. However, the recency of these technologies means that researchers and practitioners lack a clear methodology for their use. Thus, another objective of the research programme was to develop a methodology for predictive analytics in facilities management, integrating building analytics and human analytics (*Objective IV).*

This part of the research had several different foci. Firstly, Papers III and V sought to validate the proposition that the ‘experience sampling’ approach to the workplace environment survey (i.e., short, repeated assessments of 'right-here-right-now' experience) was more appropriate than the traditional approach of disseminating a questionnaire at one time only. Across both studies, the results showed that with the exception of one factor (workspace availability), participants' perceptions of environmental comfort tended to significantly vary each time they were sampled, as a result of contextual factors (indicated by low intraclass correlation). Therefore, it was concluded that the aggregated responses collected by one-time-only occupant surveys were insufficient for capturing this response nuance, and that the experience sampling approach was indeed more appropriate for measuring environmental comfort on an ongoing basis.

Indeed, the next area of focus was to explore the effects of environmental demands in more detail, by exploring which aspects of environmental comfort were most strongly associated with different outcomes. For productivity in particular, the results of Paper III showed that higher self-rated productivity was associated with lower levels of distractions, higher control over the workspace appearance and higher satisfaction with air quality. In Paper V, all measured aspects of environmental comfort (including satisfaction with air quality, thermal comfort, visual comfort, and acoustic comfort) were positively associated with self-rated productivity. These findings support the theoretical link between employee-workplace alignment and job performance from the ED-R framework, demonstrating that employees are most productive when they perceive fewer demands in their working environment.

The strongest effect sizes were for distraction (in Paper III) and acoustic comfort (in Paper V), suggesting that auditory distractions have a particularly pernicious impact upon an employee's ability to work productively. This is in accordance with previous research indicating that background noise is the most common environmental demand within open-plan offices (Haapakangas *et al.*, 2008; Kaarlela-Tuomaala *et al.*, 2009; Jensen *et al.*, 2005;

Mak and Lui, 2012; Pejtersen *et al.*, 2006), and that minimising distractions is a crucial strategy for supporting effective job performance (Candido *et al.*, 2016; Haynes, 2008; Veitch *et al.*, 2007).

The third area of focus was on the integration of objective environmental data and subjective human data, and in particular to demonstrate how the best-practice comfort boundaries found in the likes of WELL or RESET might be rigorously tested in field research. In Paper IV, the focus was on devising the initial methodology for integrating building analytics and human analytics. After combining the two streams of data and using multilevel regression models to test the relationships between variables, the results indicated that higher levels of CO_2 were associated with more negative ratings of air quality. Indeed, the CO_2 concentrations within the office frequently exceeded the 800 ppm maximum limit recommendation (M = 1,425 ppm). In line with previous research highlighting the negative consequences of indoor CO_2 concentrations higher than 800 ppm (Allen *et al.*, 2016; Seppänen *et al.*, 1999), it can be concluded that sub-optimal air quality was a prevalent environmental demand within the office.

In Paper V, the only significant effect (albeit a relatively weak one) in terms of objective IEQ was for temperature. Adherence to the recommended temperature range reduced the risk of thermal discomfort, whilst exceeding the upper limit increased the likelihood that the occupant would report feeling ‘too warm’. Therefore, in line with research demonstrating that thermal discomfort has a negative impact on productivity (Rupp *et al.*, 2015), it was demonstrated that uncomfortable temperature was a common environmental demand at this site. This finding, combined with the finding from Paper IV on CO_2, shows how the use of environmental sensors can be valuable for identifying environmental demands.

Across both studies, the effects of other aspects of IEQ were not significant. That is, no significant effects with respect to temperature nor illumination emerged in Paper IV, and no significant effects with respect to CO_2 nor illumination emerged in Paper V. This was likely due to the fact these parameters remained almost entirely within the WELL comfort boundaries throughout the study period at the respective offices. This can be regarded as a limitation of the studies because it did not allow for a test of the effects of exceeding or falling below the comfort boundaries. Having said that, it is nonetheless interesting to note that despite the adherence to comfort boundaries, there were still some negative ratings of thermal and visual comfort. This suggests that the complete mitigation of environmental demands will not be achievable through adherence to comfort boundaries alone, and other more focused strategies may also be needed.

The final area of focus was on improving participant engagement with the experience sampling method, in response to the issue of a low response rate in Papers III and IV (an initial uptake of ~20%, and a subsequent completion rate of daily surveys of ~47%). In an effort to make participation more appealing, two methodological alterations were made during Paper V: reducing the length of the survey, and using smartphone push notifications instead of e-mail reminders when asking participants to complete a survey. The results of Paper V showed that the effects of the methodological improvements were mixed. At one site both the initial uptake (~10.7%) and the completion rate of subsequent surveys (~11.4%) were notably lower than that of the pilot study, whereas at the other site the initial uptake (~57.1%) was higher than the pilot, but the survey completion rate was slightly lower (~32.6%). It was noted that the building managers at the second site were considerably more enthusiastic about the research than those at the first site, suggesting that the response rate is not only a function of the survey methodology but also of the organisational climate more generally.

5.1.3 Stress recovery in the workplace environment

The fifth objective was to explore whether innovative design strategies could be used to further improve employee wellbeing (*Objective V*). In particular, this ambition grew out of the recognition that many employees' jobs are inherently demanding. As such, stress and energetic depletion will inevitably arise even if the workplace is free of environmental demands. To address this, another critical consideration for the workplace practitioner is to explore how environmental resources might be integrated into the workplace, to support psychological restoration during times of stress. The participating organisation's decision to commission the construction of biophilic regeneration pods provided the opportunity to investigate the potential benefits of one such environmental resource.

Specifically, a randomised field experiment was used to explore the effectiveness of the regeneration pods in enhancing recovery from work stress. The results of Paper VI confirmed that participants who took a 10-minute break in the regeneration pod reported significantly lower post-break anxiety and perceived task-load, and higher post-break arithmetic task performance, than those who took a 10-minute break in an ordinary meeting room. There were also comparatively greater improvements in perceived stress and proofreading performance in the regeneration pod group, although these did not reach the criteria for statistical significance. Thus, the study supported the assumption that the regeneration pods could serve as a valuable environmental resource within offices, helping employees to proactively manage their energetic levels throughout the working day.

These results are in accordance with previous research into the benefits of enhancing micro-breaks by using biophilic design (Jiang *et al.,* 2019; Lee *et al.,* 2015, 2018). In line with Attention Restoration Theory (Kaplan, 1995), it is likely that this occurred because the regeneration pods served to enhance the recovery of attentional resources during the micro-break, leading to higher post-break productivity. Although the effect of stress was not statistically significant, the trend of lower perceived stress in the regeneration pod can also be interpreted as partial support for Stress Reduction Theory (Ulrich *et al.*, 1991), which predicts that biophilic spaces more effectively support stress reduction.

In contrast to the majority of previous research into biophilic design, the results of this study imply that biophilic design strategies do not necessarily need to involve the use of live plants nor window views to nature. Instead, similar benefits can be derived through the use of natural wooden materials, the intentional mimicry of the patterns of nature, and the use of biophilic soundscapes. This provides greater flexibility for workplace designers seeking to use biophilic design strategies within offices; in spaces where lush interior planting is deemed inappropriate, there are still numerous effective strategies that can be used to provide a calming and restorative biophilic experience.

5.2 Practical Implications and Applications

Overall, the research project – encompassing the development of the theoretical framework as well as the programme of primary research – leads to numerous practical suggestions for enhancing the workplace environment to better support the environmental comfort, wellbeing, and productivity of the occupants. In particular, there are opportunities for providing healthier workplace environments through the insight-led use of environmental sensors, a greater appreciation of employees' needs to support improved employee-workplace alignment, and the purposeful facilitation of environmental crafting. These practical implications are briefly noted in this section, along with details about the evidence-based workplace consultancy approach that was developed in collaboration with the industry partner.

5.2.1 Environmental sensors

A major motivation of the participating organisation had been to investigate how environmental sensors could be effectively used by facilities managers towards the provision of more supportive office environments. The results of Papers IV and V suggest that non-adherence to best-practice comfort boundaries raises the likelihood of discomfort amongst employees. As such, environmental sensors can be used to ensure the IEQ is maintained in adherence with these boundaries, thereby helping to mitigate some of the most common environmental demands within offices.

To translate this into a consultancy tool, the author collaborated with colleagues in the wellbeing consultancy team to develop the ‘Building Performance Index’ (a screenshot from which is shown in Figure 6) dashboard using the PowerBI software. The dashboard uses the readings from one or more environmental sensors as its input, and then assigns a quality rating to each aspect of the indoor environment based on the proportion of readings which were within the pre-specified comfort boundaries. In this way, the dashboard provides a simple yet effective mechanism for facilities managers to understand the quality of their office environments using objective data, enabling the easy identification of areas for improvement. For organisations who have installed environmental sensors, the dashboard can be used by facilities managers as part of ongoing practice to identify and mitigate environmental demands, and to provide reports of operational performance to stakeholders within the organisation.

However, the results of Papers IV and V, as well as other academic publications highlighting inter-individual variability in thermal and visual comfort requirements (e.g., Karjalainen, 2011; Rupp *et al.*, 2015; Veitch and Newsham, 2000b), also suggest that caution is warranted when considering the predictive potential of environmental sensors. In other words, facilities managers should not make the mistake of assuming that all occupants are comfortable simply because a particular component of the physical environment is within the pre-specified comfort range. Therefore, it is equally important to monitor subjective experience as it is to monitor objective IEQ.

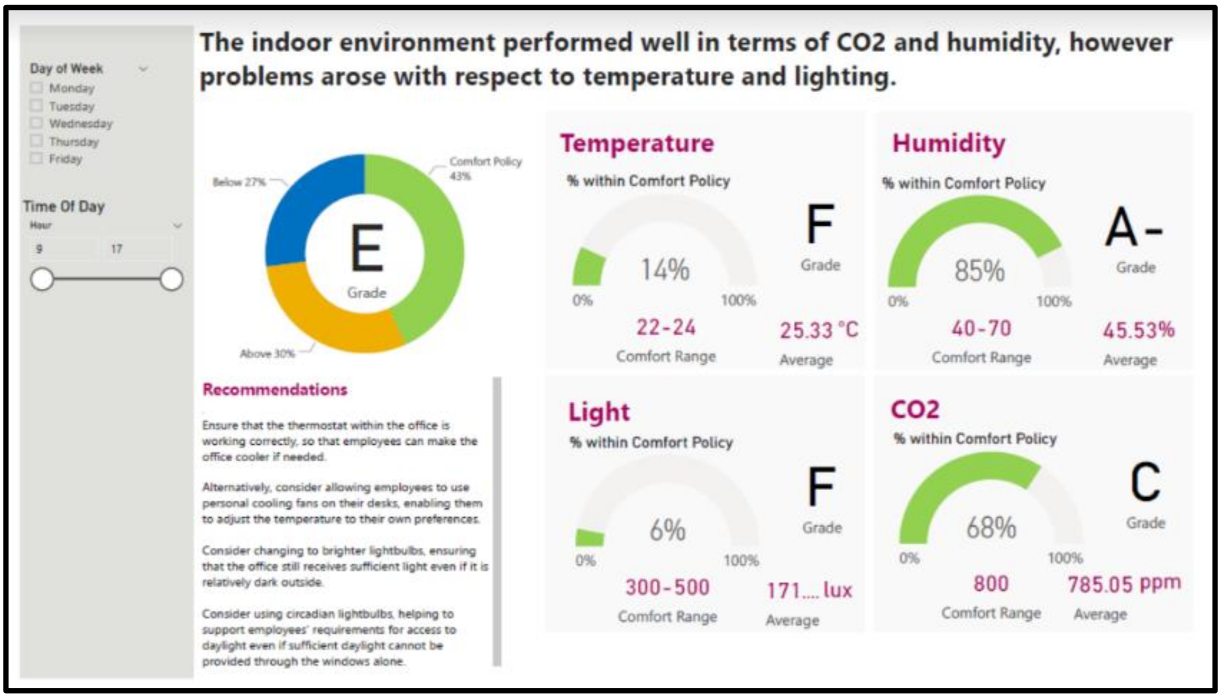

Figure 6: A screenshot from the 'Building Performance Index'

5.2.2 Experience sampling

Historically, employee (dis)satisfaction with the workplace environment has been measured using an occupant survey distributed at one time only. In Papers III and V, a new ‘experience sampling’ approach to the workplace environment survey was developed, with clear practical benefits. By providing a mechanism through which employees are able to continually report satisfaction or dissatisfaction with different aspects of the workplace environment, a feedback loop is instigated between workplace users and practitioners. In this way, the workplace can be maintained in a state of ‘perpetual beta’ (Usher, 2018), whereby practitioners are able to proactively identify and mitigate users’ subjective demands.

As such, the development of an experience sampling mobile application (app) for the workplace environment was another major practical application of the project work. A first iteration of the experience sampling app (screenshots shown below in Figure 7) was developed in Paper V, embedded within an existing app designed for creating experience sampling surveys. Subsequently, a proposal for a more detailed app was delivered to software developers within the company. The proposal suggested that the environmental comfort questions (which the user would either respond to when randomly prompted or choose themselves to complete in order to provide immediate feedback to facilities staff) should be integrated within a wider workplace app, which would also contain other useful functions (e.g., booking meeting rooms, ordering food and drink from the company café, wayfinding within the office).

Both the environmental sensor measurements and the experience sampling data can be presented to stakeholders in a single report. To assist in the creation of such reports, the author developed another interactive dashboard using PowerBI (screenshots shown in Figure 8). This provides a template for a full workplace environment report, divided into different areas (e.g., lighting, temperature, productivity), many sections of which can be automatically filled in by simply uploading sensor and experience sampling data. As with the Building Performance Index tool, the dashboard assigns ratings of quality for each aspect of IEQ, based on the combination of objective and subjective data. This tool would enable the workplace consultant to manually investigate the data in more depth, and to then fill in the report with more specific information about the nature of the identified problems and recommended solutions. In this way, the interactive dashboard can help to support environmental comfort, wellbeing, and productivity in the workplace.

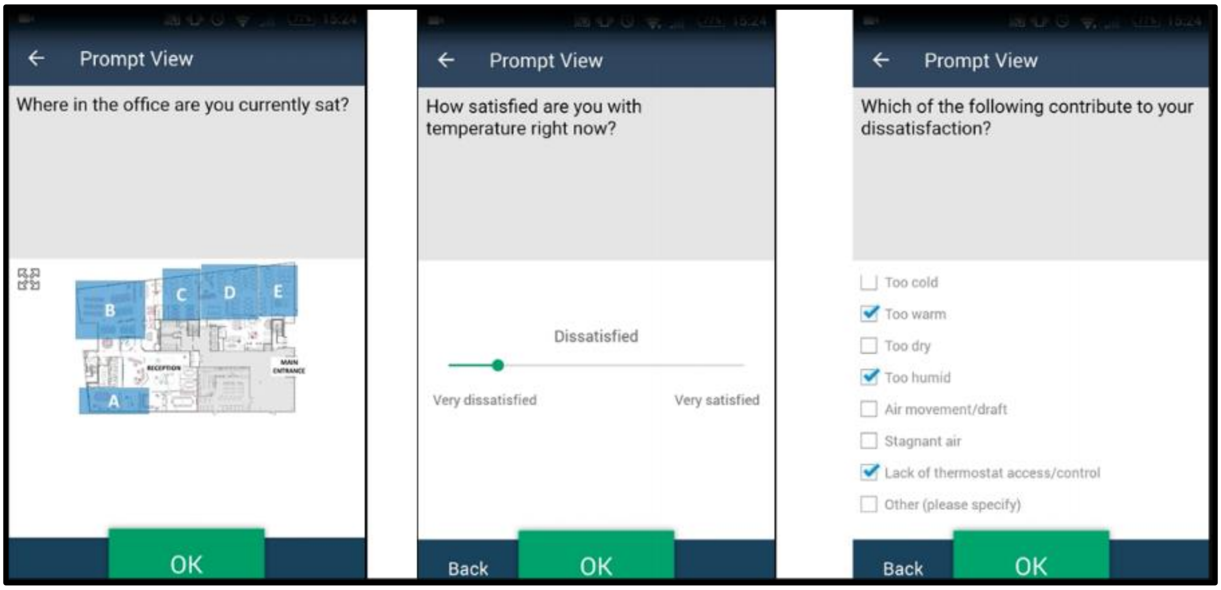

Figure 7: Screenshots from the 'experience sampling' mobile application.

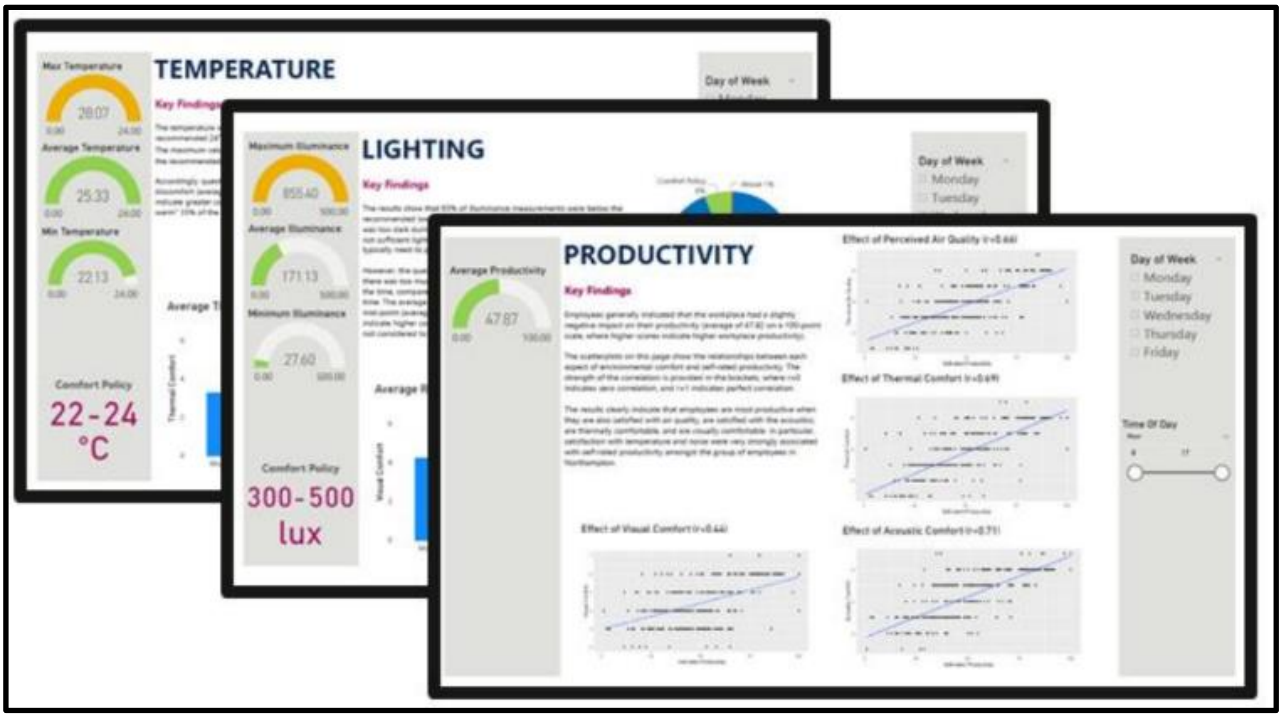

Figure 8: Screenshots from the 'interactive wellbeing dashboard'

5.2.3 Improving open-plan office design

Given that open-plan offices are likely to be the predominant form of office design for years to come, improving the design of open-plan offices has been described as the major challenge facing contemporary workplace practitioners (Oldman and Rothe, 2017; Oseland and Hodsman, 2018). Practitioners should consider what strategies can be used to ensure that demands are mitigated, and resources enhanced, in these types of spaces.

In terms of environmental demands, the results of Papers III and V demonstrated that auditory distractions in particular were the biggest issue within open-plan offices, in accordance with past research (Candido *et al.*, 2016; Haapakangas *et al.*, 2008; Haynes, 2008; Jensen *et al.*, 2005; Mak and Lui, 2012; Veitch *et al.*, 2007). To mitigate this, it has been suggested that practitioners should combine physical design solutions (e.g., the use of more sound-absorbent materials, partitions between desks, overhead noise-masking system) with behavioural solutions (e.g., the creation of silent working areas, office protocols to not make phone calls at the primary workspace) (Oseland and Hodsman, 2018).

Another environmental demand which may occur within open-plan offices is polluted air, for which the WELL Building Standard recommends an increase in the ventilation rate and ensuring air-conditioning systems are fitted with the correct filters (International WELL Building Institute, 2020b). Finally, practitioners might also consider the use of innovative new technologies which give users control over local environmental conditions, such as the desk chairs with built-in heating and cooling mechanisms used by Kim *et al.* (2019) to achieve near-perfect thermal comfort ratings.

The research programme also highlighted how environmental resources could be integrated into the design of the open-plan office. Most notably, biophilic design is a promising solution with clear empirical support (Gillis and Gatersleben, 2015; Lohr *et al.*, 1995; Kaplan, 1993, 1995; Nieuwenhuis *et al.*, 2014; Raanaas *et al.*, 2011; Smith and Pitt, 2005). A typical strategy would be to bring potted plants into the interior office environment and to enhance window views to nature where possible. Paper VI demonstrated that the same benefits can also be derived through the use of natural materials and the mimicry of the spatial complexity of nature. Whichever precise strategies are used, the use of biophilic design helps employees to periodically engage in restorative, stress-reducing micro-breaks, enabling them to more effectively manage their energetic reserves throughout the working day. The strategies could be applied in both the main seating areas of the office and within purpose-built spaces for restoration, as demonstrated in Paper VI.

5.2.4 Environmental crafting and alignment

The applications discussed thus far have essentially been practitioner-led, top-down strategies aimed at reducing environmental demands (e.g., reducing discomfort by improving IEQ, workplace design strategies to limit distraction) and enhancing environmental resources (e.g., implementing biophilic design strategies). However, the ED-R framework also highlights the potential for occupant-led, bottom-up environmental crafting strategies. Instead of trying to predict exactly what the occupant requires on an ongoing basis, it may often be more effective to simply allow them to make that determination themselves.

At a practical level, this corresponds with the growing trend towards non-territorial working practices (e.g., Veldhoen, 2008). As employees are increasingly encouraged to complete their work from numerous different workspaces, an opportunity is provided for them to craft their environment on an ongoing basis. In other words, if their current workspace becomes too demanding, they can simply move to a more suitable location instead.

From an organisational perspective, this necessitates that a suitable range of workspaces are actually provided within the office, because different workspaces will be needed by different types of employees (as demonstrated by Papers I and II). To better understand the likely needs of the employees and provide office spaces to match those needs, practitioners should therefore ensure that the workplace end users are actively involved in the design process and help to devise the rules which determine the way in which the office should be used (Babapour Chafi and Rolfö, 2019; Rolfö, 2018).

Where possible, it may be useful to extend the range of possible workspaces to beyond the primary office space. Indeed, for many knowledge workers, the ongoing coronavirus pandemic has hastened a move towards working from home. It is anticipated that flexible working (combining home-working with less frequent visits to the office,) will become 'the new normal' in the coming years (Harper, 2020). In order to implement this effectively, it will be important to ensure that employees have enough freedom to also craft their work schedules, so that they can match tasks to the environment they are expected to work at each day (e.g., individual-focused tasks on home-working days, collaborative tasks on office days). This can also be seen as an important form of environmental crafting.

In summary, the aforementioned strategies can be useful ways in which practitioners could empower employees by giving them more control over their workplace environment. By driving higher overall employee-workplace alignment, it can be expected that there will be clear benefits to employee wellbeing and productivity.

5.3 Future Research Recommendations

It was not possible (nor the intention of the research) to 'solve' all of the issues of the workplace environment. Whilst valuable contributions to the research literature have been made through the development a novel framework for the employee-workplace relationship and the early research into technology-supported workplace practice, there are nonetheless several important avenues for research which warrant further attention in future.

Most notably, the methodology developed in Papers III, IV, and V will need to be further developed at a significantly larger scale. These studies provided some insight into the effects of the physical workplace environment on occupants, using a more valid methodology than previous research. However, the findings were limited by the relatively small sample size (60 participants providing 614 survey responses across the two studies) and by the fact that the studies were conducted within just three open-plan offices, each of which had relatively good IEQ. In contrast, the database of the most popular traditional occupant survey has more than 550,000 responses from almost 4,000 different buildings (Oldman *et al.*, 2019). As such, in future research it will be vital to replicate the new methodology at a wider variety of workplaces and with many more respondents. In doing so, any individual-level and organisation-level confounds can be averaged out (or even modelled explicitly using multi-level modelling procedures), providing greater insight into the exact nature of the relationship between objective IEQ and subjective comfort.

Relatedly, it will also be important to more comprehensively explore the relationships between specific aspects of environmental comfort and specific work outcomes. At present, the evidence suggests a relatively strong link between distraction and productivity (Candido *et al.*, 2016; Haapakangas *et al.*, 2008; Haynes, 2008; Jensen *et al.*, 2005; Mak and Lui, 2012; Veitch *et al.*, 2007), however it is less clear what effects other components of comfort have upon other outcomes. Hence, practitioners working with smaller budgets have limited insight into exactly which elements of discomfort should be acted upon first to yield the greatest benefits. Building a large dataset using the experience sampling approach and combining it with other useful forms of human resources data (e.g., absenteeism statistics, turnover statistics) will enable researchers to more comprehensively investigate these important associations.

Finally, it will also be important to develop the salutogenic approach to workplace practice, testing the assumption that the workplace environment can function as a valuable resource by supporting an employee's SOC (Roskams and Haynes, 2019d). In line with wider research into salutogenesis, it will be important to empirically test the relationships between specific features of the environment and the different components comprising the SOC (i.e., comprehensibility, manageability, and meaningfulness). It will also be important to test whether other fundamental psychological needs that might be affected by the workplace environment (e.g., territoriality, aesthetic appreciation) either contribute to an individual's SOC or offer an additional protective resource against stressors. In this way, building upon the limited body of theoretical work (Dilani, 2009; Heerwagen *et al.*, 1995; Roskams and Haynes, 2019d; Ruohomäki *et al.*, 2015), an evidence-based programme of salutogenic workplace research should be developed.

6.0 CONCLUSION

6.1 Summary of the Research Project

A programme of research was conducted to better understand and improve employee comfort, wellbeing, and productivity through the workplace environment. To this end, the ED-R framework (a domain-specific extension of the JD-R model) was presented as a valid conceptual framework for capturing the complexity of the employee-workplace relationship, and was then validated through a comprehensive review of the multidisciplinary workplace environment literature. Subsequently, a series of five primary research studies were completed, further validating specific strands of the ED-R framework, and providing new insights into strategies for creating and maintaining healthier and more productive office environments.

The findings of the research are summarised as follows. The workplace environment can be conceptualised as a composite of environmental demands (i.e., features of the environment which cause strain and detract from overall work performance) and environmental resources (i.e., features of the environment which enhance engagement and support work performance). Environmental comfort, reflected in the perceived alignment with the workplace environment, can therefore be achieved by mitigating environmental demands, enhancing environmental resources, and facilitating environmental crafting strategies. The achievement of greater environmental comfort will have positive benefits in terms of improved employee wellbeing and productivity (Roskams and Haynes, 2019d, 2021; Roskams et al., 2020).

The creation of more supportive workplace environments involves a collaborative process between the workplace practitioner and the workplace end user. It must be recognised that judgments over what constitutes an environmental demand or resource are likely to differ from individual to individual (*Papers I* and *II*), and so employees should be actively involved in the design and operation of their offices, so that their preferences can be clearly heard. This user-centric approach can be further supported through the technology-enabled experience sampling approach to the occupant survey (*Papers III* and *V*), which opens up a feedback loop between practitioners and users, and enables complaints to be easily made and immediately acted upon.

Another form of technology which can be highly effective is the use of environmental sensors (*Papers IV* and *V*). These are able to monitor IEQ in real time, enabling environmental demands (e.g., airborne pollutants, temperature or lighting outside of comfort ranges) to be identified, prompting immediate remedial action. Finally, innovative workplace design strategies such as biophilic design (Paper VI) can also help, serving as a valuable environmental resource within open-plan offices by supporting attention restoration and recovery from stress.

6.2 Unique Contributions to Knowledge

Several unique contributions to knowledge were achieved at different stages of the research programme. To demonstrate these, the specific contributions made for each research objective, as well as the overall research aim, are outlined below.

6.2.1 Critical appraisal of the multidisciplinary workplace literature

Whilst other reviews of workplace environment research do exist, the reviews conducted during this project (in Chapter 3 of this thesis, and also in *Additional Papers I* and *II*) extend the existing knowledge base in two major ways. First, whereas many healthy buildings researchers have focused purely on the mitigation of pathogenic environmental stimuli, the appraisal presented here gives equal consideration to the enhancement of salutogenic stimuli. Second, whereas other reviews of the workplace environment literature are purely narrative in nature, the review conducted here also interprets the literature from the perspective of a single coherent framework for the employee-workplace relationship. The benefits of doing so are discussed in the next section.

6.2.2 Schematic representation of the common concepts across disciplines

The mapping of key interdisciplinary concepts into a single framework, subsequently termed the ED-R framework, occurred alongside the literature review. By interpreting the literature from the perspective of the ED-R framework (in *Additional Papers I, II* and *III*), the reader begins to understand how seemingly disparate aspects of the workplace environment are in fact similar in the sense that they instigate strain (environmental demands) or support motivation (environmental resources). Likewise, the reader is able to understand how a broad range of workplace behaviours are similar in the sense that they are all directed at the mitigation of demands and/or the enhancement of resources. Through this more detailed insight into the employee-workplace relationship, the reader arrives at a more nuanced understanding of the strategies that might be needed to improve workplace environments, and the potential pitfalls associated with certain strategies.

6.2.3 Individual differences in workplace requirements

Whilst previous studies had separately considered how different demographic characteristics, personality traits, and/or task characteristics moderated requirements for specific aspects of the workplace environment, the studies presented here (*Papers I* and *II*) were the first to test the effects of a wide range of individual difference characteristics concurrently, helping to identify exactly which are the most important in predicting non-uniform requirements. In particular, noise sensitivity emerged as an important determinant of workspace segregation, which could explain why the open-plan office can seem highly demanding to some employees but not to others.

6.2.4 Integrating building analytics and human analytics

The project made a major contribution to the emerging field of technology-enabled facilities management. Most notably, this was the first research project which explored how environmental sensor data could be effectively used within real workplace environments to predict subjective experiences of comfort and discomfort. Crucially, this also required the development of the experiencing sampling occupant survey, rather than the use of the traditional occupant survey. The methodology that was developed (in *Papers III, IV*, and *V*) can be used and adapted by other researchers and practitioners interested in the use of environmental sensor technology in the workplace environment.

6.2.5 Innovative workplace design for wellbeing

The fifth objective was achieved by offering a new perspective on the practice of biophilic design. Previous biophilic design studies have considered the effects of interior plants and/or window views to nature, whereas the study conducted here (*Paper VI*) was the first biophilic design study which involved neither of these. Instead, the study showed that a 10-minute break in a "regeneration pod", which used natural materials to mimic the spatial configuration of nature, could also facilitate psychological restoration. This finding has important implications for the design of workplaces, and suggests that the provision of purpose-built spaces for restoration within offices can be a valuable and effective environmental resource for employees.

6.2.6 A comprehensive framework for the employee-workplace relationship

Overall, the achievement of each of each of the initial five objectives also represented the achievement of a sixth research objective which underpins the entire programme of research: to develop and validate a theoretical framework to represent the employee-workplace relationship. Whilst the JD-R model has been enormously influential within the field of organisational psychology, there has been surprisingly very little investigation into its applicability to the workplace environment. As the conceptual analysis of the workplace environment literature (*Additional Papers I, II* and *III*) demonstrates, the ED-R framework is a valid lens through which to interpret the workplace environment, and one which overcomes the limitations of previous frameworks. Additionally, the subsequent programme of research (*Papers I, II, III, IV, V,* and *VI*) demonstrates that the ED-R framework can also function as the theoretical foundation for primary research. In these ways, the development and validation of the ED-R framework represents the major contribution to knowledge of the overall research programme.

6.3 Beneficiaries of the Research

The series of research studies were conducted within industry, and so the project had clear benefits to both academia and practice. From the academic perspective, the development of the ED-R framework was the major benefit of the research programme. In recognising both the pathogenic and salutogenic potential of the workplace environment, and the dynamic and reciprocal nature of the relationship between the workplace and the employee, the ED-R framework provides the most comprehensive representation of the employee-workplace relationship to date. This is particularly beneficial for workplace researchers aligned to the "healthy buildings" movement, who now have a clearer understanding of the myriad environmental forces which affect overall health, and the processes by which they do so.

The framework can also benefit practitioners as a "tool-kit" within which workplace interventions can be guided. For example, an audit of environmental demands, environmental resources, and environmental crafting behaviours can be performed before and after a workplace intervention, in order to determine its effectiveness. The holistic nature of the framework ensures that the entire breadth of environmental factors are taken into account, instead of simply focusing on the specific targets of the intervention and/or the factors aligned with the practitioner's specific area of expertise.

The research project also explored how specific technologies and innovative forms of workplace design could be used to mitigate demands and enhance resources, which is another benefit for workplace practitioners. As Section 5.2 has demonstrated, significant early strides have been made towards the integration of environmental sensor data and experience sampling data, and the presentation of those data through user-friendly software interfaces. These tools can help facilities managers to ensure that the workplace environment remains healthy, and that any threats to employee wellbeing are immediately identified and rectified.

Finally, the aforementioned benefits should also all support the most important beneficiaries of all – the workplace users themselves. By supporting academic research into healthy workplace environments, and developing a methodology for the effective use of environmental sensors in supporting employee health, the project will hopefully contribute to the development of healthy building standards, which prescribe the mitigation of demands and the enhancement of resources within all offices. In doing so, the research will play a role in helping to bring about a world in which office-based employees come to view their workplace as a place which makes a positive contribution to their health, rather than one which contributes to physical and psychological illness.

6.4 Concluding Comments

Deficits in employee wellbeing and productivity represent a massive cost to individual employers and national governments. Whilst the reasons for this are complex and multi-faceted, one important contributing factor is the workplace environment. In particular, the office buildings in which much of the work of modern knowledge economies takes place are all too often fraught with impediments to employee health, wellbeing, and productivity. The healthy buildings movement has emerged in response to this worrying state of affairs, but in order to be most effective it will need to be supported by academic research and innovative new technologies.

This research project has highlighted numerous strategies that will be crucial to the provision of truly healthy workplaces. In line with the pathogenic approach to healthcare, it is indeed important to identify and mitigate any environmental demands which may be impacting the health and wellbeing of the workplace users. Environmental sensors can be very helpful for this purpose. However, in line with the salutogenic approach to healthcare, it is equally important to consider how environmental resources can be used to help employees remain healthy and happy, even in the face of typical everyday stressors and hardships. For too long, the office has been a place which contributes to sickness and stress. The workplace of the future must be different – it must be a place where people can truly flourish.

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APPENDIX A. KNOWLEDGE TRANSFER PARTNERSHIPS

Whilst completing the programme of research, the author was employed as a Knowledge Transfer Partnership (KTP) Associate. The KTP scheme is a publicly-funded initiative within the UK, aimed at helping businesses to improve their competitiveness and productivity by pairing them up with academic institutions (thereby enabling them to access the knowledge, technology, and skills that reside within the UK knowledge base. Specifically, a recent graduate is hired to conduct a research and/or innovation project which is co-managed by academics from the university and stakeholders from the participating organisation. The project is co-funded by the participating organisation and the UK Government's agency for innovation, Innovate UK.

For the present project, the participating organisation was Mitie plc, a large private-sector facilities management and strategic outsourcing company within the UK. Specifically, the project was placed within the Wellbeing Consultancy team within Mitie, which aims to help clients provide and maintain healthier and more productive workplaces. The research was also closely aligned with the 'Connected Workspace' team within Mitie, who are responsible for the installation and management of various types of sensors (including environmental sensors) at client sites.

The author was encouraged to use the research findings to support innovation within the company in various ways: by ensuring that the services offered to clients were grounded in academic evidence, by improving the delivery of the services that were offered to clients, and by developing effective new services that could be offered to clients. In this way, he was able not only to develop his own academic capabilities and achieve various contributions to knowledge, but also to help the organisation to become more innovative and productive. Therefore, the research had practical significance as well as academic value.

APPENDICES B - K. PAPERS I TO VI AND ADDITIONAL PAPERS I TO IV

(PDFs of Papers I to VI and Additional Papers I to IV have been placed at the end of the document)

APPENDIX L. ETHICAL COMPLIANCE

Participant Information Sheet

“Managing work stress using micro-breaks”

You are being invited to take part in a research study. Before you decide to take part, it is important that you understand why the research is being done and what it will involve. Please read the following information and feel free to ask if you would like any more information or if there is anything you do not understand. You do not have to accept this invitation, and you should only take part if you want to.

Thank you!

1. **What is the purpose of the study?**

   The aim of this study is to explore whether a 10-minute “micro-break” effectively helps employees to recover from stress at work.

2. **Why have you asked me to take part?**

   You have been selected to take part because you are a “knowledge worker” (i.e. somebody whose job involves handling or using information). The final goal of the research project is to learn more about how to provide offices which support the wellbeing and productivity of knowledge workers.

3. **What will I be required to do?**

   If you agree to volunteer, you will be asked to set aside one hour on Thursday or Friday to attend the research session in a meeting room that the lead researcher has booked out. During this session, you will be asked to fill out some brief questionnaires, complete some cognitive tests, and use your “MoodMetric” rings to monitor stress levels.

   In the middle of these questionnaires and tests, you will be asked to take a 10-minute “micro-break”. The lead researcher will ask you to either remain in the meeting room for the break, or to take the break in the nearby “regeneration pods”.

4. **What is the legal basis for the research study?**

   Sheffield Hallam University undertakes research as part of its function for the community under its legal status. Data protection allows us to use personal data for research with appropriate safeguards in place, under the legal basis of public tasks that are in the public interest. A full statement of your rights can be found at https://www.shu.ac.uk/about-this-website/privacy-policy/privacy-notices/privacy-notice-for-research. Furthermore, all University research is reviewed to ensure that participants are treated appropriately and their rights respected. This study was approved by the University Research Ethics Committee with Converis number ER*xxxxxx.* Further information can be found at https://www.shu.ac.uk/research/ethics-integrity-and-practice.

5. Are there any risks in taking part?

No adverse effects, risks, or hazards are expected to arise from this research.

6. Are there any benefits in taking part?

By participating, you will be able to learn more about how to effectively manage your stress levels at work. Once you finish the research session, you will be given an informational booklet containing evidence-based advice for how to manage your stress effectively.

7. Will my participation be kept confidential?

All information collected during the research will be kept confidential. You will not be asked to provide any information that could be used to identify you.

8. What will happen to my data after I have completed the study?

After you complete the study, your questionnaire responses, test scores, and stress levels data will be transferred onto a secure storage drive by the lead researcher. The lead researcher and the academic supervisor for the project will have access to the data so that they can perform data analysis. Finally, the results from the study may be published in academic journals and discussed in blog posts by the participating organisation, Mitie. In all publications, individual responses will be kept completely anonymous.

9. What will happen if I want to stop taking part?

You are free to stop taking part in the study at any time, and for any reason. If you decide to do so, you will not be penalised in any way. Withdrawal will not result in any penalty or loss of benefits to which you are entitled.

10. Who can I contact if I have any more questions?

If you are unhappy with any aspect of the research, or would simply like to learn more about the study, then please feel free to contact the lead researcher Michael Roskams (m.roskams@shu.ac.uk) or the project supervisor Dr. Barry Haynes (b.p.haynes@shu.ac.uk).

If you are still unhappy, or would rather contact somebody else, then you can also contact the Data Protection Officer or the Head of Research Ethics at Sheffield Hallam University. Their contact details are below:

You should contact the Data Protection Officer if:	**You should contact the Head of Research Ethics (Professor Ann Macaskill) if:**
• you have a query about how your data is used by the University • you would like to report a data security breach (e.g. if you think your personal data has been lost or disclosed inappropriately) • you would like to complain about how the University has used your personal data DPO@shu.ac.uk	• you have concerns with how the research was undertaken or how you were treated a.macaskill@shu.ac.uk
Postal address: Sheffield Hallam University, Howard Street, Sheffield S1 1WBT Telephone: 0114 225 5555	

Participant Consent Form

"Managing work stress using micro-breaks"

Please answer the following questions by ticking the response that applies

		YES	NO
1.	I have read the Information Sheet for this study and have had details of the study explained to me.	☐	☐
2.	My questions about the study have been answered to my satisfaction and I understand that I may ask further questions at any point.	☐	☐
3.	I understand that I am free to withdraw from the study within the time limits outlined in the Information Sheet, without giving a reason for my withdrawal or to decline to answer any particular questions in the study without any consequences to my future treatment by the researcher.	☐	☐
4.	I agree to provide information to the researchers under the conditions of confidentiality set out in the Information Sheet.	☐	☐
5.	I wish to participate in the study under the conditions set out in the Information Sheet.	☐	☐
6.	I consent to the information collected for the purposes of this research study, once anonymised (so that I cannot be identified), to be used for any other research purposes.	☐	☐

Participant's Signature: ____ Date: ___________

Participant's Name (Printed): ______________________________________

Contact details: ____

____

Researcher's Name (Printed): _____________________________________

Researcher's Signature: ____

Researcher's contact details:
(Name, address, contact number of investigator)

Please keep your copy of the consent form and the information sheet together.

Debriefing Sheet

“Managing work stress using micro-breaks”

You have now completed the research study – thank you! Before you leave, there are a few extra pieces of information that you should be aware of.

1. What was the purpose of the study?

The aim of this study was to explore whether taking a 10-minute “micro-break” in the biophilic regeneration pods is more effective in helping people to recover from stress at work, compared to a 10-minute break at an ordinary workspace.

2. What results do we expect to find?

We expected that participants who took their break in the regeneration pods, rather than in the meeting room, would recover from stress more effectively. Specifically, we expected that this group would perform better on the tasks and demonstrate lower perceived and actual stress levels.

3. Was there any deception involved in the study?

One piece of deception was involved in this research. You were asked to complete a “tracing task”, in which you had to copy shapes exactly as they were presented, without lifting your pen from the paper and without going over the same line twice. In reality, two out of the three shapes on the paper were impossible to trace using these instructions.

This task was deliberately used to induce a sense of frustration and fatigue. This was considered necessary because we wanted people to experience the same sort of mental state that they would feel on a particularly difficult day at work – when they’re working hard but still don’t seem to be making any progress towards their objectives. When people are in this sort of state of mind, we would expect them to get the greatest possible benefits from taking a break from work, particularly in a purpose-built space like the regeneration pods.

4. What if I am unhappy with research or if there are any problems?

If you are unhappy with the deception or with any other aspect of the research, please feel free to contact the lead researcher Michael Roskams (m.roskams@shu.ac.uk) to ask any questions. If you are still unhappy, or would rather contact somebody else, please contact the Research Ethics committee for the Social Sciences and Humanities faculty at Sheffield Hallam University (ssh-researchethics@shu.ac.uk). When contacting this committee, please provide details of the name or description of the study (so that it can be identified), the researcher involved, and details of the complaint you wish to make.

5. Will my participation be kept confidential?

All information collected during the research will be kept confidential. Any piece of information that could be used to identify you will be kept private, and stored separately to any of your other data.

6. What will happen to my data now that I have completed the study?

Now that you have completed the study, your questionnaire responses, test scores, and stress levels data will be transferred onto a secure storage drive by the lead researcher. The lead researcher and the academic supervisor for the project will have access to the data so that they can perform data analysis. Finally, the results from the study may be published in academic journals and discussed in blog posts by the participating organisation, Mitie. In all publications, individual responses will be kept completely anonymous.

7. What will happen if I want to withdraw my data?

Even though you have completed the study, you are still free to withdraw your data, for any reason. If you decide to do so, you will not be penalised in any way. Withdrawal will not result in any penalty or loss of benefits to which you are entitled.

8. Who can I contact for support with managing stress in the workplace?

The mental health charity Mind provide various resources to help employees to manage stress and mental health in the workplace. In particular, you may find it useful to read their guides entitled "How to be mentally healthy at work" and "How to manage stress at work".

Additionally, Mitie offers its employees access to an Employee Assistance Programme (EAP), through which you are able to get free and confidential advice from qualified professionals on all things work-life, home-life, and well-being. To access this service, please go to this website and enter the username "mitiewell".

Employee-workplace alignment

Employee characteristics and perceived workplace requirements

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Abstract

Purpose – This paper aims to identify the employee characteristics which are most strongly associated with perceived requirements for different aspects of the workplace environment.

Design/methodology/approach – A questionnaire was completed by 364 employees from a large private-sector organisation. Respondents were surveyed on different work-related, personality and demographic characteristics. They then completed a series of items measuring perceived requirements for four aspects of the workplace environment (workspace segregation, workspace territoriality, individual environmental control and aesthetic quality). Associations between employee characteristics and perceived workplace requirements were explored using multiple regression analyses.

Findings – Numerous significant associations emerged. For example, the requirement for more segregated workspaces was associated with higher susceptibility to distraction, and the requirement for higher workspace territoriality was associated with less positive perceptions regarding the impact of flexible working on work effectiveness.

Originality/value – The individual difference factors which moderate satisfaction with the workplace environment have received relatively little attention in past research. The present study addresses this knowledge gap by including a wider range of employee characteristics and comprehensively investigating which of these most strongly predict differences in perceived requirements for the workplace.

Keywords Workplace, User satisfaction, Productivity, Individual behaviour, Environmental psychology, Workplace psychology

Paper type Research paper

According to Person-Environment Fit theory, workplace stress arises as a result of misalignment between the needs of the employee and the characteristics of the environment (Edwards *et al.*, 1998). The "environment" here has typically been defined in terms of psychosocial characteristics, but it is becoming increasingly recognised that misalignment can also occur with the physical workplace environment (Gerdenitsch *et al.*, 2018; Haynes, 2012; Vischer, 2007). Specifically, Haynes (2012) has stressed the need for the characteristics of the office environment to be aligned to both the working patterns and psychological characteristics of the office occupants.

The physical workplace environment can be viewed as a composite of individual environmental features, which can be classified as "demands" (if they cause physiological and/or psychological strain) or "resources" (if they stimulate engagement and motivation, and/or aid recovery from demands) (Roskams and Haynes, 2019). Thus, a workplace environment which is perfectly aligned to the occupants is one which is free of demands and abundant in resources. However, the judgment over what constitutes a demand or a resource may vary significantly between employees, as a result of different characteristics. Thus, the

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aim of the present study was to comprehensively explore the relationship between employee characteristics and perceived workplace requirements.

In particular, we focus on requirements for four aspects of the workplace environment: *workspace segregation, workspace territoriality, individual environmental control*, and *aesthetic quality*. As we will discuss in the next section, numerous potential moderators of these preferences have been identified in past research, including characteristics of the work being completed as well as the employee's personality traits and demographic characteristics. However, the existing evidence base is limited in that it typically considers only one or two characteristics at a time, meaning that there is limited insight into exactly which characteristics are most strongly associated with divergent workplace requirements. To address this limitation, we aimed to concurrently explore the influence of a wider range of employee characteristics in the present study.

Furthermore, there are also limitations in the fact that the existing research primarily explores outcomes in real workplace environments or experimental chambers. Whilst this approach has enabled researchers to identify various antecedents of satisfaction and dissatisfaction in specific contexts, there remains limited insight into the types of working environment which the users themselves believe would enable their most effective work, if they had a completely free choice of different options. To address this knowledge gap and adopt a more user-centred approach to research, we used a survey-based methodology which allowed respondents to stipulate the characteristics of a hypothetical "ideal" workplace.

Non-uniformity in workplace requirements

Workspace segregation

Office layouts differ with respect to the extent to which individual workspaces are in "segregated" or "open" locations, as a result of physical architectural characteristics. In general, employee satisfaction and productivity tends to worsen as office openness increases (Bodin Danielsson and Bodin, 2008; Kim and de Dear, 2013), however there is also evidence to suggest that responses are significantly moderated by various characteristics, meaning different employees are more or less suited to open office environments.

For example, employees completing complex and concentration-demanding tasks tend to report higher stress and distraction in shared workplaces (Fried *et al.*, 2001; Seddigh *et al.*, 2014), suggesting that this type of work is more effectively completed in segregated spaces. Similarly, tasks which require the processing of verbal/numerical (rather than visual/spatial) information are particularly susceptible to disruption by the presence of background speech (Haka *et al.*, 2009; Jahncke *et al.*, 2013), so employees completing this type of work may also be less suited to open office environments. Finally, typical interaction levels with colleagues may also be important. Employees who primarily perform more collaborative work tend to rate open-plan offices more positively than those who primarily perform individual work (Haynes, 2008), presumably because the various interactions which naturally emerge in open offices are viewed as useful rather than distracting.

Other studies have highlighted the importance of personality traits. In particular, introversion-extraversion has received significant research attention, with studies showing that introverts are more dissatisfied and disrupted than extraverts in the presence of background noise in general (Geen, 1984) and in open-plan offices in particular (Hartog *et al.*, 2018; Oseland and Hodsman, 2018). Researchers have also considered the role of sensory processing sensitivity, an innate trait concerning the individual's sensitivity to external stimuli. Individuals who are less capable at disregarding environmental stimuli also experience more distraction and dissatisfaction in open-plan offices (Maher and von Hippel, 2005; Oldham *et al.*, 1991).

Finally, in terms of demographic characteristics, it has been demonstrated that older employees (Pullen, 2014) and high-tenured employees (Fried *et al.*, 2001) are less satisfied in densely-populated open offices than their younger and lower-tenured counterparts. Older employees also tend to place less emphasis on workplaces which support collaboration and socialisation (Rothe *et al.*, 2012). Finally, it is also possible that men may prefer more segregated workspaces than women, given that women tend to rate interpersonal interactions in open-plan offices more positively than men (Bodin Danielsson *et al.*, 2015; Haynes *et al.*, 2017).

This overview of the literature identifies numerous potential moderators of workplace layout preferences, however at present it remains unclear whether some of these have a stronger influence than others. We aimed to concurrently explore the influence of each of these characteristics, and predicted that:

H1. The perceived requirement for a more segregated workspace would be associated with higher need for concentration, use of verbal information rather than visual-spatial information, lower interactivity with colleagues, higher introversion, higher sensory processing sensitivity, higher age, organisational tenure and being male.

Workspace territoriality

Another workplace trend relates to the growing adoption of non-territorial "flexible" offices, in which employees do not have assigned desks but are instead encouraged to use different workspaces around the office on an ad-hoc basis. Notably, non-territorial workplaces restrict behaviours such as desk personalisation (e.g. photos of loved ones, artwork), which are typically performed to delineate personal territory and imbue the workstation with psychological comfort and meaning (Brunia and Hartjes-Gosselink, 2009; Wells, 2000). Again, there is evidence to suggest that certain characteristics moderate the perceived importance of these behaviours.

In particular, employees who are required to regularly work from the same workstation ascribe greater importance to having a workspace which feels like an "extension of home" (Greene and Myerson, 2011), suggesting that location-dependency will predict workspace territoriality requirements. Additionally, it has been demonstrated that personalisation is more prevalent and important for well-being amongst women than men (Wells, 2000), suggesting there may also be a gender difference. As such, it was predicted that:

H2. The perceived requirement for higher workspace territoriality would be associated with being female and higher location-dependency.

Individual environmental control

Workplaces also differ in the extent to which individual employees are able to personally control local environmental conditions. Generally, employees are more satisfied and productive if they have personal control over the environment (Shahzad *et al.*, 2016), but in shared offices it is more common for employees to work under group settings. Once more, there is evidence to suggest that the importance of individual environmental control might differ between employees as a result of particular characteristics.

In particular, women may derive greater benefit than men from individual temperature control, as they tend to be more thermally sensitive and are more frequently dissatisfied with typical office temperatures (Hashiguchi *et al.*, 2010). Furthermore, the requirement for individual control might also be more important for location-dependent employees compared to mobile employees, as they tend to place a higher priority on comfort at their workspace (Greene and Myerson, 2011). As such, it was predicted that:

H3. The perceived requirement for higher levels of individual environmental control would be associated with being female and higher location-dependency.

Aesthetic quality

In contrast to the preceding aspects of the workplace environment, aesthetic quality has received very little attention in the research literature. However, it has been recognised that aesthetic judgments contribute to overall environmental satisfaction for some employees (Bodin Danielsson, 2015), and workplace professionals in practice are typically expected to provide workplaces which are not only functionally and strategically effective, but also aesthetically pleasing (Appel-Meulenbroek *et al.*, 2018). As such, we also included the perceived importance of aesthetic quality in the study for exploratory purposes, to identify whether this requirement might also be moderated by certain employee characteristics. Given the lack of previous research, we adopted the null hypothes is that:

H4. None of the employee characteristics would be significantly associated with perceived requirements for aesthetic quality.

Method

Participants

The participants for this study were 364 employees (185 male, 176 female, 3 did not answer) at a large private-sector company in the United Kingdom. Initially, 22 employees evaluated a pilot version of the questionnaire, confirming that the user-friendliness of the questionnaire was very high (M = 6.50, on a seven-point scale) and that zero items had confusing or ambiguous wording. Thus, the questionnaire was deemed appropriate to be sent to the larger sample without revision. Subsequently, a study invitation was e-mailed to employees at 11 offices (approximately 2,500 employees) and also placed on the company's intranet. Participation was completely voluntary.

Measures

Data were collected using an online questionnaire (items shown in Table I) which measured employee characteristics (demographic information, task characteristics, and personality traits) and perceived workplace requirements. The majority of items were self-generated, although where possible items were taken from validated questionnaires. Cronbach's alpha values were attained for each scale as a measure of internal consistency. Given that our scales all had five or fewer items, and alpha values tend to be lower in scales with fewer items, $\alpha > 0.60$ was judged to be the acceptable threshold for internal consistency.

Demographic information. Participants reported *gender*, *age* and *organisational tenure*.

Task characteristics. All items in this section used a seven-point response scale (1 = Disagree completely, 7 = Agree completely), with the exception of the item measuring *information type*, which had a dichotomous outcome (verbal/numerical or visual/spatial).

Three original items were used to measure *need for concentration*, as previous studies measuring similar constructs had used the average score of several independent factors (Fried *et al.*, 2001) or a single-item measure only (Seddigh *et al.*, 2014). However, our three

Scale and item(s) used	M	SD
Employee characteristics		
Gender (Open-ended: Male [N = 185], Female [176], Did not answer [3])		
"Please indicate your gender"	n/a	n/a
Age (Open-ended, re-coded into birth decade: 1950s [17], 1960s [60], 1970s [78], 1980s [134], 1990s [70], Did not answer [5])		
"Please indicate your year of birth"	n/a	n/a
Organisational Tenure (Multiple choice: Less than 6 months [35], 6-12 months [40], 1-2 years [50], More than 2 years [239])		
"How long have you been working for your current employer?"	n/a	n/a
Information type (Binary choice: 340 Verbal/Numerical information, 24 Visual/Spatial information)		
"What type of information do you deal with most often?"	n/a	n/a
Need for Concentration ($\alpha = 0.24^{*}$) (7-point Likert scale: 1 = Disagree completely, 7 = Agree completely)	n/a	n/a
[Task Heterogeneity] "My work typically follows a simple, well-learned procedure" [reverse-scored]	4.15	1.83
[Concentration Levels] "Most of my working day is spent in periods of intense concentration"	5.26	1.35
[Susceptibility to Distraction] "It is necessary for me to work in a distraction-free environment"	4.58	1.58
Interactivity ($\alpha = 0.73$) (7-point Likert scale: 1 = Disagree completely, 7 = Agree completely)	4.61	1.41
"I need to work in close proximity with my colleagues to be able to complete my work effectively"	4.51	1.72
"In my role, I typically work in a group and need to communicate regularly with colleagues"	5.07	1.69
"Having my colleagues nearby isn't necessary for the type of work I do". [reverse-scored]	4.23	1.81
Location-dependency ($\alpha = 0.51^{*}$) (7-point Likert scale: 1 = Disagree completely, 7 = Agree completely)	n/a	n/a
[Internal Mobility] "All of my work can be completed at a single location within the office" [reverse-scored]	3.38	2.22
[Importance of Flexible Working] "Having the flexibility to move around the office throughout the working day, to complete different types of task, is important to me"	4.73	1.9
[Impact on Work Effectiveness of Flexible Working] "I would work more effectively if I had the opportunity to work at a range of different workspaces"	4.1	1.9
Introversion-Extraversion ($\alpha = 0.84$) (7-point Likert scale: 1 = Very inaccurate, 7 = Very accurate)	4.64	1.31
"Generally, is it accurate or inaccurate that you are shy?" [reverse-scored]	4.83	1.73
"Generally, is it accurate or inaccurate that you are talkative?"	4.62	1.52
"Generally, is it accurate or inaccurate that you are outgoing?"	4.78	1.5
"Generally, is it accurate or inaccurate that you are reserved?" [reverse-scored]	4.33	1.63
Sensory processing sensitivity ($\alpha = 0.41^{*}$) (7-point Likert scale: 1 = Not at all, 7 = Extremely)	n/a	n/a
[Sensitivity to Environmental Subtleties] "I seem to be aware of subtleties in my environment"	5.05	1.3
[Aesthetic Sensitivity] "I notice and enjoy delicate fine scents, tastes, sounds, works of art"	4.61	1.62
[Low Sensory Threshold] "I get bothered by intense stimuli, like loud noises or chaotic scenes"	4.54	1.72
Perceived workplace requirements		
Workspace segregation ($\alpha = 0.65$) (7-point Likert scale: 1 = Very unhelpful/Not important at all, 7 = Essential/Very important, with exception of the workstation choice from the floorplan)	4.00	1.39

(*continued*)

Table I.
Full list of questionnaire items, including the means and standard deviations for all items and scales, and the Cronbach's alpha values for each of the original scales

Scale and item(s) used	M	SD
"Which workstation would you choose as your primary working location?" [from floorplan presented in Figure 1] [re-coded from 9-point scale to 7-point scale]	4.31	1.72
"An enclosed workspace, where my desk is separated from others using partitions"	3.58	1.87
"Opportunity to work in complete silence"	4.1	1.83
Workspace territoriality (α = 0.63) (7-point Likert scale: 1 = Very unhelpful/Not important at all, 7 = Essential/Very important)	4.62	1.38
"Opportunity to decorate desk with personally meaningful items (e.g. photos of loved ones, trophies and certificates, motivational phrases)"	4.52	1.88
"Being assigned a fixed desk which is mine, and which nobody else should use"	5.34	1.86
"Having a "flexible" or "agile" working concept, where I can work at different spaces throughout the day"*	4.00	1.73
Individual environmental control (α = 0.75) (7-point Likert scale: 1 = Very unhelpful/Not important at all, 7 = Essential/Very important)	5.43	1.31
"Opportunity for personal control of temperature (e.g. through individual heaters or fans)"	5.6	1.42
"Opportunity for personal control of lighting (e.g. through dimmable desk lamp)"	5.26	1.5
Aesthetic quality (α = 0.74) (7-point Likert scale: 1 = Very unhelpful/Not important at all, 7 = Essential/Very important)	4.33	1.16
"Presence of natural design features (e.g. interior plants, designs which mimic nature, window views to nature"	5.55	1.37
"Presence of inspirational artwork or photographs"	4.07	1.7
"An aesthetic internal colour scheme"	4.91	1.53
"Presence of pleasant aromas (e.g. through diffusion of essential oils in the air)"	4.3	1.77
"At your primary workspace, an acoustic soundscape playing soothing sounds (e.g. birdsong, waves, rain)"	2.85	1.85

Note: *Due to low Cronbach's alpha, the scale was disbanded and the individual items were entered separately into the analyses

Table I.

items had very poor internal consistency (α = 0.24), and would have not had reached the criteria for acceptability by dropping any individual items. As such, the three items were entered separately into the analyses as *task heterogeneity, concentration levels*, and *susceptibility to distraction*. It was predicted that requirements for more segregated workspaces would be associated with higher task heterogeneity, higher concentration levels, and higher susceptibility to distraction.

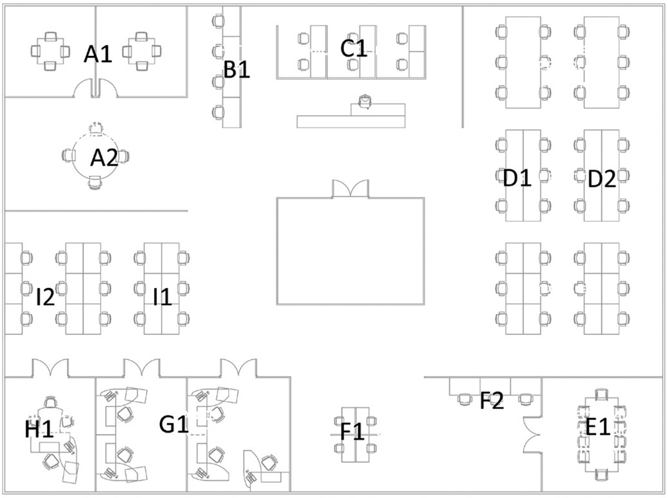
Three original items were also used to measure *location-dependency*, as the previous study on this topic had used a qualitative tool rather than a questionnaire (Greene and Myerson, 2011). However, these items also had poor internal consistency (α = 0.51) and removing individual items would not have sufficiently increased reliability. Accordingly, the three items were also entered separately into the analysis as *internal mobility, importance of flexible working*, and *impact of flexible working on work effectiveness*. It was predicted that requirements for higher workspace territoriality and higher individual environmental control would be associated with lower internal mobility, less positive perceptions regarding the importance of flexible working, and less positive perceptions regarding the impact of flexible working on work effectiveness.

Three original statements were used to measure *interactivity*, as the measure used in past research consisted of a single item scored using a dichotomous rather than continuous response (Haynes, 2008). In this case, the internal consistency for the items was acceptable (α = 0.73), so their average was used as the measure for interactivity.

Personality traits. For *introversion-extraversion*, participants viewed four personality descriptors from the Big-Five Mini-Markers Extraversion sub-scale (Saucier, 1994), and used a seven-point scale (1 = Very inaccurate, 7 = Very accurate) to rate the extent to which each described their personality. The internal consistency of these items was good (α = 0.84), so their average was taken as the measure of introversion-extraversion.

For *sensory processing sensitivity*, three statements were adapted slightly from the Highly Sensitive Person Scale (Aron and Aron, 1997) to suit a seven-point response scale (1 = Not at all, 7 = Extremely). Unexpectedly, the internal consistency for these items was unacceptable (α = 0.41), and would not have been sufficiently improved by dropping any individual item. Possibly, this surprising finding reflects recent research indicating that sensory processing sensitivity is actually a multi-factorial concept (Ershova *et al.*, 2018). Again, the three items were entered separately into the analyses, as *sensitivity to environmental subtleties, aesthetic sensitivity*, and *low sensory threshold*. It was predicted that requirements for more segregated workspaces would be associated with higher sensitivity to environmental subtleties, higher aesthetic sensitivity, and lower sensory threshold.

Perceived workplace requirements. All items in this section were self-generated. First, a novel method was used to capture *workspace segregation* requirements. Participants were asked to choose their favoured workspace from a floorplan (Figure 1) containing different workplace layouts from a common office typology: large open-plan, medium open-plan, small open-plan, shared private room, and individual private room (Bodin Danielsson and Bodin, 2008). Five additional common workspaces were also included: "quiet pods", hot-



Notes: From most integrated to most segregated): Large open-plan (central) (D1), Large open-plan (periphery) (D2), Medium open-plan (central) (I1), Medium open-plan (periphery) (I2), Small open-plan (central) (F1), Small open-plan (periphery) (F2), Shared private office (G1), Quiet pods (C1), Individual private office (H1). Not ranked in terms of integration-segregation: Hot-desk area (B1), Informal meeting area (enclosed) (A1), Informal meeting area (open) (A2), Formal meeting room (E1)

Figure 1. Integration-segregation ranking

desking area, formal meeting room, open informal meeting area, and enclosed informal meeting area.

Because position relative to circulation route also affects the amount of background activity to which one is exposed (Oseland, 2009), each open-plan zone was sub-divided into a zone close to the circulation route and a zone close to the periphery. Thus, the floorplan contained 13 workspace choices, nine of which were rank-ordered prior to the study from least to most segregated (order shown in Figure 1). The meeting spaces and hot-desks were not ranked in terms of segregation, but were included in order to understand whether respondents might prefer to work from a non-standard type of workspace. These responses (N = 16) were omitted from the workspace segregation analysis.

Subsequently, participants used a seven-point scale (1 = Very unhelpful/Not important at all, 7 = Essential/Very important) to rate the importance of various environmental features in their "ideal" workplace. Two additional items also related to workspace segregation, and were combined with the rank-ordered workspace choice (re-coded onto a seven-point response) to form a scale (α = 0.65). The perceived requirement for workspace segregation was taken as the average of the three items.

Additionally, three items measured *workspace territoriality*, two items measured *individual environmental control*, and five items measured *aesthetic quality*. In all cases, the internal consistencies of the scales were acceptable ($\alpha \geq 0.63$), so the perceived requirement for each workplace component was created by taking the average of the constituent items.

Results

Main analyses

To test the hypotheses, multiple linear regressions were performed for each perceived workplace requirement. In each case, a regression model was constructed with all of the potential predictors, using the forced entry method. Certain cases were omitted due to missing values for gender, age, and/or workspace segregation, meaning that the sample size was N = 342 for the workspace segregation analysis and N = 358 for the other three outcome variables. Summary statistics for the multiple regression models are shown in Table II, including standardised beta values and significance values for each predictor, and the variance explained by the predictors.

Workspace segregation. The multiple regression model for predicting perceived workspace segregation requirements was significant ($F(15, 326) = 11.55$, $p \leq 0.001$), and indicated that the employee characteristics accounted for approximately 35 per cent of the outcome variance ($R^2 = 0.35$). As expected, higher workspace segregation requirements were associated with higher susceptibility to distraction, being male, and higher introversion. Additionally, several predictors were also marginally above the cut-off point for statistical significance ($0.05 \leq p \leq 0.06$), and may warrant further investigation. These trends indicated that the requirement for a more segregated workspace may also have been associated with older age, lower sensory threshold, and, contrary to expectations, *lower* task heterogeneity. Results did not support predictions that interactivity, information type, or organisational tenure would be significantly associated with workspace segregation requirements.

Workspace territoriality. The model for predicting perceived workspace territoriality requirements was significant ($F(15, 342) = 9.07$, $p \leq 0.001$), and indicated that the employee characteristics accounted for approximately 28 per cent of the outcome variance ($R^2 = 0.28$). As expected, higher requirement for territoriality was associated with being female. Additionally, higher requirement for territoriality was also associated with less positive

Table II. Results of the four multiple regression analyses, with effects significant at $p \leq 0.05$ shown in italics

	Workspace segregation ($R^2 = 0.35$)		Workspace territoriality ($R^2 = 0.28$)		Individual environmental control ($R^2 = 0.16$)		Aesthetic quality ($R^2 = 0.28$)	
Predictors	β	p	β	p	β	p	β	P
Gender	*−0.14*	*<0.01*	*0.1*	*0.036*	*0.23*	*<0.001*	0.01	0.85
Age	0.09	0.052	0.01	0.91	−0.05	0.32	−0.03	0.47
Organisational tenure	0.01	0.82	0.03	0.51	0.07	0.2	−0.02	0.74
Task heterogeneity	−0.09	0.055	*−0.19*	*<0.001*	*−0.16*	*<0.01*	−0.01	0.88
Concentration levels	0.09	0.082	0.05	0.31	0	0.99	−0.03	0.59
Susceptibility to distraction	*0.38*	*<0.001*	*0.14*	*0.01*	0.04	0.54	0.04	0.49
Interactivity with colleagues	−0.09	0.082	0.1	−0.11	0.07	0.22	0.04	0.4
Internal mobility	0.02	0.64	*−0.13*	*0.016*	*−0.11*	*0.049*	−0.08	0.13
Importance of flexible working	−0.09	0.065	−0.1	0.059	0.01	0.87	−0.01	0.8
Impact on work effectiveness of flexible working	0.08	0.12	*−0.27*	*<0.001*	*0.15*	*<0.01*	*0.22*	*<0.001*
Information type	−0.02	0.69	*−0.1*	*0.037*	−0.08	0.11	−0.02	0.66
Introversion-Extraversion	*−0.12*	*0.013*	−0.06	0.18	0.04	0.4	0.07	0.14
Sensitivity to subtleties in environment	−0.04	0.38	−0.04	0.38	0.01	0.92	−0.02	0.62
Aesthetic sensitivity	0.04	0.47	−0.03	0.61	0.01	0.87	*0.43*	*<0.001*
Low sensory threshold	0.1	0.055	−0.01	0.79	*0.13*	*0.02*	0.1	0.07

perceptions of the impact of flexible working on work effectiveness, lower task heterogeneity, higher susceptibility to distraction, lower internal mobility, and by the use of verbal/numerical information. There was also a trend to indicate that higher territoriality requirements were also associated with less positive perceptions regarding the importance of flexible working, although this was marginally above the criteria for statistical significance ($p = 0.059$).

Individual environmental control. The model for predicting the perceived requirement for individual environmental control was significant ($F(15, 342) = 4.44$, $p \leq 0.001$), and indicated that the employee characteristics accounted for approximately 16 per cent of the outcome variance ($R^2 = 0.16$). Requirements for higher levels of individual environmental control were associated with being female, lower task heterogeneity, more positive perceptions of the impact of flexible working on work effectiveness, lower sensory threshold, and lower internal mobility.

Aesthetic quality. The model for predicting the perceived requirement for aesthetic quality was significant ($F(15, 342) = 8.67$, $p \leq 0.001$), and indicated that the employee characteristics accounted for approximately 28 per cent of the outcome variance ($R^2 = 0.28$). Requirements for higher aesthetic quality within the workplace were associated with higher aesthetic sensitivity and with more positive perceptions regarding the impact of flexible working on work effectiveness.

Discussion

Workspace segregation

The results confirmed 3 of the 12 propositions in *H1*, and provided partial evidence for four others. As expected, more segregated workspaces tended to be preferred by employees who were more susceptible to distraction, more introverted, and male. There were also trends to suggest that the requirement for segregation was associated with higher time spent concentrating, lower interactivity, higher age, and lower sensory threshold, although these effects were marginally above the criteria for statistical significance ($0.052 \leq p$-values ≤ 0.082). There was no evidence to support the predicted associations with task heterogeneity, information type, sensitivity to environmental subtleties, aesthetic sensitivity, and organisational tenure.

The strongest effect was observed for susceptibility to distractions, an item originally intended to measure need for concentration. Another item from the original scale, measuring time spent in concentration, also showed an effect in the expected direction, although this did not meet significance criteria. As such, our results were broadly in line with previous research indicating open offices are most unsuitable for those with high concentration requirements (Seddigh *et al.*, 2014), with distraction susceptibility emerging as especially important. This phenomenon can be interpreted through perceptual load theory, which demonstrates that susceptibility to environmental distractions is highest when the task requires high cognitive load but low perceptual load (Lavie, 2010).

We had also expected that those who primarily worked with verbal/numerical rather than visual/spatial information would prefer higher segregation, given that this type of work also involves low perceptual load and increases susceptibility to environmental distractions, particularly speech. However, this was not supported in our data. Possibly, this may have been due to highly uneven distribution between the two categories amongst our sample. Future research would help to clarify this.

Higher introversion also predicted requirements for more segregated workspaces, in accordance with previous research (Hartog *et al.*, 2018; Oseland and Hodsman, 2018).

This is thought to occur because introverts have higher natural psychophysiological arousal than extraverts, and so require workspaces which are more shielded from additional acoustic and visual stimuli, as these can cause overstimulation (Geen, 1984). The same explanation could account for the effect, marginally above statistical significance (p = 0.055), that lower sensory threshold was associated with the requirement for a more segregated workspace.

In terms of demographics, there was a small effect, also marginally above significance (p = 0.052), to suggest that higher segregation was associated with higher age, but no evidence to suggest an association with organisational tenure. It has been previously demonstrated that higher age is associated with higher noise susceptibility (Horvath *et al.*, 2009), so it is possible that the previous study which found an effect of tenure (Fried *et al.*, 2001) may simply have captured an age-related difference, as this was not controlled in their study.

Finally, in terms of gender, the results confirmed that men also tended to prefer more segregated workspaces. Possibly, this reflects findings that women more effectively use social support to support recovery from stress than men (Belle, 1991; Schwarzer and Leppin, 1989), and so require workplaces where interpersonal contact is more easily afforded.

Workspace territoriality

The results confirmed three of the four propositions within *H2*, that higher workspace territoriality requirements would be associated with being female, lower internal mobility, and less positive perceptions regarding the impact of flexible working on work effectiveness. There was also a small effect, marginally above the criteria for statistical significance, to indicate that higher workspace territoriality requirements were associated with less positive perceptions regarding the importance of flexible working. As such, *H2* was supported.

The results relating to gender are in line with previous research indicating that desk personalisation is particularly important for supporting well-being amongst women (Wells, 2000). To account for this finding, it has been suggested that women have a greater need for affiliation than men and personalisation helps to prompt social interactions. Another suggestion is that women have traditionally been viewed as homemakers in western society, and so have a greater tendency to prioritise the familiarity and attractiveness of their working area.

Although the items intended to measure location-dependency transpired to be relatively independent of one another, their associations with workspace territoriality requirements were as expected. In particular, perceptions regarding the impact of flexible working on work effectiveness had the strongest effect. This supports previous findings that more location-dependent employees have a higher requirement for familiar and homely working areas (Greene and Myerson, 2011), and may explain the common observation from case studies that many employees resist non-territorial office concepts and persist with a fixed working style and territorial behaviours (Appel-Meulenbroek *et al.*, 2011; Hoendervanger *et al.*, 2016; Skogland, 2017).

Unexpectedly, higher territoriality requirements were also associated with lower task heterogeneity. Presumably, employees completing more repetitive and procedural work do not need a variety of different functional workspaces to do so, and therefore do not believe flexible working will improve their productivity. Instead, they prioritise those psychological aspects which help to imbue the workspace with a sense of meaning.

Finally, there was another unexpected finding that higher territoriality requirements were associated with higher susceptibility to distractions. Possibly, this suggests that employees are generally able to develop coping strategies to deal with distractions at their workspace, but this capability is diminished if they change workspaces regularly. As such, individuals who are more susceptible to distractions prefer to have an assigned desk they can work from regularly, so they can learn what sorts of distractions to expect at that location and how these might be mitigated.

Individual environmental control

The results supported three of the four original propositions in *H3*. As expected, requirements for higher individual environmental control were associated with being female, with lower internal mobility, and with less positive perceptions regarding the impact of flexible working on work effectiveness. However, there was no evidence to suggest that individual environmental control requirements were associated with perceptions regarding the importance of flexible working. Thus, *H3* was mostly supported.

Gender was the strongest predictor, which may reflect the fact that women tend to be more thermally sensitive than men (Hashiguchi *et al.*, 2010). Similarly, lower sensory threshold was also associated with higher requirements for individual environmental control, and can be interpreted with the same explanation. When individuals are naturally more attuned to environmental stimuli they are more likely to be dissatisfied under group-level conditions, so personal comfort devices may be required to optimise environmental comfort.

The results also showed that higher individual environmental control requirements were associated with lower internal mobility, supporting previous research indicating more location-dependent employees place a higher priority on comfort at their workspace (Greene and Myerson, 2011). Unexpectedly, however, higher control requirements were also associated with more positive perceptions regarding the impact of flexible working on work effectiveness. Taken together, these two findings possibly indicate that the employees most in need of individual environmental control are those who would prefer to work flexibly but have no opportunity to do so. Such individuals cannot simply move to a more appropriate area in the event of environmental discomfort, and so prioritise individual control over local conditions.

Aesthetic quality

Due to the paucity of past research, *H4* made no specific predictions regarding the influence of individual differences on requirements for aesthetic quality, and a more exploratory approach was adopted. The results indicated that two employee characteristics were associated with aesthetic quality requirements. There was a strong effect to suggest that individuals with higher aesthetic sensitivity tend to ascribe more importance to the look and feel of the workplace. This is perhaps an intuitive and unsurprising finding, but nonetheless demonstrates that the perceived importance of aesthetic quality differs between employees.

Additionally, aesthetic quality requirements were stronger amongst employees who had less positive perceptions regarding the impact of flexible working on work effectiveness. Presumably, given that additional functional workspaces are less important to such employees, the aesthetic quality of the workplace takes higher priority amongst the factors that can make the office more appealing.

Limitations

The most notable limitation of the present study was the poor internal consistency of the items originally intended to measure need for concentration, location-dependency, and sensory processing sensitivity. Regarding need for concentration and location-dependency, the original items we used actually transpired to be relatively independent of one another. Similarly, recent research (published after our data collection) confirmed that the measure we used for sensory processing sensitivity actually captures multiple factors (Ershova *et al.*, 2018). In all three cases, we were able to re-interpret the precise meaning of each item and enter the items into the analysis separately. However, in future research it will be necessary to more tightly operationalise the characteristics under consideration, using previously validated scales where possible.

Second, whilst our data identified several characteristics which explain inter-individual variability in perceived workplace requirements, it is not yet clear to what extent meeting these requirements will improve well-being and productivity. In general, it is predicted that working environments which are more aligned to the needs of the users will improve job performance (Roskams and Haynes, 2019), but future research is needed to determine whether some aspects of environmental comfort are more important than others. For example, it has been demonstrated that the behavioural environment (i.e. the ability to minimise distractions and maximise useful interactions) has a stronger influence upon productivity than the physical environment (Haynes, 2007), suggesting that aspects of the workplace which directly influence these factors should be prioritised over those which are less functional in nature.

Finally, although efforts were made to choose the most appropriate employee characteristics to measure on the basis of past research, it remains possible that a larger proportion of outcome variance would have been explained had additional characteristics been included. For example, in recent studies, the personality traits of neuroticism (Oseland and Hodsman, 2018) and the psychological need for privacy (Hoendervanger *et al.*, 2018) were identified as important individual difference factors in the workplace. As research evolves, it will be necessary to hone in on those factors which are most strongly associated with workplace requirements, so that practitioners have greater clarity on what needs to be considered when providing workplace solutions.

Practical implications

The most important practical implication of the present findings is that employees have considerably non-uniform workplace requirements, and so the strategies required for aligning the workplace to the needs of the occupants may be very different at different organisations. Based on the characteristics of the workforce, the exact same office environment could be perceived as perfect or highly stress-inducing. As such, it is crucial to perform a thorough consultation of the workplace end users prior to any workplace renovation or relocation.

For example, practitioners tasked with determining whether a higher proportion of segregated workspaces are necessary might consider the extent to which the typical tasks undertaken in the office are susceptible to distraction, and/or the introversion-extraversion of the workforce. Practitioners tasked with determining the likely impact of a transition to flexible working practices might consult the employees on their perceptions regarding whether or not the opportunity to use different functional workspaces would be beneficial to them. By consulting the workplace end users and feeding the results into plans for workplace design and strategy, practitioners can help to reduce demands and increase resources in the workplace environment for the employees at that site, resulting in improved well-being and productivity.

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Acoustic comfort in open-plan offices: the role of employee characteristics

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Abstract

Purpose – This paper aims to determine the extent to which employees' experiences of acoustic comfort, well-being and productivity in open-plan offices are determined by specific characteristics (including demographic information, task characteristics, and personality traits).

Design/methodology/approach – A questionnaire was distributed to the occupants of three open-plan office sites and was completed by 166 employees in total.

Findings – The results indicated that acoustic comfort in open-plan offices is largely determined by noise sensitivity. Higher noise sensitivity was associated with more negative ratings of acoustical quality, more perceived disturbance by speech and more difficulties in concentration. More negative experiences were also reported by employees with lower interactivity with colleagues.

Practical implications – There is significant inter-individual variability in experiences of acoustic comfort, well-being and productivity in open-plan offices. As such, workplace practitioners should consider acoustic and behavioural solutions for introducing a greater diversity of functional workspaces within the office, so that employees can choose the most suitable working area for their requirements.

Originality/value – Whereas the majority of past acoustics research has been laboratory-based, this study is conducted in real office environments with a representative sample of knowledge workers.

Keywords Personality, Productivity, Individual differences, Employee characteristics, Psychoacoustics, Acoustic comfort

Paper type Research paper

Introduction

Within corporate real estate and facilities management, office "improvements" are primarily driven by a cost reduction paradigm, in which productivity gains are sought through more efficient use of space (Haynes, 2007). In particular, this paradigm has underpinned the increasing global uptake of open-plan offices, which adopt various strategies to enable the allocation of fewer square metres per employee (e.g. shared workspaces, removal of interior walls), generating clear cost savings for organisations (Brennan *et al.*, 2002).

Purportedly, the transition to open-plan offices was also supposed to support increased interpersonal collaboration and knowledge sharing within organisations. However, evidence for the effectiveness of open-plan offices relative to enclosed offices is weak, with a growing body of cross-sectional and longitudinal research indicating that communication actually worsens in open-plan offices (Bernstein and Turban, 2018; Kaarlela-Tuomaala *et al.*, 2009; Kim and de Dear, 2013; Pejtersen *et al.*, 2006), and numerous other indicators of

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environmental comfort, well-being, and productivity also suffer (Bodin Danielsson and Bodin, 2008; Brennan *et al.*, 2002; Kaarlela-Tuomaala *et al.*, 2009; Pejtersen *et al.*, 2006).

In particular, background noise is the most common environmental complaint in open-plan offices (Bodin Danielsson and Bodin, 2009; Jensen *et al.*, 2005), particularly overheard speech from neighbouring workstations (Haapakangas *et al.*, 2008; Jensen *et al.*, 2005; Mak and Lui, 2012). Background speech is particularly disruptive for knowledge workers because attending to it interferes with the articulatory rehearsal process in working memory (Gathercole and Baddeley, 1993), meaning that it more strongly disrupts cognitive task performance than other types of noise (Balazova *et al.*, 2008; Haapakangas *et al.*, 2014; Haka *et al.*, 2009; Liebl *et al.*, 2012). As such, relative to enclosed offices, open-plan offices are associated with an approximate tenfold increase in acoustic complaints (Pejtersen *et al.*, 2006) and an estimated doubling in the amount of time wasted due to noise (Kaarlela-Tuomaala *et al.*, 2009). In turn, acoustic discomfort contributes to dissatisfaction with the overall workplace environment (Lee *et al.*, 2016), productivity loss (Mak and Lui, 2012), and increased workplace conflict (Bodin Danielsson *et al.*, 2015).

However, it has been argued that these findings simply reflect the fact that the majority of open-plan offices are poorly designed. Research conducted in industry, on a database containing more than 250,000 occupant survey responses, concluded that whilst open-plan offices in general tended to be rated more negatively than enclosed offices, the small sub-sample of the highest-performing offices were almost wholly open-plan (Oldman and Rothe, 2017). This suggests that more effective workplace design could greatly alleviate many of the negative outcomes that are associated with open-plan offices. Indeed, given that organisations remain reluctant to relinquish the significant competitive advantages afforded by reductions in real estate costs, it has been recognised that the crucial challenge facing modern workplace practitioners is providing open-plan offices in which noise distractions are minimised (Haynes, 2008; Oseland and Hodsman, 2018).

To this end, it is crucial to recognise that the response to a noise source can vary significantly from employee to employee. A growing number of workplace theorists have argued that there is no such thing as good or bad workplace design *per se*, but rather workplace designs which are either aligned or misaligned to the needs of the occupants (authors, manuscript submitted for review; Gerdenitsch *et al.*, 2018; Haynes, 2012; Vischer, 2007). Thus, it is crucial to understand how the workplace requirements of different knowledge workers vary as a result of certain characteristics, so that workplace practitioners know how offices should be effectively designed and maintained for different groups of employees. In this study, we focus in particular on how employees' experiences of acoustic comfort, well-being, and productivity in open-plan offices are shaped by specific characteristics (including task characteristics, personality traits, and demographics).

Individual differences

In previous research, various employee characteristics have been found to moderate employee outcomes in open-plan offices. These can be broadly divided into characteristics of the work being completed, the employee's personality traits and also demographic characteristics.

Regarding the nature of the work, researchers have considered the *task complexity* (and, consequently, the degree to which focussed concentration is necessary for its effective completion). For example, previous studies conducted in open-plan offices have found that environmental dissatisfaction is highest among those with high job complexity (Fried *et al.*, 2001), and that distractions and cognitive stress are highest amongst those with a high need for concentration (Seddigh *et al.*, 2014). This is thought to occur because the completion of complex mental activities places high strain on the cognitive system and leaves it susceptible to disruption, but places low strain on the perceptual system and leaves more capacity for the processing of irrelevant stimuli (Lavie, 2010).

Another important task characteristic is an employee's typical *interactivity* (i.e. the degree to which their role requires collaboration with colleagues). Evidently, the effective completion of collaborative work necessitates a shared space where interaction, feedback and knowledge sharing are supported. Conversely, for those who complete mostly individual work, background speech is more likely to be task-irrelevant and a distraction. Indeed, it has been demonstrated that employees who perform a higher proportion of group work are more likely to rate the open-plan office as having a positive impact on their productivity, whereas those who perform mostly individual work rate it negatively (Haynes, 2008).

In terms of personality traits, *introversion-extraversion* has received significant attention. Numerous studies have indicated that introverts are most satisfied and productive under very low levels of background noise, whereas extraverts prefer noisier environments (Belojevic *et al.*, 2001; Cassidy and MacDonald, 2007; Dobbs *et al.*, 2011; Geen, 1984; Oseland and Hodsman, 2018). The explanation offered for this phenomenon is that extraverts naturally have lower psychophysiological arousal than introverts and need additional stimulation from the external environment to up-regulate themselves to an optimal level, whereas the same additional stimulation leads to a state of over-arousal for introverts (Geen, 1984).

A similar but distinct personality trait concerns an individual's natural responsiveness to stimuli in the external environment, termed "sensory processing sensitivity" in general or "*noise sensitivity*" when relating specifically to auditory stimuli. It has been demonstrated that higher noise sensitivity leads to increased dissatisfaction and poorer cognitive performance in the presence of background speech (Haapakangas *et al.*, 2014), higher annoyance ratings and physiological correlates of stress in response to other noise sources (Park *et al.*, 2018), and the increased use of coping strategies and higher estimated time wasted due to noise in open-plan offices (Kaarlela-Tuomaala *et al.*, 2009). It is suggested that higher noise sensitivity results in more difficulty screening out irrelevant auditory stimuli, leading to greater disruption in work.

Finally, there is also some evidence to suggest that demographic characteristics such as *age* and *gender* influence acoustic comfort in open-plan offices. Younger employees report higher satisfaction in open-plan offices than older employees (Pullen, 2014), possibly because advanced age tends to increase sensitivity to auditory distractions (Horvath *et al.*, 2009). Results relating to gender are slightly more unclear; past research has suggested that women are more likely than men to report noise disturbances in open-plan offices, but are also less likely to experience conflicts in these offices (Bodin Danielsson *et al.*, 2015) and are more likely to rate workplace interactions positively (Haynes *et al.*, 2017). Due to this ambiguity, gender was also included as a potential predictor in the study, but was not included in the hypotheses.

Aims and hypotheses

To summarise, the aim of the present study was to explore the extent to which certain employee characteristics are associated with acoustic comfort, well-being, and productivity in open-plan offices. The majority of past research in this area has been conducted in laboratory settings. Whilst this has provided researchers with high levels of control over variables, it remains unclear whether the findings generalise to real workplaces. As such, we decided to conduct this investigation within the context of real office environments, to improve the ecological validity of the findings.

In a previous study, we found that the perceived requirement for more open workspaces was predicted by lower sensory sensitivity, lower task complexity, higher extraversion, higher interactivity, and lower age (Roskams and Haynes, 2019). In particular, sensory processing sensitivity was the strongest predictor of these requirements. Here, we predict that the same characteristics will be associated with acoustic comfort, well-being, and productivity in open-plan offices, and that noise sensitivity will have the strongest impact upon the outcomes:

H1. More positive ratings for the outcome variables will be predicted by: (a) lower noise sensitivity, (b) lower task complexity, (c) higher interactivity, (d) higher extraversion and (e) lower age.

H2. Noise sensitivity will have a stronger effect on the outcome variables than the other employee characteristics.

Method

Participants

Data were collected at three open-plan office sites in the United Kingdom. Each site was a regional office for a large facilities management organisation, housing knowledge workers completing typical office activities. The study employed a cross-sectional survey design, entailing the completion of a single questionnaire at one time only. Approximately 500 employees across the three sites were contacted by email with an invitation to complete the questionnaire, in exchange for entry into a prize draw to win a £20 Amazon gift voucher.

In total, 180 employees completed the survey (response rate ~35 per cent). For the data analysis, entries with missing data ($N = 14$) were omitted, resulting in a final sample size of 166 (92 male, 74 female), with 42 to 79 respondents per site. In all, 106 participants were aged 18-35, 42 were aged 36-50, and 14 were aged 51-64.

Physical and acoustic office characteristics

At each site, two of the researchers visited the open-plan office to perform detailed acoustic testing. Background noise levels for 8 hours were measured during the daytime (9 a.m.-6 p.m.) and acoustic speech privacy parameters (ISO 3382-3:2012) were measured during night time without workers. The physical acoustics data was not used for analysis in the present study, but certain measurements are reported in Table I for the purposes of describing the research context. Specifically, the table shows the physical characteristics of each site, the measured background noise level ($L_{\mathrm{Aeq,8h}}$), the decay rate of speech ($D_{2,S}$), and the distraction distance (*rD)*.

Background noise levels varied from 52.1 to 56.5 dBA, which are similar to the levels reported by Kaarlela-Tuomaala *et al.* (2009). For $D_{2,S}$, measurements are interpreted with respect to the target values from a common industry standard (Finnish Association of Civil Engineers, (RIL), 2008), which prescribes four levels of classification: Class A (Excellent), Class B (Good), Class C (Fair), and Class D (Poor). As shown, the speech privacy at each site was relatively poor, meeting only Class C or D criteria. This is mainly due to the fact that two of the sites had very low partitions (<0.4 m from table) and the other site did not have any partitions.

Questionnaire

All questionnaire items and response scales are shown in Table II. Additionally, descriptive statistics for the sample are provided, including the Cronbach's Alpha (α) for each multi-

Table I. Physical characteristics and results of acoustic testing at each site

Site	Ceiling height (metres)	Partition height (from table, metres)	Desk height (metres)	Desk size (metres)	LAeq,8h (dBA)	D2,S (dB)	rD (metres)
Site 1 ($N = 46$)	2.7	0.38	0.72	0.8×1.2	56.3	5.7 to 7.2 *(Class C/D)*	12.2 to 15.0
Site 2 ($N = 42$)	3	No partition	0.72	0.8×1.4	52.1	4.2 to 7.9 *(Class C/D)*	9.7 to 10.8
Site 3 ($N = 78$)	2.45	0.33	0.72	0.8×1.6	56.5	7 to 7.9 *(Class C)*	10.6 to 12.7

Scale	M	SD
Task Complexity (α = 0.8) "The job requires me to use a number of complex or high-level skills"; "The job is quite simple and repetitive*"; *[1 = Strongly Disagree, 7 = Strongly Agree]*	4.39	1.51
Interactivity (α = 0.78) "The job requires a high level of group work and regular communication with colleagues"; "The job is one where I spend most of the day talking with other people, either face-to-face or on the phone" *[1 = Strongly Disagree, 7 = Strongly Agree]* "What proportion of the time do you spend doing collaborative work (e.g. working in groups, talking on the phone, impromptu interactions with colleagues) compared to individual focussed work"? *[1 = Always individual, 7 = Always collaborative]*	4.5	1.36
Extraversion (α = 0.79) "Generally, is it accurate or inaccurate that you are . . . (a) Shy*; (b) Talkative; (c) Outgoing; (d) Reserved*?" *[1 = Very inaccurate, 7 = Very accurate]*	4.83	1.09
Noise Sensitivity (α = 0.87) "I get annoyed when my neighbours are noisy"; "I get used to most noises without much difficulty*"; "I find it hard to relax in a place that's noisy"; "I get mad at people who make noise that keeps me from falling asleep or getting work done"; "I am sensitive to noise" *[1 = Disagree, 7 = Agree]*	3.94	1.49
Acoustical Quality "Overall, how satisfied or dissatisfied are you with the acoustical quality in your office?" *[1 = Very dissatisfied, 7 = Very satisfied]*	4.26	1.33
Disturbance by Speech "How disturbing do you find colleagues chatting in your office?" *[1 = Not at all, 7 = Extremely]*	3.41	1.78
Difficulties in Concentration "How often do you experience difficulties in concentration in your current working environment?" *[1 = Never, 7 = Frequently]*	3.87	1.39
Stress "How often do you experience stress in your current working environment?" *[1 = Never, 7 = Frequently]*	3.9	1.68
Engagement (α = 0.75) "How often do you experience . . . (a) enthusiasm; (b) complete absorption; (c) feeling energetic in your current working environment?" *[1 = Never, 7 = Frequently]*	4.37	1.08
Office Productivity "Overall, in your opinion, what impact does the physical environment in your current office have upon your productivity"? *[1 = Very negative, 7 = Very positive]*	4.28	1.21

Note: *Item was reverse-scored prior to analysis

Table II.
Full wording of the items used on the questionnaire, including descriptive statistics for all of the measures (N =166)

item scale, as well as the mean (*M*) and standard deviation (*SD*) for each measure. Where possible, survey items were taken from past research, although these were sometimes adapted to suit a common response format throughout the questionnaire.

The first group of items measured employee characteristics, which included demographic information, task characteristics, and personality traits. First, participants reported their *gender* and selected their *age* group from one of four categories (18-35, 36-50, 51-64, 65 and over). Next, two items were selected from the "skill variety" sub-scale of Hackman and Oldham's (1975) Job Diagnostic Survey as a measure of *task complexity* (α = 0.8), as these directly related to perceptions regarding the difficulty of one's work. Three original items were used to measure *interactivity* (α = 0.78), as the only measure we found in previous research used a dichotomous rather than continuous response (Haynes, 2008). For the personality trait measures, four descriptors were taken from the Big Five Mini-Markers Extraversion sub-scale (Saucier, 1994) as a measure of *introversion-extraversion* (α = 0.79), and five items were taken from Weinstein's (1978) Noise Sensitivity Scale as a measure of *noise sensitivity* (α = 0.87).

The second group of items measured the outcome variables. For acoustic comfort, a single-item measure was adapted slightly from Kaarlela-Tuomaala *et al.* (2009) to measure *acoustical quality* in general, and an original item was included to measure *disturbance by speech,* to recognise the most commonly mentioned noise in open-plan offices. In recognition of the fact that well-being is a multidimensional construct but is often operationalised in an overly vague and broad manner (Hanc *et al.*, 2019), we selected three specific dimensions including both negative and positive symptoms. A single-item measure was adapted slightly from Kaarlela-Tuomaala *et al.* (2009) to measure *difficulties in concentration* and one additional item was used to measure perceived *stress.* Three original items were used to measure *work engagement*, derived from items on the Utrecht Work Engagement Scale (Schaufeli *et al.*, 2002). Finally, one item was adapted from Haynes (2008) to measure *office productivity*, defined as the perceived impact of the physical workplace upon productivity.

Statistical analyses

All data analysis was performed using R Studio. Specifically, the *lm* function from R's base package was used to create multiple regression models, the *Anova* function from the "car" package (Fox and Weisberg, 2011) was used to perform the multivariate hypothesis tests, and the *eta_sq* function from the "sjstats" package (Lüdecke, 2019) was used to generate partial eta-squared estimates for the predictors in the regression models.

Results

Descriptive statistics

For descriptive purposes, means and standard deviations are shown for each of the employee characteristics and outcomes (Table II). Additionally, a correlation matrix showing the interrelationships between the different outcomes are reported (Table III). As shown, in the majority of cases the outcomes were significantly correlated with one another, albeit relatively weakly (all absolute r values $\leq$ 0.35). The strongest correlations indicated that increased concentration difficulties were generally associated with more negative ratings of acoustical quality ($r = -0.35$) and higher disturbance by speech ($r = 0.32$). Whilst the relationships between outcomes were generally as expected, non-significant correlations indicated that work engagement was independent of disturbance by speech ($r = -0.02$) and stress (r = -0.05) in the present sample.

	Acoustical Quality	Disturbance by Speech	Difficulties in Concentration	Stress	Engagement	Office Productivity
Acoustical Quality	X	X	X	X	X	X
Disturbance by Speech	−0.32***	X	X	X	X	X
Difficulties in Concentration	−0.35***	0.32***	X	X	X	X
Stress	−0.24**	0.2**	0.2**	X	X	X
Engagement	0.21**	−0.02	0.14	−0.05	X	X
Office Productivity	0.25***	−0.25***	−0.24**	−0.16*	0.27***	X

Notes: * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$

Table III.
A Correlation matrix showing the interrelationships between the different outcome variables

Regression analyses

Multiple regression analyses were used to explore the associations between the employee characteristics and the outcome variables. Due to the inter-relationships amongst the outcomes, a multivariate multiple regression analysis was used to test the statistical significance of each predictor. A dummy variable to represent the site at which the data was collected was included in the regression model to control for any between-context variance. The results of the regression analysis are displayed in Table IV. Specifically, Table IV shows the *p*-values from the multivariate multiple regression analysis, and also shows summary statistics from each univariate regression model (the unstandardised coefficient (*B*) and partial eta-squared (η-*p2*) for each predictor to indicate the nature and size of the effect, and the R^2 for each model to indicate the overall variance in the outcome explained by the employee characteristics). Effect sizes are discussed with respect to Cohen's (1988) recommendations for statistical power analysis in the behavioural sciences.

The results of the multivariate analysis show that the strongest predictor of the outcome variables was noise sensitivity (F (6, 152) = 18.46, $p < 0.001$). In particular, there were large effects to indicate that higher noise sensitivity was associated with greater disturbance by speech and more difficulties in concentration. Additionally, a small effect was observed with respect to three of the other outcome variables, such that higher noise sensitivity was associated with more negative ratings of acoustical quality, higher levels of stress, and lower self-rated productivity.

Two other employee characteristics emerged as significant predictors of the outcome variables, task complexity (F (6, 152) = 2.57, $p = 0.02$) and interactivity (F (6, 152) = 2.18, $p = 0.05$). Contrary to expectations, results suggested that higher task complexity was actually associated with *higher* levels of work engagement and self-reported productivity. Regarding interactivity, the results indicated that higher interactivity with colleagues was associated with higher levels of work engagement. There were also small effects indicating that higher interactivity was associated with fewer difficulties in concentration, less disturbance by speech, more positive ratings of acoustical quality, and higher ratings of productivity.

The results also indicated several small effects in line with the hypotheses. Specifically, there was some evidence that higher age was associated with lower ratings of acoustical quality and higher disturbance by speech, and also that higher extraversion was associated with higher ratings of productivity. However, neither the multivariate hypothesis test for age (F(6, 152) = 1.04, $p = 0.29$) nor extraversion (F(6, 152) = 1.2, $p = 0.31$) were significant, so it cannot be concluded that these effects did not arise by chance.

Discussion

The aim of this study was to investigate the extent to which employee characteristics were associated with acoustic comfort, well-being, and productivity in open-plan offices. In doing so, we aimed to identify the types of knowledge worker who were more or less suited to working in this type of environment. Multiple regression analyses were used to explore the relationships between the variables. The implications of the findings are discussed, and suggestions for future research are offered.

The results supported the hypothesis that noise sensitivity would have the strongest impact on the outcome variables (H_2). Specifically, participants with higher noise sensitivity tended to rate the acoustical quality of the office more negatively, were more disturbed by speech, had greater difficulties in concentration, were more stressed, and had lower self-rated productivity. The effect size was particularly strong in the case of disturbance by speech, where noise sensitivity alone accounted for almost 40 per cent of the outcome

Table IV.
A Table presenting summary statistics from the six multiple regression analyses, including the unstandardised beta (B) and partial eta-squared (p-η^2) for each predictor, the R-squared statistic for each regression model (R^2), and the p-values from the multivariate regression analysis

Predictor		Outcome: Acoustical Quality	Disturbance by Speech	Difficulties in Concentration	Stress	Engagement	Productivity	p-value
Site = 2	B	0.006	−0.11	−0.01	0.42	0.07	−0.18	0.89
	p-η^2	0.000	0.01	0.000	0.035^	0.016^	0.006	
Site = 3	B	−0.07	−0.23	−0.08	−0.15	0.11	−0.44	0.43
	p-η^2	0.001	0.003	0.000	0.001	0.009	0.043^	
Gender	B	0.093	0.27	0.08	0.5	0.17	0.15	0.41
	p-η^2	0.006	0.002	0.001	0.02	0.007	0.011^	
Age	B	−0.25	0.11	−0.05	−0.29	0.04	0.01	0.29
	p-η^2	0.016^	0.016^	0.000	0.005	0.019^	0.002	
Task Complexity	B	0.079	−0.13	−0.1	0.06	0.21	0.11	0.02
	p-η^2	0.007	0.008	0.014	0.006	0.11^^	0.023^	
Interactivity	B	0.068	−0.002	−0.15	0.07	0.19	0.05	0.05
	p-η^2	0.011^	0.021^	0.045^	0.003	0.074^^	0.017^	
Extraversion	B	−0.018	−0.028	0.03	0.13	0.08	0.19	0.31
	p-η^2	0.000	0.001	0.000	0.006	0.008	0.029^	
Noise Sensitivity	B	−0.2	0.77	0.35	0.15	−0.001	−0.11	<0.001
	p-η^2	0.048^	0.38^^^	0.13^^^	0.018^	0.000	0.019^	
Model R^2		0.08	0.41	0.18	0.09	0.21	0.13	

Notes: Effect size interpretation (Cohen, 1988): ^Small ($0.01 \leq p\text{-}\eta 2 < 0.06$); ^^Medium ($0.06 \leq p\text{-}\eta 2 < 0.13$); ^^^Large ($p\text{-}\eta 2 \geq 0.13$)

variance. Thus, it can be concluded that the appropriateness of open-plan office for effective work performance is largely moderated by an individual's noise sensitivity.

These results are in accordance with previous findings on the influence of noise sensitivity in indoor environments (Haapakangas *et al.*, 2014; Kaarlela-Tuomaala *et al.*, 2009; Park *et al.*, 2018). At the physiological level, higher noise sensitivity heightens the response to auditory stimuli, characterised by both a stronger response to the stimulus (increased respiratory rate and electrodermal activity, decreased heart rate), and a slower return to baseline in the recovery phase (Park *et al.*, 2018). At the cognitive level, this is manifest in increased involuntary attention to auditory stimuli and more difficulty in re-focusing following disruption, leading to greater noise disturbance and time wasted due to noise in open-plan offices (Kaarlela-Tuomaala *et al.*, 2009).

Regarding predictions made about the influence of the other employee characteristics (H_1) were only partially supported. There was evidence to support predictions that employees' interactivity with colleagues would be associated with certain outcomes. Specifically, it was confirmed that employees who interacted with colleagues less frequently tended to rate the acoustical quality of the office more negatively, were more disturbed by the speech of others, experienced more concentration difficulties, showed lower work engagement, and had lower self-rated productivity. This is in accordance with previous research indicating that employees who primarily perform individual work tend to rate the open-plan office as having a more negative impact on their productivity, compared to employees who primarily perform collaborative work (Haynes, 2008). Again, this highlights the fact that the open-plan office environment is more suitable for certain employees than others do, in this case, as a result of the type of work that they typically do.

However, other predictions contained within H_1 were not supported. Two unexpected effects emerged, both relating to task complexity. On the basis of research indicating that environmental dissatisfaction and stress in open-plan offices were highest amongst those completing more complex work (Fried *et al.*, 2001; Seddigh *et al.*, 2014), we had originally predicted that higher task complexity would be associated with more negative ratings of all our outcome variables. However, task complexity did not exert a significant effect on four of the outcomes, and the effects on two of the outcomes were in an unexpected direction; higher task complexity was actually associated with *higher* work engagement and productivity.

Possibly, these results indicate that employees viewed the complexity of their work as a "challenge demand" (i.e. work obstacles that are worthy of engagement, as they are linked to learning and higher achievement). Jobs with higher levels of challenge demands, as opposed to "hindrance demands" (i.e. unnecessary obstacles which thwart personal growth and attainment), have been previously associated with higher levels of work engagement (Bakker and Sanz-Vergel, 2013) and job performance (Lepine *et al.*, 2005). Indeed, if there is a skill-demand imbalance (i.e. if the task is perceived as being too easy), then individuals are unable to enter the state of complete immersion termed "flow" (Csikszentmihalyi, 1975; Engeser and Rheinberg, 2008). Thus, we suggest that any negative effects of the open-plan office environment for our sample were not strong enough to disrupt the natural relationship between challenge demands and more engaged and productive work.

Additionally, several of the predicted associations were not supported. For example, on the basis of past research (Belojevic *et al.*, 2001; Cassidy and MacDonald, 2007; Dobbs *et al.*, 2011; Geen, 1984; Oseland and Hodsman, 2018) it had been anticipated that higher levels of extraversion would be associated with more positive outcomes in open-plan offices. However, whilst there was a small effect to indicate that higher extraversion was associated with higher ratings of productivity, the results of the multivariate analysis indicated that introversion-extraversion was not a significant predictor. Similarly, age did not emerge as a significant predictor of the outcome variables, contrary to expectations.

Although in a previous study we had found that each of the employee characteristics was independently associated with requirements for workspace openness (authors, manuscript submitted for review), it is possible that the non-significant findings reflect certain variables accounting for the effects of others in the regression models. For example, it has previously been observed that the effects of age upon workplace requirements can be explained because older individuals tend to be more noise-sensitive than younger individuals (Horvath *et al.*, 2009). Similarly, it has been demonstrated that introversion-extraversion and noise sensitivity are not completely independent (Aron and Aron, 1997), and so previously demonstrated effects of introversion-extraversion may actually have reflected an effect of noise sensitivity. In the present study, the inclusion of noise sensitivity in the regression models may have negated any additional predictive value of age and introversion-extraversion. Future research would help to clarify this.

Another possible contributing factor is the fact that our study was conducted in real workplaces whereas much of the past research was conducted in tightly controlled experimental settings or, in the case of our previous study (authors, manuscript submitted for review), based upon perceived requirements rather than actual outcomes. This leaves open the possibility that real knowledge workers develop the capability to mitigate environmental demands in offices by exerting additional effort and/or by using various coping strategies. For example, some employees may have effectively coped with the open-plan office environment by using headphones. Whilst this may be effective in the short term, it is possible that the requirement for extra effort to meet the same goals will lead to emotional exhaustion and burnout in the longer term (Meijman and Mulder, 1998), so these results do not detract from the importance of providing more appropriate work settings where possible.

Finally, whilst it had been expected that the same characteristics which predicted acoustic discomfort would also predict stress, the results showed that the only characteristic which exerted an effect on stress was noise sensitivity, and this was a small effect with low practical significance. This suggests that stress was more strongly influenced by other (unmeasured) variables than acoustic comfort in our sample, and the impact of acoustic comfort on stress was negligible. Indeed, the correlation matrix for the outcome variables in the study shows that the relationships between stress and the two measures of acoustic comfort were significant but weak ($r < 0.25$). Additional workplace factors which might have influenced ratings of stress include, for example, high work pressure and long working hours (Bakker and Demerouti, 2014).

Practical implications

The results of our study suggest that acoustic comfort in open-plan offices is significantly moderated by employee characteristics, with noise sensitivity in particular exerting a strong impact on participants' responses. Whilst it might be seen as relatively intuitive that higher noise sensitive is associated with greater acoustic discomfort, few studies have demonstrated this relationship within the context of the open-plan office and when concurrently examining the role of other employee characteristics. Furthermore, the fact that noise sensitivity is at least partially innate (Heinonen-Guzejev *et al.*, 2005) suggests that noise sensitive employees cannot simply adjust to the characteristics of the open-plan office in the same way that their less noise sensitive colleagues can.

This is crucial from a practical perspective because the role of individual differences is still largely ignored in much of workplace practice, meaning "one-size-fits-all" designs are always likely to be misaligned to the needs of a significant proportion of the intended occupants. As such, the most salient implication of the present findings is the necessity of carrying out a detailed consultation of the needs of the workplace end users prior to any office relocation or renovation. The engagement process, which might involve surveys, interviews, and/or observations of current working practices, should be targeted towards a deeper understanding of the employees' characteristics and how these might affect their workplace requirements.

In the event that a significant proportion of employees are naturally more susceptible to visual and auditory distraction (i.e. due to high noise sensitivity and/or a high proportion of individual work), additional strategies will need to be considered to facilitate productive work. Historically this might have been supported through the provision of enclosed private offices, however the space efficiency benefits afforded by open-plan designs mean such designs are likely to remain prevalent. Nonetheless, certain acoustic design strategies can help to mitigate the inevitable presence of speech in open-plan offices. For example, practitioners might consider the use of sound-absorptive partitions between workstations, and the use of sound-masking systems through overhead speakers to reduce the intelligibility of background speech. These strategies would help to reduce speech transmission from neighbouring desks and help to increase individual privacy.

Additionally, workplace management strategies could also help to improve acoustic comfort in open-plan offices by giving employees more control over their working environment. Indeed, the perception of control over noise has been identified as an effective way of reducing noise disturbance for all individuals, regardless of personality type (Oseland and Hodsman, 2018). One way to facilitate this would be through the clear demarcation of "quiet zones" (and the enforcement of explicit rules governing the use of these spaces) combined with the implementation of an activity-based working policy would be effective in ensuring that occupants are able to choose a space which suits their current requirements (i.e. a space for silence or a space in which speech is encouraged and is not seen as distracting). Additionally, organisations could allow employees to wear headphones whilst working, to cancel out the noise from surrounding workstations.

In this way, the implementation of flexible practices would allow employees to develop different strategies which would help them effectively cope with background noise, enabling them to work more productively. This would be particularly valuable in organisations where employee turnover is high, as the ever-changing nature of the workforce limits the extent to which the office can be designed to be aligned to the group of users.

Limitations

In terms of study limitations, it should be noted that several of the employee characteristics and outcomes were assessed using single-item measures or a small sub-set of items from existing scales, which potentially raises concerns regarding content validity. However, it has been demonstrated that single-item measures tend to correlate well with their multi-item counterparts, and often have practical benefits in reducing participant burden during the completion of the questionnaire (Gardner *et al.*, 1998; Hoeppner *et al.*, 2011; Wanous *et al.*, 1997). Indeed, the adoption of this approach in the present study was primarily motivated by the aim of improving response rates at each site by reducing the questionnaire length. As such, whilst it would be useful in future research to use full multi-item scales where possible, we do not regard the use of single-item measures in the present research as a major limitation.

Additionally, although we endeavoured to include a wider range of employee characteristics than had been typically considered in past research, it is nonetheless likely that additional unmeasured traits or characteristics also contribute to acoustic comfort and productivity in open-plan offices. For example, in Oseland and Hodsman's (2018) recent study, neuroticism (i.e. the tendency to experience negative emotions and experience anxiety and apprehension) had the largest effect on various noise metrics, particularly difficulties in concentration. Another recent study conducted in open-plan offices found that the psychological need for privacy was the strongest predictor of general environmental satisfaction (Hoendervanger *et al.*, 2018). Given that there are often significant overlaps between the characteristics under investigation, it will be necessary in future research to ascertain exactly which traits are most strongly associated with the outcomes of interest, so that practitioners have a simple yet effective tool for understanding employees' workplace requirements.

Finally, it should be acknowledged that we used a cross-sectional questionnaire with self-reported measures and investigated one type of office only. With this methodology, we demonstrated that employees' acoustic comfort in open-plan offices is largely determined by their noise sensitivity, and from this, we inferred that employees who struggle to work productively in these offices will require more segregated workspaces. However, it will be necessary in future research to empirically validate such assumptions. For example, it would be useful to directly test the proposition that highly noise-sensitive employees are most productive in enclosed offices, or that strategies to reduce speech transmission in open-plan offices are particularly effective for highly noise-sensitive employees. It would also be valuable if objective measures of well-being and productivity could be used in addition to subjective measures, in order to strengthen the evidence base.

Conclusion

The aim of this study was to explore the extent to which employees' experiences in open-plan offices are shaped by certain demographic, task-related, and personality characteristics. The results highlighted the importance of noise sensitivity, in particular. More noise-sensitive respondents tended to give more negative ratings of the acoustical quality of the office, were more distracted by speech, had greater concentration difficulties, and had lower self-rated productivity. More negative experiences were also reported by employees who had lower levels of interaction with colleagues.

These findings provide further evidence that individuals vary significantly in their workplace requirements, and that the design of open-plan offices needs to reflect this in order to enable the entire group of employees to work effectively. In particular, it is suggested that there needs to be greater consultation of the end users when considering workplace design and strategy solutions, and that particular attention needs to be paid to strategies aimed at minimising the disruption caused by overheard speech.

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An experience sampling approach to the workplace environment survey

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Abstract

Purpose – The purpose of this study is to pilot test the effectiveness of the experience sampling approach for measuring employee satisfaction with the workplace environment. Additionally, the authors also aimed to explore, which aspects of environmental comfort have the strongest impact on momentary well-being and productivity.

Design/methodology/approach – In total, 15 knowledge workers in an open-plan office environment were sent a brief survey (measuring environmental comfort, momentary well-being and perceived productivity) each day over an 11-day study period and provided 78 individual survey responses in total.

Findings – All but one of the measures on the survey had low test-retest reliability, indicating that employees' experiences of environmental comfort varied significantly each time they completed the survey. Additionally, higher environmental comfort was associated with improved well-being and productivity.

Practical implications – The results suggest that an experience sampling approach to the workplace occupant survey is justified to better capture the temporal variability in experiences of environmental comfort. The results also suggest that improving environmental comfort, particularly by reducing the level of distractions, will enable employees to work more productively.

Originality/value – To the best of the authors' knowledge, this is the first field study which has attempted to directly address limitations in traditional occupant surveys by using an experience sampling approach rather than a one-time-only questionnaire.

Keywords Environmental management, Productivity, Environmental psychology, Methods, Post-occupancy evaluation, Workplace psychology

Paper type Research paper

Introduction

It has been suggested that the most effective workplaces of the future will be maintained in a state of "perpetual beta", able to repeatedly adapt to occupants' requirements in a cycle of continuous improvement (Usher, 2018). This necessitates the implementation of a feedback loop between those responsible for maintaining the building and those who occupy it. Indeed, seeking feedback from workplace end-users regarding the perception of the physical workplace environment is a core component of the post-occupancy evaluation (POE) process (Oseland, 2018), ostensibly aimed at identifying and resolving any issues in the workplace that might be negatively affecting employee well-being and/or productivity.

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Facilities

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Traditionally, such data have been collected via occupant surveys, such as the occupant indoor environmental quality (IEQ) survey (Zagreus *et al.*, 2004), the building use studies (BUS) occupant survey (Leaman, 2010), the building occupants survey system Australia (BOSSA), time-lapse survey (Candido *et al.*, 2016) or the Leesman Index (2018). The exact items used to differ from survey to survey, but generally, the questions assess occupants' satisfaction with different components of IEQ (e.g. air quality, thermal comfort, visual comfort and acoustic comfort) and with the overall suitability of the workplace environment (e.g. office layout, office furnishings and office cleanliness).

In theory, the POE should provide architects and/or facilities managers with the occupiers' perceptions of IEQ and the suitability of the building's furnishings, and feed into practical strategies aimed at supporting the goal of continuous improvement (Zimmerman and Martin, 2001). However, workplace researchers have highlighted various limitations of occupant surveys and have called for new approaches to be considered (Candido *et al.*, 2016; Deuble and de Dear, 2018; Li *et al.*, 2018). In particular, two notable concerns relate to insufficient contextual information and a lack of clarity regarding the extent to which satisfaction with the workplace environment is related with actual job performance.

Lack of context

Occupant surveys tend to be administered at one time only, usually 6 to 12 months following the occupation of a new or renovated workplace. Deuble and de Dear (2018) argue that this approach is of limited practical utility as responses are too general and can be biased by various non-building-related factors.

First, there is the issue regarding the lack of spatio-temporal specificity. When respondents are asked to report their experience of a particular sensation over a lengthy period of time, a single response is not able to account for the fact that this sensation might fluctuate markedly at different times and/or in different locations around the workplace. As such, individual responses tend to be aggregated (i.e. representing the average of the total of experiences in the workplace), and are of limited instrumental utility to practitioners, who wish to correlate them directly with time- and location-bound physical environment data.

The relatively long timeframe also increases the possibility that the responses are contaminated by different forms of bias. In particular, recall bias (i.e. inaccuracies in the memories of past events) may limit the extent to which the feedback accurately reflects the actual workplace environment. Furthermore, it has been observed that occupant surveys are often used as a vehicle for airing negative views about general workplace issues that are completely unrelated to the office itself (e.g. complaints about management, bullying), presumably most commonly in organisations with ineffectual mechanisms for reporting such grievances via human resources. As such, responses can also be biased by the organisational context.

In response, various workplace researchers have argued that these issues can be overcome by replacing or supplementing the traditional occupant surveys with "right-here-right-now" assessments conducted multiple times over an extended period and combined with objective building performance data (Candido *et al.*, 2016; Choi and Lee, 2018; Deuble and de Dear, 2018; Li *et al.*, 2018; Oseland, 2018). By restricting responses to a narrow timeframe and asking respondents to report their current location, the feedback collected can provide the spatio-temporal specificity that is not possible using traditional questionnaires. Additionally, by using specific language and encouraging respondents to see the value of engaging in the feedback process, the risk of responses being contaminated by more general grievances is also reduced. As such, the first aim of the present study was to pilot test a methodology for repeatedly measuring occupants' perceptions of the workplace environment, capturing how they feel "right now" rather than in general [hereafter referred to as the "experience sampling methodology"; Fisher and To (2012)].

Relationship to job performance

The second limitation of traditional occupant surveys concerns the extent to which satisfaction with the workplace environment can be regarded as a useful measure from the perspective of the occupying organisation. Environmental comfort, in general, is commonly posited as a determinant of overall job performance (Haynes, 2012; Roskams and Haynes, 2019; Vischer, 2007), however, there is still limited evidence regarding, which aspects of environmental comfort, in particular, are most strongly related to individual productivity. This reflects the fact that academic workplace research has tended to be segmented by specialism and multivariable studies are less common (Sander *et al.*, 2019). From a practical perspective, this is problematic because organisations have limited budgets for workplace improvements and are forced to prioritise between different possible interventions, but have limited research evidence to guide these decisions.

The few exceptions to this, which have directly tested different aspects of environmental comfort as predictors of perceived productivity, have tended to highlight the importance of the behavioural environment in particular (i.e. the ability to regulate interactions and distractions). For example, Haynes (2007) demonstrated that the behavioural environment had a stronger impact on perceived productivity than the physical environment (i.e. satisfaction with indoor environment and office furnishings). Similarly, other studies have highlighted that the most important environmental determinants of productivity include satisfaction with acoustics and privacy (Candido *et al.*, 2016; Veitch *et al.*, 2007), and satisfaction with concentration, privacy and communication (Groen *et al.*, 2018). Thus, it can be generally concluded that productivity is best supported when distractions are minimised without restricting the occupant's ability to engage in useful interactions.

However, the fact that these data came from occupant surveys means that they too share the aforementioned contextual limitations (i.e. lack of spatio-temporal specificity, the possibility of response bias). Thus, it is necessary to explore whether the findings are consistent when the experience sampling approach is adopted. To our knowledge, only Lamb and Kwok's (2016) study has used a longitudinal design of this type. They found that self-reported work performance was predicted by noise annoyance and lighting satisfaction, but not by thermal comfort. However, their operationalisation of environmental stress was restricted to these three variables, and the possible effects of other components of environmental comfort were not explored.

As such, the second aim of this study was to use the experience sampling approach to explore a wider range of environmental comfort variables (encompassing multiple aspects of both the physical and the behavioural environment) in relationship to momentary productivity. It was expected that each component of environmental comfort would be positively associated with productivity, and that satisfaction with distractions, in particular, would have the strongest effect.

Additionally, we also tested the extent to which the different components of environmental comfort were associated with two measures of affective well-being, namely, psychological comfort (on a scale from highly anxious to highly comfortable) and enthusiasm (on a scale from highly depressed to highly enthusiastic) (Warr, 2013). The measures, which have tended to be used in extant research (e.g. self-rated health, job satisfaction, presenteeism; Hanc *et al.*, 2018) may also face the limitations associated with aggregation over time, which is why we chose to use emotion-based momentary measures instead. Given that well-being and productivity tend to be related to each other

(Zelenski *et al.*, 2008), we again predicted that the components of environmental comfort would be positively associated with psychological comfort and enthusiasm and that distractions would have the strongest impact.

The present study

To summarise, the purpose of the present study was to pilot the use of the experience sampling methodology to assess employees' momentary perceptions of the workplace environment and to test the extent to which these were associated with well-being and productivity. On the basis of past research, it was hypothesised that:

H1a. Higher levels of environmental comfort will be associated with higher ratings of psychological comfort.

H1b. Higher levels of environmental comfort will be associated with higher ratings of enthusiasm.

H1c. Higher levels of environmental comfort will be associated with higher ratings of productivity.

H2. The behavioural environment, particularly distractions, will be more strongly associated with each of the outcome variables than the physical environment.

Method

Site

The study was conducted at the office site of a large facilities management provider in the UK. The office had a predominantly open-plan design, with an "activity-based working" concept in which employees did not have assigned workstations. The office was divided into different "neighbourhoods" for each business unit, so employees generally used different workspaces within their neighbourhood each day. One neighbourhood within the office, containing 58 workstations and, bookable meeting rooms and informal break-out areas (Figure 1), were selected as the pilot study area.

Participants

In addition, 47 employees on the business unit's e-mail distribution list were contacted with an invitation to participate in the study. Additionally, information leaflets were placed on desks within the study area, and the primary investigator verbally communicated information about the study while in the office. All of the employees within the business unit were knowledge workers used in various administrative, analytical and management roles. No incentives were offered for participation. Overall, 15 employees (9 male and 6 female) volunteered to participate (~20 per cent of regular employees in the study area). Participants' age ranged between 24 and 47 ($M = 31.3$).

Materials

A workplace evaluation survey was created to capture participants' momentary assessments of environmental comfort, well-being and productivity. The items on the survey were designed to correspond to traditional occupant surveys, although slight alterations were made to item wordings to capture momentary (rather than general) perceptions. Additionally, in accordance with guidelines suggesting daily assessments should take no longer than three minutes (Fisher and To, 2012), we reduced the

Figure 1.
The floor plan of the study area, which contained 58 non-assigned workstations

questionnaire length by using a lower number of items that would be found on traditional occupant survey. The full list of items, including summary statistics for each scale is shown in Table I. Briefly, the different sections on the questionnaire included:

- *Identification code.* Participants generated a unique identification code using the first letter of their surname, their birth month and the first two letters from their birthplace. This enabled their responses to be linked from one time to the next, without compromising their right to anonymity.
- *Work location.* Participants viewed Figure 1 and selected their current workstation (or chose "other" if they were working at a different location). This enabled their responses to be linked to a specific location and a corresponding set of physical environment data. These data were not used in the present study, but will be reported in a separate paper regarding the development of a methodology for predicting subjective environmental comfort using objective environmental data.
- *Physical environment.* Five items were adapted slightly from the occupant IEQ survey (Zagreus *et al.*, 2004), so that they captured perceptions in the past half hour

Table I.
Each of the scales on the questionnaire, including the full wording for all individual items, the mean (M), standard deviation (SD) and intraclass correlation coefficient (ICC) of each scale and the Cronbach's alpha (α) for all multi-item scales

Scale and item(s) used	M	SD	ICC
Physical environment			
"Over the past half hour, how satisfied are you with the following elements of the indoor environment?"			
[1 = Very dissatisfied, 7 = Very satisfied"]			
[Satisfaction with air quality] "air quality (i.e. stuffy/stale air, cleanliness, odours)"	4.69	1.21	0.4
[Satisfaction with temperature] "temperature"	4.5	1.47	0.08
[Satisfaction with humidity] "humidity"	4.72	1.17	0.15
[Satisfaction with light intensity] "amount of light"	4.94	1.27	0.19
[Satisfaction with daylight] "amount of natural daylight"	4.88	1.55	0.21
"How well do the following statements describe how you are able to use your workplace today"			
[1 = No, not at all, 7 = Yes, very much so]			
[Individual environmental control, α = 0.88] "I am able to ensure that I am not too hot or cold while I am working"; "I am able to ensure that the lighting at the workplace suits my preferences"; and "I am able to ensure that it not too quiet or noisy while I am working"	3	1.37	0.26
[Control over workspace appearance, α = 0.81] "I determine the organisation/ appearance of my work area"; and "I can personalise my workspace"	2.24	1.43	0.43
[Workspace availability] "the variety of workspaces needed for my job is available to me"	4.85	1.61	0.67
Behavioural environment			
"Over the past half hour, how accurately do the following statements describe your experience?"			
[1 = No, never, 7 = Yes, all the time]			
[Distractions, α = 0.84] "I have experienced auditory distractions in my work area"; "I have experienced visual distractions in my work area"; "My work environment is too noisy"; and "My working area feels crowded"	3.36	1.63	0.44
[Privacy] "I have adequate privacy in my primary, individual work area"	5.46	1.04	0.16
[Work-related interactions] "I am able to easily contact all of the colleagues I need to interact with"	5.46	1.04	0.16
[Social interactions] "My work environment is socially isolating*"	5.55	1.34	0.43
Momentary well-being			
"In the past half hour, I have felt. . ."			
[1 = None of the time, 7 = Always]			
[Depression-enthusiasm, α = 0.82] "enthusiastic"; "depressed*"; "inspired"; and "despondent*"	4.5	1.25	0.48
[Anxiety-comfort, α = 0.86] "calm"; "anxious*"; "relaxed"; and "worried*"	4.46	1.34	0.49
Momentary productivity			
"In the past half hour, I would rate the impact of the workplace on my productivity as follows. . ."			
[1 = Very negative impact, 7 = Very positive impact]			
[Productivity] "impact on productivity"	4.33	1.39	0.29

Note: * Item was reverse scored prior to analysis

rather than in general. Specifically, respondents rated their satisfaction with *air quality, temperature, humidity, light* and *natural daylight.*

Three original items were also included to measure *indoor environmental control*, including control over temperature, light and noise. The Cronbach's alpha for this scale indicated good internal consistency (α = 0.88).

Three items were taken from Lee and Brand (2005) to measure control over the workspace, including control over the general appearance, the extent to which the workspace can be personalised and the availability of different workspaces. The internal consistency of this scale was questionable (α = 0.6), but improved to good (α = 0.81) by dropping the item relating to workspace availability. As such, *control over workspace appearance* and *workspace availability* were considered separately in the analyses:

- *Behavioural environment*. The behavioural environment was originally conceptualised as the extent to which distractions and interactions had been experienced in the preceding half hour. To measure distractions, four items were taken from Lee and Brand's (2005) measure, including items relating to auditory distractions, too much noise, visual distractions, and privacy. Additionally, one item relating to the perception of crowding was taken from Haynes (2008). The internal consistency of this scale was poor (α = 0.58), but improved to good (α = 0.84) by dropping the item relating to privacy. As such, *distractions* and *privacy* were considered separately in the analyses. For interactions, two items were adapted slightly from Haynes' (2008) measure, including interactions relating to work and for social purposes. However, these items showed a weak correlation (r = 0.18), and so *work-related interactions* and *social interactions* were also analysed separately.
- *Well-being*. Eight items were taken from the institute of work psychology multi-affect indicator (Warr, 2013), to measure momentary affective well-being in terms of two-dimensions. Four items measured *depression-enthusiasm* (α = 0.82), and four items measured *anxiety-comfort* (α = 0.86). For all items, participants rated the extent to which they had experienced that emotion in the previous half hour.
- *Productivity*. Finally, one original item was used to measure the perceived impact of the workplace on the respondent's *productivity* in the previous half hour.

Procedure

The workplace evaluation survey was e-mailed to each participant for 11 consecutive working days. To ensure responses were collected at different times of a day, a random number generator was used to randomly assign the time of each survey invitation, with four possible options: 10:00 a.m., 11:30 a.m., 1:30 p.m. or 3:00 p.m. The survey had no expiry time, meaning that in theory respondents could complete the survey at any time they chose. However, in practice, the online survey platform showed that respondents tended to either complete the survey within an hour of the invitation or did not respond at all on that day.

In total, 78 complete surveys were returned across the 11-day study period (response rate ~47 per cent). The mean number of completed surveys per respondent was 5.2, although this varied notably, ranging from one (in the case of one participant, who primarily worked from a different office but expressed an interest in the study on the day of attending the site) to 14 (in the case of a participant who responded to all survey invitations, and also elected to complete three additional surveys).

Results

Because the data had a nested structure (repeated measurement occasions within participants), data were analysed using a multilevel linear modelling approach, following the procedure outlined in Field *et al.* (2012). Multilevel linear modelling is an extension of linear regression, which entails the estimation of both fixed effects and random effects. As such, the analysis can test whether the effects of the predictors on the outcomes vary between different participants. An additional advantage is that it is capable of accounting for uneven sample sizes per unit (i.e. different number of survey responses per participant), including situations where there is only one observation for the higher-level unit (Bell *et al.*, 2008), as it was the case in our study for the participant, who only provided one response.

All data analysis were conducted using the RStudio software (R Studio Team, 2016), using the *nlme* package (Pinheiro *et al.*, 2017) for fitting and comparing multilevel models, and the *MuMIn* package (Barton, 2018) for calculating estimates of pseudo-R^2 values for the final models. All regression models were fitted using the restricted maximum likelihood estimation method.

Descriptive statistics

Table I shows the mean ratings and standard deviations of each component of environmental comfort, well-being and productivity. As shown, ratings of IEQ were generally slightly higher than the midpoint of the seven-point scale, indicating moderate satisfaction. However, aspects of the physical environment relating to control over workspace appearance and over environmental conditions were rated lower, reflecting workspace policies discouraging personalisation, and the use of personal comfort devices. The behavioural environment was more supportive than disruptive, with participants reporting relatively high levels of interactions and low levels of distractions. In terms of the outcomes, slightly higher than midpoint ratings tended to be given for each of depression-enthusiasm, anxiety-comfort and productivity.

The intraclass correlation coefficient (*ICC*) was calculated for each of the outcome measures. The *ICC* measures the proportion of total variance that is due to variance between participants, and can, therefore, be used as a measure of test-retest reliability (i.e. the extent to which the participant gave similar responses each time they completed the survey). According to Cicchetti's (1994) guidelines, $ICC > 0.6$ is the minimum criteria for "good" test-retest reliability. The only measure that met these criteria was workspace availability ($ICC = 0.67$), with most measures showing very poor test-retest reliability, particularly satisfaction with temperature ($ICC = 0.08$) and distractions ($ICC = 0.06$). This suggests that there was significant intra-individual variability in responses for each item, highlighting the fact that these momentary experiences tended to temporally fluctuate as a result of various contextual factors. This suggests that they are more appropriately measured using the repeated survey rather than the one-time-only questionnaire, supporting the use of the experience sampling approach.

Main analyses

Multilevel analyses were conducted to explore the extent to which the different components of environmental comfort predicted depression-enthusiasm, anxiety-comfort and productivity. For each of the three outcome variables, the need for a multilevel analysis was assessed by comparing an intercept-only regression model with a regression model in which the intercept was allowed to vary across different participants. An analysis of variance was used to compare the goodness-of-fit of the two models. In all three cases, the reduction in the log-likelihood ratio was significant ($p < 0.0001$), indicating that multilevel analyses were appropriate.

Subsequently, a forward-selection model building process was followed to test the hypotheses. To determine the order in which variables should be entered during this process, a series of simple linear random-intercept models were created to explore the bivariate relationships between each explanatory variable and each outcome (Table II). The t-values were noted in each case, and variables were entered from strongest to a weakest relationship with the outcome. Model fit statistics were compared after the creation of each new model, and different subsets of predictors were tested when there was no significant improvement in model fit. For purposes of conciseness, only the final model, which best fit the data (indicated by the lowest Bayesian information criterion value) is reported here.

Depression-Enthusiasm. The simple regressions revealed that seven of the explanatory variables were significantly associated with depression-enthusiasm at the bivariate level. From strongest to weakest, the bivariate relationships indicated that higher momentary enthusiasm was associated with higher satisfaction with air quality ($p = 0.001$), lower levels of distractions ($p = 0.004$), more individual environmental control ($p = 0.01$), more control over workspace appearance ($p = 0.02$), higher satisfaction with light intensity ($p = 0.02$), higher satisfaction with humidity ($p = 0.04$) and higher satisfaction with daylight ($p = 0.05$).

The model-building procedure was followed, and the final model with the lowest BIC (F (1, 60) = 314.91, $p < 0.0001$) retained two predictors, respectively. Higher momentary enthusiasm was predicted by higher satisfaction with air quality ($p = 0.02$) and also by lower levels of distractions, although this latter effect was marginally above the threshold for statistical significance ($p = 0.055$). The pseudo-R^2 estimate for this model indicated that approximately 11.8 per cent of the variance in depression-enthusiasm was accounted for by these two predictors (*marginal* $R\_GLMM^2 = 0.118$).

Anxiety-Comfort. The simple regressions revealed that higher momentary comfort was significantly associated with lower levels of distractions ($p = 0.0054$), higher satisfaction with air quality ($p = 0.02$), higher satisfaction with daylight ($p = 0.02$), more control over workspace appearance ($p = 0.02$), higher satisfaction with light intensity ($p = 0.04$) and more individual environmental control ($p = 0.05$). However, the model-building procedure showed that the model which best fit the data was the original model predicting anxiety-comfort from distractions only ($F(1, 61) = 337.15$, $p < 0.0001$). The pseudo-R^2 estimate for this model indicated that approximately 6.5 per cent of the variance in anxiety-comfort was predicted by distractions (*marginal* $R\_GLMM^2 = 0.065$).

Productivity. The simple regressions revealed that nine of the explanatory variables were significantly associated with productivity at the bivariate level. Higher ratings of productivity were associated with lower levels of distractions, more individual environmental control, higher control over workspace appearance, higher satisfaction with air quality, higher satisfaction with humidity (all p-values < 0.0001), higher satisfaction

Explanatory variable	Depression-enthusiasm		Anxiety-comfort		Impact on productivity	
Explanatory variable	*t*	*p*	*t*	*p*	*t*	*p*
Air quality satisfaction	*3.34*	*0.001*	*2.39*	*0.02*	*4.14*	*<0.0001*
Temperature satisfaction	1.64	0.11	1.76	0.08	*2.87*	*0.006*
Humidity satisfaction	*2.1*	*0.04*	1.81	0.08	*4.03*	*<0.0001*
Light intensity satisfaction	*2.28*	*0.03*	*2.12*	*0.04*	*3.45*	*0.001*
Daylight satisfaction	*2.01*	*0.05*	*2.4*	*0.02*	*2.94*	*0.005*
Control over workspace appearance	*2.32*	*0.02*	*2.32*	*0.02*	*4.53*	*<0.0001*
Workspace availability	1.01	0.32	0.85	0.4	*2.31*	*0.02*
Individual environmental Control	*2.59*	*0.01*	*2.04*	*0.05*	*4.58*	*<0.0001*
Distractions	*−2.98*	*0.004*	*−2.9*	*0.005*	*−5.12*	*<0.0001*
Privacy	0.93	0.35	0.99	0.33	0.98	0.33
Work-related interactions	0.83	0.41	−0.84	0.41	1.11	0.27
Social interactions	0.19	0.85	−0.24	0.82	−1.38	0.17

Table II. Bivariate relationships between each explanatory variable and each outcome variable, with significant associations shown in italics with light intensity ($p = 0.001$), higher satisfaction with daylight ($p = 0.005$), higher satisfaction with temperature ($p = 0.006$) and higher workspace availability ($p = 0.02$).

The model-building process was followed, and the final model with the lowest BIC retained three predictors ($F(1, 59) = 482.2$, $p < 0.001$). In this model, higher momentary productivity was predicted by lower levels of distractions ($p = 0.0026$), higher ratings of control over workspace appearance ($p = 0.0091$) and higher satisfaction with air quality ($p = 0.039$). The pseudo-r^2 estimate for this model indicated that approximately 35 per cent of the variance in productivity was accounted for by the three predictors (*marginal* $R\_GLMM^2 = 0.35$).

Discussion

The aim of this study was to pilot test a methodological framework for measuring satisfaction with the workplace environment using an experience sampling approach, and to test the extent to which environmental comfort was associated with momentary well-being and productivity. The results are discussed below, along with the practical implications and limitations of the research.

Suitability of methodological framework

Overall, the study supported the utility of an experience sampling approach to the occupant survey. The only measure for which participants tended to give broadly similar responses on each measurement occasion was workspace availability, which is understandable given that neither the number of workspaces nor the number of people who needed to access the office changed during the study period. For the other measures, the low test-retest reliability demonstrates that participants' responses differed notably each time the survey was taken. This was particularly true for satisfaction with temperature and distractions, for which there were very high levels of intra-individual variability. These findings support the contention that satisfaction with different aspects of the workplace environment varies on a momentary basis as a result of contextual factors, and thus, the aggregated responses provided by one-time-only occupant surveys are insufficient.

The experience sampling methodology adopted in the study provides a suitable foundation for a more appropriate approach to the occupant survey. By recording the exact time and location of each survey response, researchers and practitioners will be able to explore the contextual factors which affect employees' momentary experiences of environmental comfort, well-being, and productivity. This will also help to prompt more immediate and effective remedial action in the event that the workplace environment is misaligned to the occupants' needs.

However, it should be noted that both the initial uptake (~20 per cent) and subsequent completion rate of daily surveys (~47 per cent) was low. Although we had not intended that the methodology in this study will be directly translated into practice, the low response rate nonetheless raises an important concern that will need to be dealt with if the experience sampling approach is to be used effectively in real workplaces.

Several factors might help to explain the low response rates. Although these comments were not recorded formally, many employees expressed regret to the primary investigator that they simply did not have enough time to complete the surveys (even though the average completion time was 5 min), indicating that they had a busy workload and needed to prioritise other activities. Additionally, it is also possible that our use of a web-based survey with e-mail reminders also discouraged responses, as it required participants to open the email and navigate to the webpage.

To address these limitations so that the repeated sampling approach can be effectively implemented in practice, we suggest several strategies. First, practitioners may wish to consider using purpose-built experience sampling mobile applications to deliver the survey, where reminders can be automatically delivered using push notifications. This would further reduce the response burden on employees, increasing the likelihood of a response. Second, it would be useful to shorten the survey even further and/or only send a subset of the overall survey on each measurement occasion, and send the survey out less frequently overall (e.g. only twice per week). Again, this would reduce the response burden, ensuring that continued participation is more likely in the longer term.

Finally, incentives should be considered. While monetary incentives have often been used to improve participation in experience sampling studies, this may not be appropriate for organisations looking to integrate these measures into daily workplace life. Instead, we suggest that it is more important to ensure that survey responses form part of a continuous feedback loop driving continuous workplace improvements, which rarely happens in practice currently (Deuble and de Dear, 2018). By visibly demonstrating to employees that they have the power to instigate positive change by engaging with the feedback process, it is more likely that they will respond to subsequent survey reminders.

Relationship to well-being and productivity

We had predicted that higher levels of environmental comfort, in general, would be associated with higher levels of well-being and productivity and that aspects of the behavioural environment (especially distractions) in particular would have the strongest impact upon the outcomes. These hypotheses were partially supported by the data. At the bivariate level, 9 out of the 12 components of environmental comfort were significantly associated with at least one of the outcomes. While many of these associations were no longer significant when predictors were entered into the models concurrently, the data nonetheless provided evidence that each of the outcomes was significantly predicted by at least one component of environmental comfort.

As expected, lower perceived distractions were strongly associated with higher ratings of perceived productivity and were also significantly associated with higher ratings of psychological comfort and enthusiasm. This highlights, the crucial importance of enabling effective job performance by minimising distractions in the workplace environment, in accordance with previous research (Candido *et al.*, 2016; Groen *et al.*, 2018; Haynes, 2008; Veitch *et al.*, 2007). Interruptions disrupt the state of concentration, leading to higher stress and frustration and more errors made during work (Mark *et al.*, 2008). The same mechanism may also explain the associations with comfort and enthusiasm, given that productivity and well-being tend to be inter-related (Zelenski *et al.*, 2008). As such, we conclude that the crucial challenge for workplace practitioners is designing and maintaining workplaces in which distractions are minimised.

While we had generally considered distractions arising from the physical and behavioural environment (e.g. irrelevant background speech and movement in the visual field), it should also be acknowledged that distractions and disruption may also arise from the "digital environment" (e.g. e-mail notifications and malfunctioning software). Therefore, employees may be distracted even when the workplace itself is optimised. As such, in future research, it would also be useful to explore the potential impact of digital distractions and how these can be mitigated, in a bid to provide workplace environments, which are even more conducive to productive work.

Satisfaction with air quality also emerged as an important component of environmental comfort and was positively associated with enthusiasm and productivity. When considered in relation to previous research indicating that concentration levels are highest when airborne pollutants are minimised (Zhang *et al.*, 2016), this suggests that office occupants are capable of detecting sub-optimal air quality. Thus, given that not all organisations have the resources to perform continuous physical measurements of airborne pollutants, these findings suggest that repeated surveys might be a suitable alternative (albeit a less detailed one) for assessing indoor air quality.

Finally, the finding that perceived control over workspace appearance also predicted productivity might be related to the fact that employees place a high value on being able to determine the appearance of their working area, as this confers a sense of familiarity and comfort in the workplace (Brunia and Hartjes-Gosselink, 2009; Wells, 2000). Control over the workspace has been increasingly undermined in recent years by non-territorial workplace concepts such as activity-based working, in which employees are prohibited from personalising their workspace in a bid to encourage them to switch workstations more regularly. The results here suggest that organisations should consider whether and how these office concepts can be applied without conflicting with the important psychological need for territoriality and identity expression in the workplace. For example, Babapour (2019) suggested that a sense of ownership can be maintained within activity-based offices through personalisation at the group level, rather than the individual level. This would be an interesting proposition for future researchers to explore.

The most important limitation to consider with respect to the findings concerns the low overall sample size (15) and a number of observations (78). The practical implications of this limitation have already been discussed, but from a theoretical perspective it is important to note that the low sample size raises the possibility that the study lacked sufficient power for detecting statistically significant results. Indeed, this may explain why predictions regarding privacy and interruptions were not supported in our data, contrary to previous research (Groen *et al.*, 2018; Haynes, 2008), and why certain effects were significant at the bivariate level but not in the multivariable analyses. As such, these findings should only be viewed as tentative early indicators until additional research with significantly larger sample sizes has been undertaken.

Similarly, it should also be acknowledged that the study took place within a single zone of one workplace. From the research perspective, this limits the extent to which we can generalise the findings to workplaces with different features. For example, all of the workspaces we studied were within an open-plan layout with low architectural privacy, so we could not test the effects of working in more enclosed areas. Additionally, the temperature and humidity within the office were generally maintained within comfort guidelines, so it is not clear if the same findings will generalise to offices with poorer environmental quality. As such, it will be important to conduct future research within a greater quantity and diversity of workplaces, and with a greater number of employees.

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Predictive analytics in facilities management

A pilot study for predicting environmental comfort using wireless sensors

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Abstract

Purpose – Advancements in wireless sensor technology and building modelling techniques have enabled facilities managers to understand the environmental performance of the workplace in more depth than ever before. However, it is unclear to what extent this data can be used to predict subjective environmental comfort. This study aims to pilot test a methodological framework for integrating real-time environmental data with subjective ratings of environmental comfort.

Design/methodology/approach – An open-plan office was fitted with environmental sensors to measure key indoor environmental quality parameters (carbon dioxide, temperature, humidity, illumination and sound pressure level). Additionally, building modelling techniques were used to calculate two spatial metrics ("workspace integration" and workspace density) for each workspace within the study area. In total, 15 employees were repeatedly sampled across an 11-day study period, providing 78 momentary assessments of environmental comfort. Multilevel models were used to explore the extent to which the objective environmental data predicted subjective environmental comfort.

Findings – Higher carbon dioxide levels were associated with more negative ratings of air quality, higher "workspace integration" was associated with higher levels of distractions, and higher workspace density was associated with lower levels of social interactions.

Originality/value – To our knowledge, this is the first field study to directly explore the relationship between physical environment data collected using wireless sensors and subjective ratings of environmental comfort. The study provides proof-of-concept for a methodological framework for the integration of building analytics and human analytics.

Keywords Environmental sensors, Smart buildings, Predictive analytics, Environmental comfort, Workplace environment, Wireless sensors

Paper type Research paper

Introduction

One of the facilities manager's core responsibilities is to ensure that the workplace environment remains comfortable for its occupants so that they can work in a healthy and productive manner. The traditional focus on cost reduction is increasingly seen as outdated, and practitioners are now expected to support their clients through value-added services instead (Haynes, 2007). One such way to add value is to optimise indoor environmental quality (IEQ), as this plays a major role in either supporting or impeding the health and productivity of workplace users (Al Horr *et al.*, 2016). For example, practitioners might follow guidelines for IEQ maintenance found in best-practice certifications such as the WELL Building Standard (International WELL Building Institute, 2018).

Evidently, to ensure optimal IEQ is being maintained it is necessary to perform physical measurements of key environmental parameters to determine whether these remain in

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pre-specified comfort boundaries. Previously, such measurements would have necessitated the use of a mobile cart equipped with numerous onboard meters (Candido *et al.*, 2016; Parkinson *et al.*, 2015). The inherent limitations of this approach, namely the high material and labour costs and the fact that it is only possible to monitor a certain location within the building for a limited period of time, meant that organisations traditionally performed IEQ measurements rarely or eschewed them entirely.

However, recent developments in the field of wireless sensor technology have introduced an encouraging alternative solution. Sensors are comparatively cheap to install and operate and are capable of providing continuous measurements of key environmental parameters, bound to specific locations at specific times. The output from hundreds of sensors can be overlaid onto a three-dimensional model of the workplace and visualised in real time, allowing the immediate identification and remediation of sub-optimal environmental conditions. Indeed, technology is being developed to integrate sensor readings into "smart" heating, ventilation and air-conditioning (HVAC) systems to ensure that the process of remedying poor IEQ occurs automatically, while simultaneously improving the energy efficiency of the HVAC system by up to 39 per cent (Foster *et al.*, 2016; Salamone *et al.*, 2017). In this way, wireless sensors can help facilities managers to understand and manage the environmental performance of the workplace in more depth than ever before.

While such developments certainly appear promising, they have somewhat preceded a clear framework for how the building data can be effectively used in the overall workplace strategy. In particular, the prediction that compliance with environmental comfort boundaries will optimise occupant comfort remains to be empirically validated in real workplace environments. To our knowledge, only one previous field study has used sensors to monitor IEQ in offices (MacNaughton *et al.*, 2017). However, the environmental data in that study was provided for largely descriptive purposes to illustrate differences between "green" and "non-green" buildings and was not directly tested against occupants' subjective responses. As such, there is still limited information regarding the extent to which the measured environmental parameters predict relevant subjective outcomes.

Thus, the aim of this study was to pilot the use of environmental sensors in a real workplace environment and trial a methodology for testing the extent to which objective IEQ measurements predict momentary subjective environmental comfort. Additionally, a secondary aim was to test whether certain responses could be predicted by other (non-sensor-based) spatial metrics, recognising that the complexity of the workplace environment cannot be captured through sensors alone. Specifically, it is proposed that the combined approach would more accurately capture aspects of both the "physical environment" (i.e. IEQ) and the "behavioural environment" (occupants' experiences of distraction and interaction).

Indoor environmental quality comfort boundaries

Typical sensor-based measurements of IEQ include carbon dioxide (CO_2; in parts per million [ppm]), temperature (in degrees Celsius [°C]), humidity (in relative humidity, expressed as a percentage [per cent RH]), sound pressure level (in A-weighted decibels [dBA]), and illuminance (in lux). These metrics generate a detailed approximation of IEQ within the workplace and can be benchmarked against pre-determined comfort boundaries. In this paper, we will generally refer to the comfort boundaries recommended within the WELL Building Standard (International WELL Building Institute, 2018).

For indoor air quality, WELL recommends that CO_2 levels are kept below 800 ppm. This in accordance with research indicating that the risk of experiencing "sick building syndrome" (SBS) symptoms (e.g. concentration difficulties, fatigue and headaches) increases progressively as CO_2 rises above 800 ppm (Seppänen *et al.*, 1999). It is also expected that productivity will be higher if this threshold is met, based upon a study indicating that cognitive performance was 101 per cent higher when CO_2 was reduced from 1,400 ppm to 600 ppm (Allen *et al.*, 2016). It is worth noting that deficits are not necessarily directly caused by the presence of CO_2 *per se*, but rather that CO_2 is used as a surrogate measure of other airborne pollutants (e.g. particulate matter and volatile organic compounds). Generally speaking, however, good indoor air quality can be assumed when CO_2 is below 800 ppm.

To optimise thermal comfort, WELL prescribes compliance with Standard 55-2013 from the American Society for Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE, 2013), which itself prescribes that acceptable temperature ranges in mechanically-ventilated offices should be determined using the "predicted mean vote" (PMV) method. The PMV equation uses five input values (radiant temperature, air velocity, humidity, clothing insulation and metabolic rate) to prescribe an ambient air temperature range, which will purportedly satisfy 95 per cent of occupants.

For humidity, the comfort boundary is derived from the United States Environmental Protection Agency (US EPA, 2019), which recommends that optimal indoor humidity is achieved at 30-50 per cent RH, although humidity up to 60 per cent RH is acceptable. If these conditions are not maintained, there is an increased risk of the development of mould and respiratory irritation.

In terms of illumination, it is suggested that light intensity must simply support visual acuity of office tasks without causing eye strain or discomfort (e.g. through insufficient light exposure or glare). To achieve this, WELL prescribes that ambient lighting should exceed 215 lux and that, if ambient lighting is below 300 lux, task lighting should be made available to provide light of 300-500 lux at individual workstations. This corresponds to recommendations issued by the Society for Light and Lighting (SLL, 2015), indicating that computerised office work is supported by an ambient illumination level of 300-500 lux.

Finally, for noise levels, WELL does not prescribe comfort boundaries for sound pressure level, suggesting instead a behavioural solution in which certain sections of the office are segmented as "quiet zones". This reflects growing consensus amongst workplace practitioners that the objective properties of sound only account for approximately 25 per cent of its propensity for annoyance (Oseland and Hodsman, 2018), and that the same noise source can be viewed by different employees as a useful form of interaction or as an annoying distraction (Haynes, 2008). Accordingly, an effective acoustic design solution focuses on providing functionally different workspaces and providing occupants the ability to choose between them, rather than on trying to control noise levels as such. Having said that, it has previously been suggested that the optimal noise level within open-plan is 45-48 dBA (Bradley and Gover, 2004), on the basis that measurements, which exceed 48 dBA are indicative of excessive and potentially disruptive levels of human speech. Possibly, this could be a useful comfort boundary for facilities managers to consider.

Additional spatial metrics

While the use of sensors can provide facilities managers with a useful approximation of IEQ, these parameters are limited to the physical environment and do not capture the complexity of the behavioural environment. As such, we also considered whether two additional spatial metrics might also be used to predict occupants' experiences of interactions and distractions in the workplace.

First, we considered *workspace density*, referring to the ratio between the size of the workplace and the number of occupants it houses. In recent years, workspace density has generally increased as organisations pursue strategies aimed at maximising space efficiency. While this offers a competitive advantage in terms of corporate real estate costs, higher-density offices have been associated with lower overall environmental satisfaction and increased perception of crowding (Hua *et al.*, 2011; May *et al.*, 2005).

Additionally, although it might be logical to assume that more dense workplaces will engender higher levels of interaction between colleagues, research actually indicates that higher workspace density is associated with lower perceived support for collaboration (Hua *et al.*, 2011). Possibly, this occurs because occupants in more dense environments need to concentrate harder to block out distractions, thus reducing collaboration (Hua *et al.*, 2011) and/or because they lose the ability to regulate their face-to-face interactions, and so revert to digital forms of communication to preserve their privacy (Bernstein and Turban, 2018).

Second, we also considered the "visibility graph analysis" (VGA) technique, which can be used to calculate objective measurements of *workspace integration* by assigning a numerical score to each individual workspace based upon the extent to which it can be seen from other workspaces. For example, a workspace with low architectural privacy (e.g. located away from dividing walls, no partitioning between desks) will be highly visible from other locations and so receive a high score for integration, whereas workspaces with high architectural privacy are less visible and so receive a low score for integration. This overcomes limitations of previous approaches, which differentiated between overall office layouts rather than between desks (Bodin Danielsson and Bodin, 2008), meaning that the variation between different workspaces within an office (e.g. due to architectural characteristics of the desk) could not be captured.

VGAs have been most commonly used in urban design, but researchers have recently considered their potential utility in the context of the workplace. In previous studies the technique has been used to distinguish between "sociopetal" and "sociofugal" workspaces (designed to encourage or prohibit interaction, respectively) (Sailer and Psathiti, 2017), and there is evidence to suggest that employees working from more integrated workspaces tend to engage in a higher number of knowledge-sharing activities (Appel-Meulenbroek, 2014). Thus, in the present study, we considered whether workspace integration could be used to effectively predict experienced interaction and distraction levels.

The present study

To summarise, the aim of the present study was to investigate the extent to which objective real-time measurements of IEQ and spatial workplace metrics could predict subjective ratings of environmental satisfaction. Based on the research and guidelines discussed earlier, it was hypothesised that:

H1. CO_2 concentration will be negatively associated with ratings of air quality.

H2. Compliance with thermal comfort policy will be positively associated with ratings of thermal comfort.

H3. Compliance with humidity comfort policy will be positively associated with ratings of satisfaction with humidity.

H4. Illumination will be positively associated with ratings of satisfaction with light levels.

H5. Sound pressure level, workspace density and workspace integration will be positively associated with distraction levels.

H6. Sound pressure level and workspace integration will be positively associated with interaction levels, whereas workspace density will be negatively associated with interaction levels.

Method

Participants

The participants for this study were real office workers from one office used by a large private-sector organisation in the UK. The office had an open-plan design, which was divided into different "neighbourhoods" for each business unit. The organisation used an activity-based working concept, meaning employees did not have assigned desks and generally worked from different workstations within their neighbourhood. One neighbourhood within the office, containing 58 non-assigned workstations, was designated as the study area (see Figure 1 for floorplan).

An e-mail containing information about the study was sent to 47 employees, using the distribution list for the business unit. Additionally, given that employees from other business units also used the study area semi-regularly, flyers with an invitation to participate in the study were placed on each desk, and the primary investigator verbally communicated information about the study while in the office. No incentives were offered for participation. In total, 15 employees (9 male, 6 female) volunteered to participate.

Building analytics

Prior to the first day of the study period, the study area was equipped with wireless environmental data loggers. The position of the data loggers is shown on Figure 1. On each of the 11 banks of desks within the study area (each containing between four and six individual workstations), a HOBO U12 Data Logger (Onset, 2019a) was placed in the centre of the desks to continuously measure temperature, humidity, and light intensity. Additionally, separate data loggers were also placed on two desks (F1 and I5): Telaire 7001 CO2 sensors (Onset, 2019b) were used to continuously measure CO_2 (ppm) and PCE-322A Sound Level Meters (PCE Instruments, 2019) were used to continuously measure sound

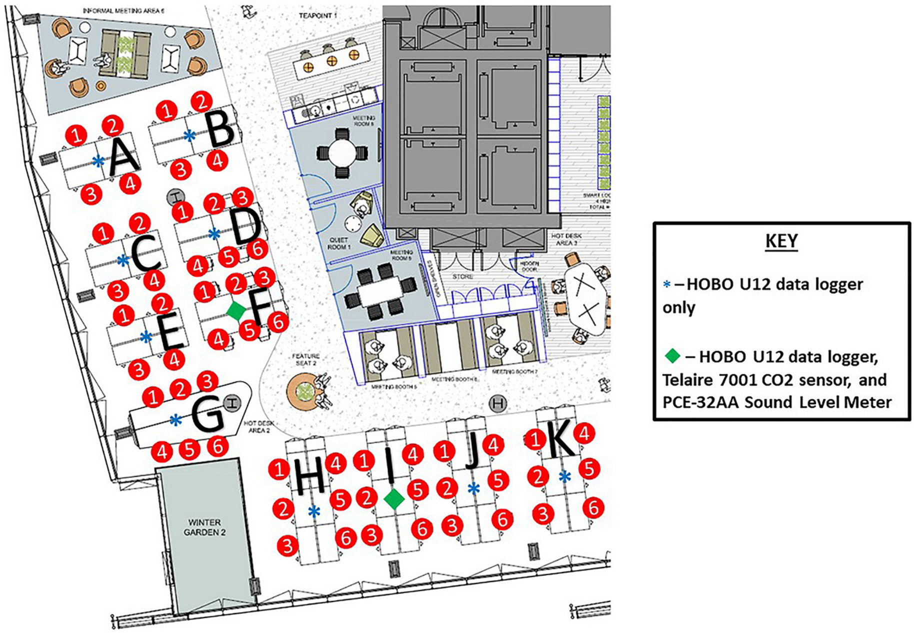

Figure 1.
The office floorplan, including the location of the wireless sensors

pressure level (dBA). The two desks were specifically chosen as they were approximately in the middle of the two zones within the study area.

For the purposes of data analysis, we averaged the environmental data across the half-hour preceding the completion of each survey. For CO_2, light intensity, and sound pressure level, raw measurements were used given that it was predicted that occupant comfort would get progressively worse (in the case of CO_2 and sound pressure level) or better (in the case of light intensity) as the measurement increased. For temperature and humidity, it was necessary to calculate the degree to which the readings were within or outside of the "optimal" comfort zone (i.e. the degree of compliance with the comfort policy), given that both "too low" and "too high" readings were predicted to result in lower occupant comfort.

For temperature, the PMV method was used to calculate an optimal value, using an online thermal comfort tool compliant with ASHRAE Standard 55 (Center for the Built Environment, 2019). Inputted values included the average measured humidity during the study period (52.18 per cent RH), a typical office airspeed value (0.1 m/s), a typical metabolic rate for office work (1.1 met), and the clothing insulation value for typical winter indoor clothing (1.0 clo). Based on these values, the online tool indicated that 22.4°C was the optimal temperature. For the purposes of the analysis, 22.4 was subtracted from the raw values and the resultant scores were squared to yield value to represent the extent of non-compliance, in absolute terms, with the thermal comfort boundary.

For humidity, 30-50 per cent RH was the optimal range indicated by the US EPA (2019). Therefore, for the purposes of analysis, any raw value that was within this range was scored as "0". As it happened, during the study period the humidity never dropped below 30 per cent RH, and the only measurements, which were outside of the comfort policy were those which exceeded 50 per cent RH. As such, to reflect the extent to which these measurements were outside of the comfort boundary, 50 was subtracted from these raw values, and the resultant scores were used in the analyses.

Finally, building modelling techniques were used to calculate the additional building metrics, using the DepthmapX software (DepthmapX development team, 2017). The VGA technique was used to attain an objective value of workspace integration at each of the workspace, where scores range between 1 (highly segregated) to 10 (highly integrated). Workspace density was calculated as the number of additional workspaces within 15 feet of the target workspace.

Human analytics

Each day during the study period, participants were sent an e-mail with a link to a workplace evaluation survey. On each occasion, the survey was sent at one of four times (10:00 a.m., 11:30 a.m., 1:30 p.m or 3:00 p.m.), using a random number generator to randomly assign participants to different time-slots each day.

The survey contained items that corresponded approximately to the items found on typical workplace occupant questionnaires, with slight adaptations so that ratings were confined to the preceding half-hour, to capture momentary rather than general perceptions. The full list of items used, including summary statistics, is shown in Table I. Specifically, the different sections of the survey included:

Identification code. Participants provided a unique identification code using the first letter of their surname, their birth month, and the first two letters from their birthplace, each time they completed the survey. This enabled their responses to be linked from one time to the next without compromising their right to anonymity.

Work location. Participants viewed the floor plan in Figure 1 and selected their current workspace (or chose "Other" if they working at a different location). This enabled their

Table I. List of questionnaire items used in the analyses, including the means and standard deviations for all items and scales, and the Cronbach's alpha values for the distraction scale

Scale and item(s) used	M	SD
Physical environment		
"Over the past half hour, how satisfied are you with the following elements of the indoor environment?" [1 = very dissatisfied, 7 = very satisfied]		
[Satisfaction with air quality] "air quality (i.e. stuffy/stale air, cleanliness, odours)"	4.69	1.21
[Satisfaction with temperature] "temperature"	4.5	1.47
[Satisfaction with humidity] "humidity"	4.72	1.17
[Satisfaction with light intensity] "amount of light"	4.94	1.27
[Satisfaction with daylight] "amount of natural daylight"	4.88	1.55
Behavioural environment		
Over the past half hour, how accurately do the following statements describe your experience?" [1 = No, never, 7 = Yes, all the time]		
[Distractions, α = 0.84]	3.67	1.26
"I have experienced auditory distractions in my work area"	4.08	1.6
"I have experienced visual distractions in my work area"	3.36	1.49
"My work environment is too noisy"	3.74	1.49
"My working area feels crowded"	3.51	1.53
[Privacy] "I have adequate privacy in my primary, individual work area"	3.36	1.63
[Work-related interactions] "I am able to easily contact all of the colleagues I need to interact with"	5.46	1.04
[Social interactions] "My work environment is socially isolating"*	5.55	1.34

Note: *Item was reverse-scored prior to analysis

responses to be linked with the corresponding set of environmental data from the nearest sensors.

Physical environment. Four items were included to measure satisfaction with different components of IEQ. Specifically, respondents rated their satisfaction with *air quality, temperature, humidity*, and *light intensity* in the past half hour. As shown in Table I, ratings for each tended to be slightly higher than the midpoint on the seven-point scale ($4.5 \leq M \leq 4.94$), indicating moderate satisfaction with the physical environment.

Behavioural environment. Originally, satisfaction with the behavioural environment was conceptualised as the extent to which distractions and interactions had been experienced in the preceding half-hour, using a seven-point scale. To measure distractions, four items were taken from Lee and Brand's (2005) measure (auditory distractions, too much noise, visual distractions, adequate privacy) and one item was taken from Haynes' (2008) measure (crowding). However, the Cronbach's alpha associated with this scale was poor (α = 0.58), but would be significantly improved by dropping the item relating to privacy. As such, the remaining four items were retained as the measure of *distractions* (α = 0.84), and the single item measuring *privacy* was also included in the analyses. It was predicted that sound pressure level, workspace density, and workspace integration would be negatively associated with perceived privacy.

To measure interactions, the same seven-point scale was used to rate two items from Haynes' (2008) measure, reflecting interactions for work and for social purposes. However, the correlation between these items was weak (r = 0.18), so *work-related interactions* and *social interactions* were analysed separately. It was predicted that sound pressure level and workspace integration would be positively associated with both forms of interaction, while workspace density would be negatively associated with both forms of interaction.

The descriptive statistics shown in Table I indicate that participants generally had positive perceptions of the behavioural environment, indicating relatively high levels of work-related (*M* = 5.46) and social interactions (*M* = 5.55), and low levels of distractions (*M* = 3.67). However, perceived privacy was low (*M* = 3.36).

Results

Given that the same participants were repeatedly sampled at different occasions during the study, multilevel linear modelling was used to accommodate the nested structure of the data (repeated measurement occasions within participants). All data analysis was performed using the RStudio software (R Studio Team, 2016), following the procedure outlined by Field *et al.* (2012). The *nlme* package (Pinheiro *et al.*, 2017) was used for fitting and comparing multilevel models, and the *MuMIn* package (Barton, 2018) was used for calculating pseudo-R^2 estimates for the final models. All regression models were fitted using the restricted maximum likelihood estimation method.

Descriptive statistics for sensor readings and spatial metrics

Table II shows average sensor measurements for each component of IEQ. The full data set contains tens of thousands of individual measurements from different locations around the study area, providing a high degree of spatio-temporal specificity. For the purposes of simplicity, in this table, we have combined the measurements from the different sensors on the different days into single hourly averages and overall averages for each environmental parameter.

As shown, the average CO_2 level (*M* = 1,424.9 ppm) and average sound pressure level (*M* = 53.99 dBA) were above the recommended range. Humidity (*M* = 52.18 per cent RH) also tended to be slightly outside the optimal comfort boundary but was within the wider boundary judged to be acceptable by the US EPA (2019), which extends to 60 per cent RH. Temperature (*M* = 23.59°C) was slightly higher than the "optimal" temperature of 22.4°C but was still within the wider comfort boundary determined using ASHRAE 55-2013. The average illumination (*M* = 448.91 lux) was within the comfort boundary.

Descriptive statistics were also calculated for the spatial metrics. The scores for workspace integration (*M* = 4.98, *SD* = 0.58, *Min* = 4.55, *Max* = 6.58) indicate that all of the workspaces were in moderately integrated locations, with relatively low variation. Workspace density showed more response variance and indicated that on average there were 12 employees within 15 feet of the workspace (*M* = 12.3, *SD* = 12.4, *Min* = 4, *Max* = 22).

Time of day	CO_2 (PPM)	Temperature (°C)	Humidity (%RH)	Illumination (lux)	Sound pressure level (dBA)
08:30 to 09:00	816.8	22.9	51.04	372.57	53.19
09:00 to 10:00	1,048.31	23.2	51.69	386.77	54.63
10:00 to 11:00	1,286.94	23.43	51.96	406.33	54.5
11:00 to 12:00	1,438.51	23.58	52.14	436.82	54.55
12:00 to 13:00	1,506.97	23.65	52.13	455.01	54.66
13:00 to 14:00	1,515.88	23.64	52.37	462.09	53.12
14:00 to 15:00	1,594.72	23.76	52.61	513.12	53.6
15:00 to 16:00	1,650.45	23.89	52.56	538.04	54.1
16:00 to 17:00	1,623.43	23.85	52.47	492.87	53.11
17:00 to 18:00	1,464.74	23.68	52.24	389.84	N/A
Overall	1,424.9	23.59	52.18	448.91	53.99

Table II. Average sensor readings for each of the physical environment parameters throughout the working day

Main analyses

Physical environment. To assess the need for a multilevel structure in the regression analyses, intercept-only and random-intercept regression models were compared for satisfaction with air quality, temperature, humidity and light intensity. The reduction in log-likelihood ratio was significant in the cases of air quality ($p < 0.0001$) and light intensity ($p = 0.05$), so multilevel regression techniques were used for these variables. However, there was no improvement in model fit for the models predicting temperature ($p = 0.49$) or humidity ($p = 0.14$), so ordinary regression techniques were used in these cases.

For each environmental comfort variable, regression models were conducted to predict the subjective response using the appropriate objective environmental variable(s). There was no evidence to support the predictions that compliance with thermal comfort policy would predict satisfaction with temperature ($p = 0.27$), that compliance with humidity comfort policy would predict satisfaction with humidity ($p = 0.07$) or that light intensity would predict satisfaction with light levels ($p = 0.9$).

The only significant effect on the physical environment analyses was for air quality. There was evidence to suggest that higher measured levels of CO_2 were associated with more negative ratings of air quality ($p < 0.0001$). The pseudo-R^2 estimate for this model indicated that approximately 14.8 per cent of the variance in ratings of air quality could be attributed to the CO_2 level ($marginal\_GLMM^2 = 0.148$).

Behavioural environment. Again, intercept-only and random-intercept regression models for each of the behavioural environment variables were compared to assess the need for a multilevel structure. In this case, there was a significant improvement in model fit for perceived privacy ($p < 0.0001$), social interactions ($p < 0.0001$), and work-related interactions ($p = 0.04$), indicating that multilevel modelling was appropriate. However there was no significant improvement in model fit for distractions ($p = 0.42$), so an ordinary regression was appropriate here.

For each behavioural environment outcome, the effects of three explanatory variables (sound pressure level, workspace integration, and workspace density) were tested. In each case, simple regression models were constructed to assess the bivariate relationship between each predictor and outcome. If more than one predictor was significant at the bivariate levels, multiple regression models were constructed and compared with the earlier model, using the Bayesian Information Criterion to determine the model which best fit the data.

The results showed that none of the explanatory variables were significantly associated with perceived privacy ($p \geq 0.23$) or work-related interactions ($p \geq 0.2$). The model predicting social interactions showed that neither sound pressure level nor workspace integration were significant predictors ($p \geq 0.14$), but that there was a significant negative relationship between social interactions and workspace density ($p = 0.05$).

For distractions, the bivariate models revealed significant positive associations with both sound pressure level ($p = 0.02$) and workspace integration ($p < 0.001$), but not workspace density ($p = 0.69$). The two significant variables were retained in a multiple regression model, which accounted for approximately 19.6 per cent of the variance in levels of distractions ($R^2 = 0.196$), and in which workspace integration remained significant ($p = 0.02$) but sound pressure level rose marginally above significance ($p = 0.056$).

Discussion

The aim of this pilot study was to test the extent to which the data collected via wireless environmental sensors and additional spatial metrics could predict employees' momentary ratings of environmental comfort. The results of the study provided mixed support for the hypotheses, and are discussed with respect to their theoretical and practical implications.

Physical environment

It had been predicted that measured CO_2 levels would be negatively associated with momentary air quality satisfaction ratings (*H1*). Our results supported this hypothesis, indicating that more negative ratings of air quality were more likely at higher concentrations of CO_2. This is in accordance with previous laboratory studies demonstrating an association between CO_2 and subjective ratings of air quality (Park and Yoon, 2011; Zhang *et al.*, 2017). Associations between higher levels of CO_2 and the prevalence of SBS symptoms has also been previously demonstrated (Allen *et al.*, 2016; Seppänen *et al.*, 1999), indicating that the indoor air quality may have contributed to issues such as concentration difficulties and respiratory problems amongst the employees within our office.

The predictions that compliance with thermal comfort policy would be associated with higher ratings of thermal comfort (*H2*), that compliance with humidity comfort policy would be associated with higher satisfaction with humidity (*H3*), and that higher illuminance would be associated with higher satisfaction with light intensity (*H4*) were not supported by the data. We suggest that two factors may have contributed to these non-significant findings, both of which will be discussed in more detail in later sections.

First, it should be noted that temperature, humidity, and illumination were almost entirely within the prescribed comfort boundaries, meaning that we were not able to test the effects of sub-optimal environmental conditions for these parameters. Second, it has also been previously demonstrated that individual difference characteristics can moderate the individual response to a particular component of the physical environment (e.g. the response to temperature is moderated by gender and age; Wang *et al.*, 2018), so it is also possible that the extent to which occupant comfort can be predicted using a single environmental variable will always be significantly restricted.

Behavioural environment

It had been hypothesised that higher perceived distractions would be predicted by higher sound pressure level, workspace density, and workspace integration (*H5*). The data provided partial support for this hypothesis, demonstrating that higher levels of distractions tended to occur at more integrated workspaces. This effect was observed despite the fact that there was relatively low variance in workspace integration, and may have been even more pronounced had the study included a wider range of workspaces. Thus, the suggestion that using VGA to calculate workspace integration can helpfully distinguish sociofugal and sociopetal workspaces (Sailer and Psathiti, 2017) was supported. There was also a trend to suggest that higher levels of distractions were associated with higher average sound pressure level, although this effect rose marginally above the criteria for statistical significance in the multiple regression analysis.

It was also predicted that sound pressure level, workspace density, and workspace integration would be associated with levels of work-related and social interactions (*H6*). Only one significant effect was observed for these outcomes, indicating that respondents working from areas with higher workspace density tended to report lower levels of social interaction. This is in accordance with research suggesting that interpersonal communication actually worsens in more dense and open workplaces (Bernstein and Turban, 2018; Hua *et al.*, 2011; Kim and de Dear, 2013), and suggests that workplace alterations designed to increase space efficiency (e.g. transition to open-plan office, increasing desks within existing space) should not be justified in terms of supposed interpersonal benefits.

Finally, we also tested whether sound pressure level, workspace integration and workspace density were associated with perceived privacy. Privacy had originally been conceptualised as an aspect of distraction, but transpired to be relatively independent of the other items used to measure distractions. It had been anticipated that employees would report lower perceived privacy at more dense and more integrated workspaces, and when the average sound pressure level was higher. However, there was no support for this hypothesis. Again, this might also reflect the fact that there was relatively low variation in workspace type and/or that individual difference factors, particularly noise sensitivity, can significantly moderate the individual's experience of the acoustic environment (Roskams and Haynes, 2019; Haapakangas *et al.*, 2014), which in turn could affect their perception of privacy.

Limitations

The main aim of this study was to provide proof-of-concept for a methodological framework for integrating human analytics and building analytics, and so a relatively small-scale study within one zone of a single workplace was conducted. While this enabled us to develop the framework, it also led to various limitations, which might explain the lack of support for some of the hypotheses.

Firstly, it should be acknowledged that three IEQ factors (temperature, humidity and illumination) were almost entirely within the prescribed comfort boundaries during the study period. From the research perspective, this is a limitation because there was insufficient data to test whether poor environmental conditions (i.e. non-compliance with comfort boundaries) results in lower levels of environmental comfort. In future research, it could be useful to adopt a quasi-experimental approach in which the investigators are able to manipulate environmental conditions or to conduct field studies at a more diverse range of workplaces, including those with poorer IEQ.

Similarly, the types of workspace within the study area were all relatively similar, in that they were all located within a medium-to-large open-plan area. While there was some variance in workspace density, generally reflecting the position of the workspace relative to exterior walls, the scores for workspace integration tended to be quite similar. While some significant effects were observed even at this low level of variation, it would be more beneficial in future research to test a greater diversity of workspaces (particularly enclosed and segregated working areas), to more rigorously test the hypotheses.

The fact that this was a pilot study also means that there were a relatively low number of observations used in the analysis, which raises the possibility that there may have been insufficient statistical power for detecting significant effects. Thus, the present findings should be viewed tentatively until further research has been conducted. As the methodological framework for integrating building analytics and human analytics continues to develop, it will be necessary to conduct similar investigations but with significantly larger samples and across a large and diverse group of different workplaces, to test the hypotheses more definitively. With the core infrastructure in place (i.e. sensors installed within workplaces, technological solution to repeatedly sample employee experiences), very large datasets can be compiled relatively easily and analysed for valuable insights.

Finally, there is a small risk that a Hawthorne effect may have occurred (i.e. that changes in the employees' responses were a result of being observed rather than fluctuations in environmental conditions). To mitigate this risk, we took several steps to ensure that participants' working environment and practices during the study period closely replicated normal conditions. The sensors used were small and unobtrusive, and the daily questionnaires were designed to be completed relatively quickly. All communications about the study clearly outlined the purpose of the study, and encouraged participants to answer completely honestly so that their responses could be used to help researchers to learn more about the environmental conditions, which best support occupant comfort and productivity. As such, we believe there is only a low probability that a Hawthorne effect occurred, and it can be reasonably concluded that the findings truly reflect individuals' responses to different environmental conditions.

Practical implications

Overall, the results of the study provide moderate support for the utility of using wireless sensors to effectively support occupant comfort. When viewed together with the fact that sensors are comparatively cheaper than traditional solutions for measuring IEQ, particularly in the long term and with a high degree of spatio-temporal specificity, the results here suggest that the installation of sensors will be useful for helping facilities managers to monitor and improve IEQ in workplaces.

For example, our results indicated that lower ratings of air quality were more likely when CO_2 concentrations were higher. A sensor-based approach could be used to continuously monitor CO_2 that it stays below the 800 ppm threshold, where remedial action is prompted whenever the measurements rise above this threshold. As smart building technology continues to develop, this could be done completely automatically as part of a demand-controlled ventilation system, which automatically triggers increased ventilation when the sensors detect CO_2 levels have risen above 800 ppm. In this way, adherence to best-practice certifications can be balanced with a sustainable energy strategy using a sensor-based climate control system (Foster *et al.*, 2016).

We previously noted that for certain environmental parameters, particularly temperature and noise, the employee's response can be moderated by various individual difference factors, limiting the extent to which comfort policy adherence can adequately predict subjective comfort. However, sensors may also form part of the solution here. Researchers are working on the development of office desks with integrated systems for personal control over the local environment, where machine-learning algorithms use both environmental sensor data and occupants' behaviours to generate individual "comfort profiles" that can be automatically loaded for individual users (Aryal *et al.*, 2018). Similarly, a recent trial of office desk chairs, which allowed the user to customise local temperatures found that thermal satisfaction votes increased to 96 per cent across a range of ambient air temperatures (Kim *et al.*, 2019). While such technology is still in early stages of development, it is certainly feasible that the offices of the future will combine wireless sensors and controllable comfort systems in this manner, to ensure high occupant comfort even when individual users have markedly different preferences.

The results also supported the utility of the spatial metric analyses, particularly the use of VGAs to distinguish between sociopetal and sociofugal working areas (Sailer and Psathiti, 2017), on the basis that less integrated spaces appear to be more suitable for shielding occupants from distractions. It is becoming increasingly common for workplaces to use activity-based working concepts, in which employees do not have assigned desks but are encouraged to use different functional workspaces on an ad-hoc basis to support different types of task (Wohlers and Hertel, 2017). In particular, "spaces for concentration" and "spaces for collaboration" are two functional zones, which are frequently highlighted as important aspects of the modern workplace. Possibly, the use of VGAs could assist workplace practitioners to ensure that these spaces are appropriately designed. Additionally, it might be useful for different functional zones to have different acoustic comfort policies (e.g. strict in spaces for concentration, relaxed in spaces for collaboration), and environmental sensors could be used to ensure that the spaces are being used in the intended manner.

Conclusion

In conclusion, we have provided proof-of-concept for a methodological framework to integrate building analytics and human analytics, towards the goal of optimising environmental comfort in the workplace. The findings of our study provide a tentative indication that the data from sensors can help to ensure occupant satisfaction with air quality and that the VGA technique can help to support the provision of different types of functional workspace. In future research, significantly larger sample sizes and greater diversity in the types of workplaces under investigation will be necessary so that hypotheses regarding the effects of different elements of the workplace environment can be more rigorously tested.

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Testing the relationship between objective indoor environment quality and subjective experiences of comfort

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ABSTRACT
At present, workplace researchers lack a suitable methodology for combining objective indoor environmental quality (IEQ) data with repeated subjective assessments of comfort in real offices. To address this gap, we conducted a study at two office sites. Four IEQ parameters (carbon dioxide, temperature, humidity, and illuminance) were continuously monitored at each site, and brief environmental comfort surveys were sent to employees' smartphones four times per day across the study period. In total, 45 employees across the two sites completed 536 surveys. The findings confirm that the repeated sampling approach is a more appropriate method for measuring comfort than a questionnaire delivered at one time only. Adherence to recommended temperatures reduced the risk of thermal discomfort, however this effect was weak and other predicted associations between the physical environment and environmental comfort were not supported. The results also showed a strong association between environmental comfort and self-rated productivity, such that employees rated themselves as most productive when they were satisfied with noise levels, temperature, air quality, and lighting within the office. Overall, the results highlight that it is critically important to consider strategies for optimising occupant comfort, although this is unlikely to be achieved through adherence to environmental comfort boundaries alone.

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The workplace industry is in the midst of a paradigmatic shift, whereby the traditional focus on cost reduction is being gradually superseded by a more user-centric approach in which the building occupants are seen as vital assets to which value can be added through the provision of more supportive working environments (Haynes, 2007). A crucial part of making workplaces healthier and more suitable for their users is by mitigating environmental sources of physical and/or psychological discomfort (Roskams & Haynes, 2019a; Vischer, 2007. 2008), enabling the employees to conserve attentional focus and energy for their work, instead of expending it to cope with adverse environmental conditions.

Sub-optimal indoor environmental quality (IEQ; the physical conditions within a building, encompassing air quality, the thermal environment and the luminous environment) can be a major source of discomfort in office buildings, leading to deficits in employee wellbeing and productivity (see Al Horr et al., 2016a, 2016b, for reviews). Hence, a key component of best-practice sustainability and wellbeing certifications such as the WELL Building Standard (International WELL Building Institute, 2018) is the prescription of recommended ranges or limits for key parameters of IEQ. These guidelines are premised on the assumption that occupant comfort, and consequently occupant wellbeing and productivity, will be highest when these 'comfort boundaries' are adhered to. However, a major limitation is that the supporting literature is largely derived from experimental studies performed in climate chambers, and so questions remain over whether the guidelines will generalize to real office environments where numerous additional confounds might be present.

Suitable field studies remain very rare. This can be at least partially ascribed to the fact that previous solutions for continuous IEQ measurements in offices required the use of costly and impractical mobile carts equipped with on-board sensors (e.g. Candido et al., 2016; Parkinson et al., 2015), leading field researchers to instead take spot measurements of IEQ at indicative locations and combine these with questionnaires which ask respondents to report how they feel *in general* whilst in the office. In these types of study, a significant problem is that neither the IEQ measurements nor the employees' perceptions are spatio-temporally specific (i.e. the measurement cannot be assigned to a particular space at a particular time). Hence, there are growing calls for

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field studies which capture 'right-here-right-now' assessments of the workplace environment, conducted multiple times across an extended period and combined with objective IEQ data (Candido et al., 2016; Choi & Lee, 2018; Deuble & de Dear, 2014; Li et al., 2018).

Such studies have now been made possible through recent developments in technology. In particular, 'smart building' sensor technology enables IEQ to be measured more easily than before, and with highly precise spatio-temporal specificity. Sensors can be installed and operated at a relatively low cost, enabling the continuous measurement of key IEQ parameters at different locations within a workplace. In terms of subjective data, advancements in computer and smartphone technology have also made it easier for occupants to provide repeated assessments of their workplace environment. As such, there is now a golden opportunity for researchers to conduct research which will enable them to more rigorously evaluate how occupants are affected by environmental factors in the workplace.

Two existing studies have made valuable contributions here, but neither quite demonstrates how specific aspects of IEQ can be tested against momentary assessments of comfort. MacNaughton et al. (2017) used sensors to measure IEQ in office buildings with or without sustainability certifications, and confirmed that occupant's environmental satisfaction and cognitive performance was higher in the certified buildings. However, their analyses did not directly associate environmental data with subjective responses, and so the precise effects of different aspects of IEQ cannot be ascertained. Romero Herrera et al. (2018) also used sensors to monitor IEQ within real offices and combined these with repeated subjective comfort ratings, however their analyses focused solely on temperature and thermal comfort, and they did not consider the role of specific comfort criteria.

Therefore, the purpose of this study was to build upon these existing studies by developing a more comprehensive methodology for combining sensor-based IEQ data and repeated subjective assessments of the workplace environment. We also aimed to evaluate the process for using environmental sensors as part of operational practice. The study can be seen as a second cycle in the development of this methodology, following on from a small pilot study (Roskams & Haynes, 2019b). One major finding from the pilot was a low response rate, so further aims of the present study included testing strategies for improving the response rate whilst rolling out the implementation to a wider group of employees. Additionally, we also demonstrate how hypotheses regarding the nature of the IEQ-comfort relationship can be tested, starting with the baseline assumption (as might a building manager) that adherence to the WELL guidelines will lead to the highest levels of environmental comfort.

Measuring environmental perceptions through experience sampling

First, it will be necessary to verify that the proposed methodology is valid in the first place. To do this, we can assess the extent to which each individual's responses differ every time they complete the survey. If their responses are relatively stable each time, then the use of repeated sampling is unnecessary and a questionnaire distributed once will be sufficient. However, in line with the criticisms of existing methodologies (Candido et al., 2016; Choi & Lee, 2018; Deuble & de Dear, 2014; Li et al., 2018), we predict that there will actually be a high degree of variability in their survey responses, indicating that repeated sampling is the most appropriate method for measuring these experiences.

> H_1: There will be high variability in each respondent's perceptions of environmental comfort each time they complete the survey.

Exploring the role of air quality

At the time the research was conducted, most commercially-available sensor devices used carbon dioxide (CO_2) as their sole indicator of indoor air quality. CO_2 rises in indoor environments due to the combination of human respiration and insufficient ventilation, and so it is often used as a surrogate measure of the effectiveness of the ventilation system for removing airborne pollutants *in general*, and therefore as a surrogate measure of overall air quality. WELL recommends that indoor carbon dioxide (CO_2) is maintained at 800 parts per million (ppm) or lower (International WELL Building Institute, 2018).

This 800 ppm threshold is in accordance with research that shows the risk of 'sick building syndrome' symptoms increases progressively when CO_2 rises above 800 ppm (Apte et al., 2000; Seppänen et al., 1999; Tsai et al., 2012). Furthermore, the 800 ppm threshold is also approximately consistent with research demonstrating that cognitive performance and decision-making abilities are highest when CO_2 concentrations are at 600 ppm, and progressively deteriorate at higher concentrations (Allen et al., 2016; Satish et al., 2012). Therefore, it can be assumed that CO_2 concentration, as measured using the sensors, can be used to predict occupant satisfaction with air quality.

> H_2: Satisfaction with air quality will be negatively associated with CO_2 concentration.

Exploring the role of temperature

Thermal comfort is not only a function of the ambient air temperature itself, but also depends upon a range of environmental and individual factors. As such, WELL does not prescribe a particular temperature range, but rather recommends that temperatures within mechanically-ventilated offices should adhere to ASHRAE Standard 55-2013 (ASHRAE, 2013), which itself uses Fanger's (1970) Predicted Mean Vote (PMV) equation to develop a suitable range. This method enables practitioners to input three environmental parameters (mean radiant temperature, air velocity, and relative humidity) and two occupant-related parameters (clothing insulation and metabolic rate) in order to generate an ambient air temperature at which a predicted 95% of occupants will be comfortable.

The PMV method is based on decades of experimental research from climate chambers (Van Hoof, 2008), although the extent to which it generalizes to real offices has been called into question by studies indicating its predictive validity actually tends to be very low in practice (Cheung et al., 2019; Oseland, 1995). However, given the aforementioned methodological limitations of previous field studies, it is important to verify these findings using the 'right-here-right-now' data collection procedure. Therefore, we start with the baseline assumption that thermal comfort really will be highest at the recommended temperature, and that employees will increasingly feel 'too warm' the more that the recommended temperature is exceeded and 'too cold' the more that the actual temperature falls below the recommended temperature.

> H_{3A}: Thermal comfort will progressively decrease the more that actual temperature deviates from (PMV-derived) recommended temperature.

> H_{3B}: The likelihood of feeling 'too warm' will increase the more that temperatures exceed the recommended temperature.

> H_{3C}: The likelihood of feeling 'too cold' will increase the more that temperatures fall below the recommended temperature.

Exploring the role of illumination

Office guidelines for illumination simply seek to ensure that the light level is sufficient for supporting visual acuity during computerized tasks, balanced with sustainability requirements for preserving energy where possible. According to WELL, this is achieved by ensuring that light levels are maintained between 300 and 500 lux, or by maintaining light levels above 215 lux and additionally providing individualized task lighting at each workstation so that the user can increase the light level above 300 lux if they prefer (International WELL Building Institute). The 300 lux lower limit also corresponds with guidelines issued by the Society for Light and Lighting (2015).

Though research evidence in this area is limited, there is some evidence to suggest that these guidelines match actual employee preferences. For example, in one study where office workers were given control over individual task lighting, approximately 90% chose an illumination of 300 lux or above (Veitch & Newsham, 2000). Hence, it can be assumed that illumination measured through sensors will be useful for predicting employee's visual comfort, particularly when the illumination falls below 300 lux.

> H_4: Visual comfort will be positively associated with illumination.

Exploring the impact on productivity

Finally, it should be acknowledged that the implementation and ongoing use of sensor technology within offices represents an additional cost for building owners and employers, and so it is important to demonstrate their significance not only for subjective comfort *per se*, but also for other organizational outcomes such as productivity. As we have already mentioned, WELL and similar guidelines are premised on the assumption that higher environmental comfort will consequently improve employee wellbeing and productivity. However, this too is yet to be tested using the proposed methodology. As such, in this study we also test the extent to which environmental comfort (including satisfaction with air quality, thermal comfort, visual comfort, and also acoustic comfort) is associated with self-rated productivity.

> H_5: Each aspect of environmental comfort (satisfaction with air quality, thermal comfort, visual comfort, and acoustic comfort) will be independently and positively associated with self-rated productivity.

Method

Site characteristics

The study took place in late summer in the United Kingdom. The research occurred opportunistically, following a request by a large facilities management organization to help them interpret the practical significance of data they were collecting through (commercial-grade) environmental sensors installed at one of their offices. The research was conducted at this office site and at one additional office site belonging to the same company, who had not installed any sensors permanently but had expressed an interest in trialling temporary data loggers to measure the same parameters. Both sites could be considered as relatively typical examples of office buildings within the United Kingdom, and neither had achieved any sustainability or wellbeing certification.

Both offices featured predominantly open-plan layouts, where banks of permanent workstations without partitions were shared by four, six, or eight employees. Additionally, both sites had enclosed meeting rooms as well as breakout areas within the open-plan areas, so that employees could hold formal and informal meetings. In total, Site A had permanent seating for 142 employees, whereas Site B had seating for 56 employees. Due to differing levels of availability indicated by building managers at each site, there was a 4-week data collection period at Site A and a 2-week data collection period at Site B. The employees at both sites had a similar set of work activities, involving knowledge-based activities such as data analytics, report writing, and managing relationships with clients.

Environmental sensors

At Site A, 17 Elsys ERS CO_2 sensors (Elsys, 2019) had been permanently installed on interior and exterior walls around the workplace, at approximately head height. These sensors provided continuous measurements of carbon dioxide (CO_2, in parts per million [ppm]), temperature (°C), relative humidity (%RH), and illumination (lux). At Site B, no permanent sensors were installed, so the lead researcher visited the site to install temporary data loggers to measure the same environmental parameters. Eight HOBO U12 (Onset, 2019a) data-loggers were installed in the office, with one data-logger placed on a central desk within each bank of desks. The HOBO sensors continuously monitored temperature, relative humidity, and illumination. To measure CO_2, three Telaire 7001 CO_2 sensors (Onset, 2019b) were attached to three of the HOBO data-loggers. The location of the sensors at each site is shown in Figure 1.

Although the use of different sensor models with low scientific precision at each site may be construed as a limitation, this was an unavoidable consequence of conducting the research with an industry partner who had already chosen the technology to implement at each site. However, the use of commercial-grade technology can also be seen as a positive in that it mirrors the type of device that is actually used in practice, enabling us to explore their strengths and limitations. Additionally, the technical specifications for each sensor suggest that their measurement accuracy is largely similar (see Table 1). The one possible exception to this is the measurement of illumination using the HOBO U12, for which the manufacturers provide no information regarding measurement accuracy. This limitation is discussed in the interpretation of findings relating to visual comfort and illumination.

Hypotheses relating to CO_2 and illumination assumed linear relationships with environmental comfort, so raw

Figure 1. Simplified floorplans showing the location of the sensors at each site.

Table 1. Measurement accuracy of the sensors used in the study.

Sensor	IEQ Parameter	Measurement range / (accuracy)
Elsys ERS CO_2 (Site A)	Carbon dioxide	0–2,000 ppm / (± 50 ppm + 3% of reading)
	Temperature	0–40°C / (± 0.2°C)
	Relative Humidity	0–100% / (± 2%)
	Lux	4–2000 lux / (± 10 lux)
Telaire 7001 CO_2 (Site B)	Carbon Dioxide	0–10,000 ppm / (± 50 ppm + 5% of reading)
HOBO U12 Temp/ RH/Light (Site B)	Temperature	−20–70°C / (± 0.35°C)
	Relative Humidity	5–95% / (±2.5%)
	Lux	10–30,000 / (*exact accuracy not stated*)

sensor measurements were used. For temperature, the hypotheses concerned the extent to which the actual temperature deviated from the recommended temperature, rather than the actual temperature *per se.* As such, a transformation was applied to the temperature data. The recommended temperature (i.e. the temperature at which PMV = 0) was calculated at each of the two offices, using the online thermal comfort tool developed by the Center of the Built Environment (CBE) at the University of California (CBE, 2020). We inputted the average measured humidity at each site (45.63% RH at Site A, 45.47% at Site B), and assumed constant radiant temperatures (same as dry-bulb temperature), a typical office airspeed value (0.1 m/s), a typical metabolic rate for office work (1.1 met), and a typical clothing insulation matching office dress code guidelines (1.0 clo) between participants. This calculation indicated that the optimal temperature at both sites was 22.55°C. Consequently, to represent 'deviation from recommended temperature', we created a new variable by taking the absolute difference between each measured value and 22.55 (i.e. measurements of 20.55°C and 24.55°C would both be scored '2').

Questionnaire

Subjective data were captured using the experience sampling methodology, in which the participants provided repeated assessments of momentary environmental comfort during the study. As with the pilot study (authors, blinded for review), the questionnaire was designed to cover the same broad topic areas as a traditional occupant survey, allowing occupants to report their moment-by-moment assessments of core aspects of IEQ. However, in a bid to improve response rate, two major alterations were made to the way in which the survey was designed and distributed.

First, several participants in the pilot study suggested that the daily e-mail reminders to complete the workplace assessment were ineffective, as they had fallen into the habit of ignoring non-urgent e-mails. Second, even though the pilot survey had only taken five minutes to complete, it was reasoned that this may still have been too long for employees with busy workloads. As such, in the present study we used smartphone notifications to deliver a shorter one-minute survey (retaining only the core questions on subjective environmental comfort).

The survey was designed within LifeData (LifeData, 2020), a commercially-available smartphone application (app) for experience sampling research studies. The app was programmed to alert participants (using push notifications) to complete the survey at four random intervals each working day. Hence, participants at Site A each received 80 notifications across the 4-week study period, whilst participants at Site B received 40 notifications across the 2-week study period. Participants were encouraged to respond to as many notifications as they could, without disrupting their ordinary working activities. If the participant chose not to respond within 10 minutes of the notification, the notification disappeared.

On the first page of the survey, participants viewed simplified floorplans of their office divided into different zones (shown in Figure 1), and were asked to select the zone that they were currently seated in. Next, single-item measures were used for each of the five IEQ comfort criteria. The same 7-point Likert scale (1 = Very dissatisfied, 7 = Very satisfied) was used to assess *satisfaction with air quality, thermal comfort, visual comfort,* and *acoustic comfort.* Importantly, questions were worded so that they referred to the participant's experience 'right-here-right-now', rather than in general (e.g. 'How satisfied are you with the noise levels right now?').

If the participant indicated dissatisfaction (i.e. a rating of 1–3) for any component of environmental comfort, then they were prompted with a follow-up question which invited them to list the source(s) of their dissatisfaction. For the purposes of this research, we recorded whether or not a respondent had recorded a vote of 'Too warm' and 'Too cold' following a response of thermal discomfort.

Finally, *self-rated productivity* was measured using an item asking 'What impact has the workplace had upon your productivity in the past half hour?', where participants used a slider scale to indicate their response on a 100-point scale (1 = Very negative impact, 100 = Very positive impact). This item was intentionally limited to the impact of the workplace environment upon productivity, so that results were not confounded by any non-environmental influences on productivity.

After the data collection period had elapsed, spatial and temporal identifiers were used to combine questionnaire responses with objective IEQ data. The participant's response for 'current working location' was used

Table 2. Mean measurements of the environmental parameters at the two sites.

	Carbon Dioxide (in ppm; <800 ppm recommendation)		Temperature (in °C; 22.55°C recommendation)		Humidity (in %RH; 40–60%RH recommendation)		Illumination (in lux; 300–500 lux recommendation)	
Time of Day	Site A	Site B	Site A	Site B	Site A	Site B	Site A	Site B
09:00–10:00	748.33	847.76	22.64	24.71	46.32	48.32	247.25	157.62
10:00–11:00	794.43	872.02	22.73	25.10	45.94	47.58	244.07	166.85
11:00–12:00	788.15	854.75	22.70	25.36	45.82	46.61	242.07	174.30
12:00–13:00	774.78	812.78	22.71	25.52	45.52	45.50	252.09	177.18
13:00–14:00	794.66	784.56	22.75	25.62	45.41	44.69	253.66	173.14
14:00–15:00	779.87	749.59	22.79	25.61	45.57	44.00	234.43	183.45
15:00–16:00	733.76	724.86	22.76	25.59	45.57	43.48	213.21	188.39
16:00–17:00	641.98	675.74	22.62	25.50	45.01	43.34	187.29	165.00
Overall	753.19	785.05	22.71	25.33	45.63	45.53	233.16	171.13

to identify the closest sensor(s) on each occasion, and the relevant timepoint was identified through data automatically collected by LifeData on the exact time each survey was completed. Specifically, we combined each survey response with the data from the nearest sensor, taking the average of each IEQ parameter in the half hour preceding the completion of the survey.

Participants

Participation in the study simply entailed downloading the LifeData app and relevant survey package, and then completing workplace assessments when a smartphone notification was received. At Site A, the 121 permanent employees at the site were contacted by e-mail with information about the study and an invitation to participate. In total, 13 individuals from this site participated in the study, and together provided 119 momentary assessments of the workplace environment across a 4-week data collection period. At Site B, 56 employees were contacted and 32 agreed to participate, together providing 417 momentary assessments across a 2-week data collection period. As such, the combined dataset contained 536 observations from a total sample size of 45 employees (24 female, 21 male). Participants' age ranged between 22 and 63 ($M = 32.8$).

Results

Procedure

The experience sampling method yields a 'nested' data structure, whereby individual survey responses (Level 1) are nested within participants (Level 2). Using ordinary regression techniques for nested data increases the likelihood of producing spuriously significant effects (Hox, 1997), so multilevel modelling methods were used instead, following the procedure outlined by Field et al. (2012). Specifically, the intraclass correlation coefficient (*ICC*), which partitions the proportion of total outcome variance attributable to Level 1 and Level 2 factors, was calculated to assess the extent to which subjective responses fluctuated on each measurement occasion (H_1). Then, multilevel linear modelling was used to test the extent to which the subjective responses could be predicted by the objective IEQ data (H_2-H_5).

All data analysis was performed using R Studio (R Studio Team, 2015), using the *nlme* package (Pinheiro et al., 2017) for fitting and comparing the multilevel models and the *MuMIn* package (Bartoń, 2018) for calculating pseudo-R^2 estimates for the models. Models were fitted using the restricted maximum likelihood procedure.

Descriptive statistics

Table 2 shows the mean measurements for each IEQ parameter across the working day at each site. As shown, the 800 ppm upper bound for CO_2 concentration was rarely exceeded at either office, and the overall average was within the comfort boundary ($M = 753$ ppm at Site A, $M = 785$ ppm at Site B). Temperature was very close to the 22.55°C recommendation at Site A and was maintained within a relatively narrow range, but at Site B temperatures were significantly warmer and the average measurement ($M = 25.33$°C) was almost three degrees higher than the recommendation. Humidity at both sites was entirely within the 30–50% boundary specified by WELL ($M = 45.6$% RH at Site A, $M = 45.5$% at Site B). Finally, both sites failed to achieve the recommended lower bound for light intensity ($M = 233$ lux at Site A, $M = 171$ lux at Site B), indicating that both offices were relatively dark throughout the working day.

Table 3 shows the corresponding descriptive statistics from the subjective questionnaire responses. All responses were approximately normally distributed, and averages tended towards the midpoint of the scale. Interestingly, despite the closer adherence to recommended temperatures at Site A than Site B, subjective thermal comfort was lower at this site ($M = 3.49$ at Site A

Table 3. Descriptive statistics for each of the survey items.

Item	Site A		Site B		Combined		
	M	*SD*	*M*	*SD*	*M*	*SD*	*ICC*
[PERCEIVD AIR QUALITY] 'How satisfied are you with air quality right now?' (1=Very dissatisfied, 7=Very satisfied)	4.55	1.45	3.76	1.24	3.93	1.33	0.51
[PERCEIVED THERMAL COMFORT] 'How satisfied are you with temperature right now?' (1=Very dissatisfied, 7=Very satisfied)	3.49	1.7	3.71	1.39	3.66	1.46	0.26
[PERCEIVED ACOUSTIC COMFORT] 'How satisfied are you with noise levels right now?' (1=Very dissatisfied, 7=Very satisfied)	4.97	1.46	4.23	1.28	4.39	1.35	0.56
[PERCEIVED VISUAL COMFORT] 'How satisfied are you with the overall lighting right now?' (1=Very dissatisfied, 7=Very satisfied)	4.18	1.33	4.37	1.17	4.35	1.18	0.61
[SELF-RATED PRODUCTIVITY] 'What impact has the workplace had upon your productivity in the past half hour?' (1=Very negative impact, 100=Very positive impact)	51.05	19.36	48.71	17.83	48.93	17.95	0.59

vs. $M = 3.71$ at Site B). The most positively-rated aspects of each office were the acoustics, which were slightly higher than satisfactory at both sites ($M = 4.97$ at Site A, $M = 4.39$ at Site B).

Table 3 also shows the *ICC* for each of the outcome measures. *ICC* ranges between 0 and 1, with values closer to 1 indicating a lower proportion of within-participant variance. As such, the *ICC* is commonly used as a measure of reliability, where $ICC > 0.6$ is viewed as the minimum criteria for 'good' test–retest reliability (Cicchetti, 1994). As shown, the only outcome which met this cut-off point was perceived visual comfort ($ICC = 0.61$), whilst self-rated productivity ($ICC = 0.59$) and perceived acoustic comfort ($ICC = 0.56$) were marginally below the cut-off point. The weakest test–retest reliability was observed for perceived thermal comfort ($ICC = 0.26$). Together, these results demonstrate relatively high fluctuation each time each respondent completed the survey, and so H_1 was supported.

Main analyses

For each outcome (perceived air quality, thermal comfort, visual comfort, and productivity), a random-intercept model fit the data better than an intercept-only model (p-values < 0.0001), indicating that multilevel modelling procedures were appropriate for testing the hypotheses. A binary variable representing site (1 = Site A, 2 = Site B) was added to all of the models to control for any contextual variance between the two sites. Linear models were used in all cases except for H_{3B} and H_{3C}, where logit models were used to model the binary response variables. The number of observations that each analysis was performed upon ranged from 460 to 536 due to missingness. Summary statistics for each of the multilevel linear models are presented in Table 4.

The results of the analyses provided mixed support for the study's hypotheses. In terms of the effects of the physical environment, the only significant effects arose with respect to the thermal environment. As expected, deviation from recommended temperatures was negatively associated with thermal comfort ($p = 0.031$), although the pseudo-r^2 estimate indicated that this was a very small effect, with only 1.1% of the outcome variance explained ($marginal\_GLMM^2 = 0.011$). The results of the logit models also confirmed that higher temperatures increased the likelihood of a 'Too warm' vote ($p < 0.001$), but there was no evidence

Table 4. Summary statistics for each of the multilevel linear regression models.

	Model for predicting perceived air quality (*n* = 536 observations, from 39 participants)		
Explanatory Variable	Estimate	t-value	*p*-value
Organization	−0.26	−0.75	0.46
CO_2 concentration (ppm)	0.0001	0.89	0.37
Temperature (deviation from comfort policy; °C)	−0.18	−4.24	<0.0001
Marginal $r^2 = 0.063$			
	Model for predicting perceived thermal comfort (*n* = 535 observations, from 39 participants)		
Explanatory Variable	Estimate	t-value	*p*-value
Organization	0.45	1.34	0.19
Temperature (deviation from comfort policy; °C)	−0.12	−2.17	0.031
Marginal $r^2 = 0.011$			
	Model for predicting perceived visual comfort (*n* = 460 observations, from 31 participants)		
Explanatory Variable	Estimate	t-value	*p*-value
Organization	−0.93	−1.73	0.1
Illumination (lux)	0.00004	0.33	0.74
Marginal $r^2 = 0.054$			
	Model for predicting self-rated productivity (*n* = 460 observations, from 31 participants)		
Explanatory Variable	Estimate	t-value	*p*-value
Organization	−0.78	0.19	0.85
Visual comfort	2.41	4	0.0001
Satisfaction with air quality	2.23	4.34	<0.0001
Thermal comfort	3.46	7.68	<0.0001
Acoustic comfort	4.2	8.21	<0.0001
Marginal $r^2 = 0.52$			

that the likelihood of a 'Too cold' vote increased at lower temperatures ($p = 0.84$). Overall, H_{3B} was supported and H_{3A} was partially supported.

Contrary to expectations, there was no evidence to support a negative association between CO_2 concentration and satisfaction with air quality ($p = 0.21$). Thus, H_2 was not supported. However, a second model was tested *post-hoc* in which deviation from recommended temperature was added in as an explanatory variable. The results confirmed a significant effect whereby satisfaction with air quality decreased the more that temperature deviated from the thermal comfort policy ($p < 0.0001$). Approximately 6.3% of the variance in satisfaction with air quality was accounted for by the predictors ($marginal\_GLMM^2 = 0.063$).

There was also no evidence to support the predicted positive association between illuminance and visual comfort ($p = 0.74$). Indeed, the very small coefficient for illumination indicates that illuminance and subjective visual comfort were almost entirely independent of one another in the sample. Therefore, H_4 was not supported.

Finally, a multivariable multilevel regression model was used to test the hypothesized relationship between environmental comfort and self-rated productivity. As expected, the results of the model confirmed that self-rated productivity was independently and positively associated with acoustic comfort ($p < 0.0001$), thermal comfort ($p < 0.0001$), perceived air quality ($p < 0.0001$), and visual comfort ($p = 0.0001$). The pseudo-r^2 calculation revealed that these four components of environmental comfort together accounted for 50.8% of the variance in ratings of productivity ($marginal\_GLMM^2 = 0.508$). Acoustic comfort had the strongest impact upon ratings of productivity. As such, H_5 was supported.

Discussion

The development of environmental sensor technology opens up a golden opportunity for research combining spatially and temporally bound measurements of IEQ with 'right-here-right-now' assessments of environmental comfort in real offices. Accordingly, the aim of this study was to develop a methodology for integrating building and human analytics in this way, and to evaluate the process by which it could be used in real offices to measure and improve employee's comfort and productivity. The findings and their implications are discussed in the following sections, along with the limitations of the study and suggestions for future research.

Relationship between IEQ and subjective comfort

Mixed support was found for the study's hypotheses about the role of IEQ. It was confirmed that adherence to the recommended temperature reduce the risk of thermal discomfort, and that exceeding the recommended temperature increased the likelihood that the occupants would report feeling 'too warm', however these effects were relatively weak. In contrast to the pilot study (Roskams & Haynes, 2019b) there was no association between CO_2 and satisfaction with air quality, and neither was there an association between visual comfort and illumination.

At first glance, these findings seem to imply that environmental sensors are of limited utility for predicting subjective comfort. However, this should be interpreted with caution, given that the IEQ at both sites was generally within recommended ranges. Probably, environmental sensors are most useful for predicting (dis)comfort when physical conditions deviate most strongly from comfort policies. Indeed, the one IEQ issue that was detected in the study (frequent exceedance of temperature at Site B in particular) likely contributed to the statistically significant effects of temperature. In the pilot study, temperature remained almost entirely within the comfort boundary and no significant effect on thermal comfort was found, however CO_2 significantly exceeded the recommended upper bound ($M =$ 1,425 ppm) and a significant effect on satisfaction with air quality *was* found (Roskams & Haynes, 2019b). As such, the failure to detect significant effects here does not necessarily imply that the use of environmental sensors would not be valuable at sites which have worse IEQ conditions.

Having said that, it is also important to consider the possible limitations of the sensor technology and the assumptions underlying their use. In particular, the assumption that CO_2 is an accurate measure of overall air quality may not be completely valid. For example, the study by Ramalho et al. (2015) showed that whilst CO_2 is significantly correlated with most indoor air pollutants, the associations tend to be weak and can be affected by numerous seasonal, building-related, and occupant-related factors. Moreover, we also unexpectedly found that temperature was a significant predictor of satisfaction with air quality, indicating that air quality judgements may involve complex and multi-faceted determinants. To provide building managers with more useful information, therefore, it will be valuable to extend the range of IEQ parameters that are continually monitored. Indeed, more recent commercially-available sensor devices also monitor five additional types of airborne pollutant as well as CO_2 (e.g. uHoo, 2020).

The failure to find a significant effect of illumination was surprising, given that illuminance at both sites was consistently below the recommended lower bound. Possibly, this may also relate to a limitation of the sensor devices (especially for the data loggers, which did not specify measurement accuracy). However, the observed association in this case was so weak that it is more likely that moderate levels of visual comfort were achieved despite relatively dark conditions simply because the backlit computer screens enabled users to complete their tasks effectively, regardless of ambient illumination. It remains to be seen whether increasing the ambient lighting would be sufficient for achieving even higher ratings of visual comfort, or whether it will be necessary to use additional strategies such as supporting occupants' circadian rhythms through increased daylighting (Edwards & Torcellini, 2002).

Indeed, subjective environmental comfort was relatively modest for all aspects of IEQ, despite relatively high adherence to comfort boundaries. Possibly, the most effective way of optimizing environmental comfort will be to allow employees to adjust local conditions to their own preferences, instead of attempting to satisfy all occupants with the same configuration of IEQ. For example, in thermal comfort research it is now recognized that there is significant inter-individual variability in thermal comfort preferences (Wang et al., 2018), which may explain why the PMV method tends to be a relatively poor predictor of actual thermal comfort in practice (Cheung et al., 2019; Oseland, 1995). One study which trialled individual temperature control (through heaters and fans embedded in the desk chair) succeeded in greatly improving thermal comfort amongst a small sample of participants (Kim et al., 2019), and similar strategies have also been suggested to improve visual comfort (Veitch, 2013).

Relationship between subjective comfort and productivity

Interestingly, whilst the relationship between IEQ and subjective comfort was complex and unclear, there was a very clear and strong association between subjective comfort and self-rated productivity. As expected, employees reported the highest levels of productivity when they were satisfied with the air quality, temperature, illumination, and noise levels within the office. This is in line with theoretical expectations that environmental comfort is a crucial factor which mediates the relationship between the physical environment and employee job performance (Roskams & Haynes, 2019a; Vischer, 2007, 2008), in that *dis*comfort contributes to stress, and draws attentional and energetic resources away from the completion of work-related activities. Hence, however it might be achieved, the provision of subjective comfort amongst employees should be a crucial consideration for employers.

The strong effect size associated with acoustic comfort in particular is in accordance with previous research highlighting that distraction by irrelevant speech has an especially pernicious impact on employee productivity in open-plan offices (e.g. Haapakangas et al., 2014; Mak & Lui, 2012). Environmental sensors used to measure sound pressure level could ostensibly help to detect conditions which are more likely to result in distraction, however it should be noted that distraction does not result from loudness *per se,* but rather from the intelligibility of the irrelevant noise source and the extent to which it captures the employee's attention (Oseland & Hodsman, 2018). Therefore, it would be most effective to combine their use with psychoacoustic design strategies, such as the provision of silent working areas within the office and/or the use of more absorbent building materials to limit sound transmission.

Process evaluation

In addition to developing a methodology for integrating building analytics and human analytics, we also wanted to evaluate whether this process was justified and to identify the factors which affected its implementation at real office sites. Turning first to the justification for the methodology, the results confirmed that individual experiences of environmental comfort and productivity tended to fluctuate each time the survey was completed, casting aspersions on the assumption that these phenomena can be reliably measured using a one-time-only questionnaire asking employees how they feel *in general.* As critics have noted (e.g. Deuble & de Dear, 2014), this methodology appears to yield responses which are far too general to be practically useful. For example, an average response of 'moderately comfortable' could refer equally to an employee who is moderately comfortable at all times and an employee who spends half the time highly uncomfortable and the other half highly comfortable. Hence, our results support the contention that the experience sampling methodology is a more appropriate for measuring employees' experiences in the workplace.

Secondly, recognizing that the use of the sensor devices will be most useful when a high proportion of office users agree to provide repeated measures of subjective experience, we also wanted to explore whether response rate could be improved by reducing the length of the survey and distributing it via smartphone rather than e-mail. The effectiveness of this strategy was mixed. At Site A, both the initial uptake (~10.7%) and the subsequent completion rate of the distributed surveys (~11.4%) was notably lower than that of the pilot study. However, at Site B there was significantly higher uptake (~57.1%) and also a relatively good completion rate of the distributed surveys (~32.6%).

This suggests that response rate is not simply a function of the way in which the survey was designed and distributed, but is also strongly affected by organizational-contextual factors. Indeed, it has been previously demonstrated that the degree to which employees within an organization feel autonomous or externally-controlled affects the way in which they respond to survey reminders (Romero Herrera et al., 2018). On a similar note, in the present study we observed that the building managers at Site B were considerably more enthusiastic about the research, and took it upon themselves to repeatedly encourage employees at the site to participate in the research. These findings imply that organizational leadership and company culture may play a significant role in influencing engagement with the technology. This prediction could be verified in future by also capturing qualitative and/or quantitative data about the organization itself, and considering which factors differentiate the most and least engaged groups of respondents.

Limitations

The present study demonstrates a sound methodology for interrogating the relationship between IEQ and subjective comfort in real offices, making use of the latest technological developments and overcoming the limitations of previous research. Nonetheless, our current findings are restricted to two office sites with relatively good IEQ, and may not generalize to other environments. Similarly, the relatively small dataset in the present study also limited our ability to add additional important variables to the models (e.g. age, gender), in order to preserve statistical power. By way of contrast, the database of the most popular traditional occupant survey currently has more than 550,000 responses from almost 4,000 different buildings (Oldman et al., 2019). Accordingly, we believe an important next step is to grow the overall dataset and increasingly incorporate measurements from a more diverse range of offices with more varied environmental conditions.

As the size of the overall dataset grows, so too does the statistical power for analysing the associations between the variables of interest. The methodology we have developed can be easily replicated within any workplace, using commercially-available sensor and mobile smartphone technology. By compiling a large dataset in this manner, and potentially by developing it even further through the inclusion of individual variables and organizational variables, researchers can test increasingly complex models for predicting employee environmental comfort. This will provide valuable new insights into the nature of the IEQ-comfort relationship.

Secondly, it should also be noted that our research is passive, in that we made no active intervention to the workplace environment (other than installing the temporary data loggers at Site B). In practice, facilities managers will increasingly use live environmental sensor data as part of their everyday operational practice, and may also incorporate repeated subjective assessments of occupant experience as this study recommends. However, there is limited understanding at present of how this type of feedback loop between building users and managers can be most effectively used within real organizations to proactively support occupant comfort, wellbeing, and productivity. This would be a useful focus of investigation in future research.

Conclusion

With smart building technology predicted to exponentially increase in popularity in coming years, it is crucial to understand how new technology can be effectively used to enhance occupant experience in the workplace. Our research is the first to develop the methodology for directly combining environmental sensor data with repeated assessments of subjective experience, in order to test the extent to which compliance with IEQ comfort criteria effectively improves occupant comfort.

The results showed that there was a weak relationship between temperature and thermal comfort, but no relationship between CO_2 and satisfaction with air quality, nor between illumination and visual comfort. However, there was a strong effect to suggest that employees felt most productive when they were satisfied with the air quality, temperature, illumination, and noise levels within the office. Therefore, the optimization of environmental comfort is highly important but also very complex, and may necessitate strategies beyond mere compliance with comfort criteria. In the next stage of the research, it will be necessary to apply the methodology more widely, and to investigate the implementation of a proactive facilities management service which combines both environmental sensor data and subjective human data.

Disclosure statement

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A randomised field experiment to test the restorative properties of purpose-built biophilic “regeneration pods”

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Abstract

Purpose – There has been limited investigation into how “biophilic design” (i.e. the integration of nature within the built environment) can be effectively used within the workplace to facilitate the process of psychological restoration. The purpose of this study was to focus, in particular, on the effectiveness of biophilic “restoration pods” in promoting recovery from stress.

Design/methodology/approach – A randomised field experiment was conducted. A total of 32 employees from a participating organisation completed two tests replicating typical office work (proofreading and arithmetic) and subjective ratings of stress, anxiety and task-load both before and after a 10-minute micro-break, taken in either the regeneration pods (treatment group) or an ordinary meeting room (control group).

Findings – The results showed that participants who took their break in the regeneration pod reported lower post-break anxiety and perceived task-load, and higher post-break arithmetic task performance, than the control group.

Practical implications – The findings suggest that purpose-built spaces for restoration within office buildings will be effective for helping employees to proactively manage their stress levels while at work. Biophilic design principles will enhance the effectiveness of these spaces, and this does not necessarily need to involve direct exposure to plants or views of nature.

Originality/value – To the best of the authors’ knowledge, this is the first randomised field experiment to test the effectiveness of a purpose-built space for restoration within offices. Additionally, this paper explores different forms of biophilic design than previous studies.

Keywords Workplace, Stress, Environmental psychology, Restorative environment, Office, Biophilic design

Paper type Research paper

One of the major health concerns for modern knowledge workers is work-related stress, which is experienced whenever the perceived demands of a situation exceed the perceived ability to cope. High work performance necessitates the prolonged use of different higher-order cognitive functions coupled with self-regulatory processes (e.g. focussed attention, inhibitory control). However, the psychological resource responsible for self-regulation (termed the “ego”) is limited and can become quickly depleted (Baumeister and Vohs, 2007), particularly in open-plan offices where numerous non-task-related environmental demands

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(e.g. poor indoor air quality, auditory and visual distractions) further impede effective task completion (Roskams and Haynes, 2020).

To mitigate the pernicious effects of stress, organisations should consider opportunities to facilitate *restoration* (i.e. the process of renewal in which depleted social, psychological or physical resources are replenished; Hartig, 2004) in the workplace. Importantly, the restoration of attentional resources is expedited when the individual detaches psychologically from work, practices physiological relaxation and experiences high autonomy (Sonnentag and Fritz, 2007). For this reason, work breaks – even "micro-breaks" lasting ten minutes or less – are considered to be an effective means of helping employees to proactively restore depleted attentional resources and effectively cope with psychophysiological stress throughout the working day (Sonnentag *et al.*, 2012; Wendsche *et al.*, 2016).

To date, limited attention has been paid to the ways in which spaces for restoration within offices can be most effectively designed. As such, the present study aimed to test the effectiveness of using "biophilic" design strategies for this purpose.

What is biophilic design?

The "biophilia hypothesis" suggests that humans possess an innate tendency to seek connections with nature and other forms of life, and that nature contact plays a crucial role in supporting human health and well-being (Wilson, 1984). Indeed, it has been repeatedly demonstrated that contact with nature leads to reductions in psychological, physiological and neurological indicators of stress (Hartig *et al.*, 2014; Norwood *et al.*, 2019; Park *et al.*, 2010). Popular theories to account for the beneficial effects of nature exposure are grounded in evolutionary psychology. For example, attention restoration theory (ART; Kaplan, 1995) argues that humans are evolutionarily primed to find natural environments "softly fascinating", meaning that they can be viewed with effortless attention, allowing the depleted capacity for directed attention to recover. Similarly, stress reduction theory (SRT; Ulrich *et al.*, 1991) proposes that exposure to nature elicits positive emotions and feelings of interest and tranquillity, prompting a return to equilibrium from the physiological activation instigated by a stressor.

Just as contact with nature is associated with improved psychological functioning, so too is insufficient nature contact associated with psychological deficits (Louv, 2011). This is a particular concern in the modern developed world, where increasing urbanisation has left many inhabitants unable to experience the benefits associated with nature contact. Hence, there is an emerging trend within architecture and urban design for biophilic design, comprising strategies aimed at "maintaining, enhancing, and restoring the beneficial experience of nature in the built environment" (Kellert and Heerwagen, 2013).

In an effort to arrange different biophilic design strategies into a coherent framework, Ryan *et al.* (2014) proposed that 14 "patterns" of biophilic design strategies could be grouped into three broad categories: "nature in the space" (the direct integration of nature within the built environment, e.g. through window views of nature or interior planting); "natural analogues" (the indirect evocation of nature, e.g. through wooden furnishings or the use of complex biomorphic designs); and "nature of the space" (mimicry of the spatial configurations found in nature, e.g. designing spaces which provide both prospect and refuge).

Biophilic design within office spaces

In recent decades, workplace researchers and practitioners have increasingly considered the potential benefits of biophilic design within office spaces, focussing largely on "nature in the space" design strategies. Consistently, such studies point to the conclusion that biophilic design positively supports the well-being and productivity of office occupants. For example, comparisons of office spaces with and without plants have demonstrated that the presence of plants is variously associated with improvements in physiological stress and objective task performance (Lohr *et al.*, 1996), attention capacity (Raanaas *et al.*, 2011) and self-reported concentration and productivity (Nieuwenhuis *et al.*, 2014). Similarly, views of nature, compared with views of urban/built environments, are associated with improvements in stress, positive affect, sustained attention, task performance and general perceptions of health (Jiang *et al.*, 2019; Lee *et al.*, 2015, 2018; Kaplan, 1993; Ulrich *et al.*, 1991).

These benefits are typically accounted for with reference to ART and SRT. By directing attention away from work tasks and towards natural features within the field of vision, employees are able to prompt "micro-restorative experiences" which enable them to continually restore attentional resources that deplete through the task-related and non-task-related demands of everyday working life. In doing so, they are able to more effectively moderate stress and attention on an ongoing basis, resulting in improved well-being and productivity at work.

While these studies have provided useful insight into how biophilic design can be effectively implemented within the workplace, one limitation that has been noted is that the vast majority of the biophilic design literature focusses solely on the aforementioned "nature in the space" strategies, and less is known about the effects of other aspects of biophilic design (Yin *et al.*, 2019). That is, it remains unclear whether similar benefits could be elicited in office spaces through the use of "natural analogues" and "nature of the space" strategies.

Present study

The opportunity to address this gap was presented to the present researchers by a participating organisation who had recently commissioned the construction of two "regeneration pods" (shown in Plate 1) for their office, to be used as a purpose-built space for recuperation. These were designed by an architect, entirely independent of the research team, who explicitly used several biophilic design strategies which have been little considered in previous research.

First, the pods were constructed by using bamboo wood and designed to follow the structural logic of nature using complex biomorphic forms, reflecting both the "material connection with nature" and "biomorphic forms and patterns" strategies from the "natural

Plate 1.
Images of the meeting room (control condition, left) and the regeneration pods (treatment condition, right)

analogues" biophilic design category (Ryan *et al.*, 2014). There is some suggestion in the research literature to suggest that these should be associated with improved outcomes. For example, one literature review concluded that there is good early evidence to suggest that exposure to wooden environments also reduces numerous psychophysiological indicators of stress (Burnard and Kutnar, 2015), although the need for more robust research was noted.

Second, the pods were designed in accordance with prospect-refuge theory, meeting a prescription from the "nature of the space" category (Ryan *et al.*, 2014). In line with the evolutionary assumption that humans have an innate desire to observe without being seen, the pods (located in an enclosed room in the corner of the floor plate) provide significant visual and auditory enclosure from other parts of the office but grant the user a clear view from the window. Owing to the location of the office (in central London, England), there was very limited greenery present in the window view; however, it was assumed that the expansive view and daylight exposure would be valuable nonetheless. The room housing the pods was decorated with several cacti plants, although these are not directly in the user's line of sight during use.

Finally, the pods also allow users to initiate a 10-minute soundscape featuring calming sounds of nature, played through overhead speakers. This meets the criteria for "non-visual connection with nature" in the "nature in the space" category (Ryan *et al.*, 2014) and corresponds with the previous research indicating that hearing natural soundscapes is associated with improvements in mood (Benfield *et al.*, 2014). Overall, the combination of these hitherto under-considered biophilic design strategies was predicted to yield similar benefits to those previously demonstrated through the use of interior plants and window views to nature.

The aim of the present study was to test this prediction. Specifically, a randomised field experiment was conducted to explore whether a micro-break taken within a "regeneration pod" had greater benefits than a micro-break within an ordinary enclosed meeting room. It was hypothesised that participants in the regeneration pod group would experience even lower post-break levels of subjective anxiety *(H1)* and stress (*H2*), higher post-break performance on proofreading (*H3*) and arithmetic (*H4*) tasks and lower perceived task-load during task completion (*H5*), relative to those in the control group.

Methods

Study design and context

Data were collected at the head office of the large private-sector organisation who had commissioned the regeneration pods. A randomised field experiment design was adopted, following on from similar studies by Lee *et al.* (2018) and Jiang *et al.* (2019). Employees were randomly assigned (using a random number generator) to one of two conditions: a "control" condition involving a 10-minute break in an enclosed meeting room; or a "treatment" condition involving a 10-minute break in the regeneration pod. Full ethics approval for the experimental procedure was granted by the ethics committee at the authors' university.

The enclosed meeting room was located on the interior of the floor plate and included a central table surrounded by six desk chairs and a television monitor fastened to the wall opposite the door. The room did not feature any interior plants or artwork, nor were any natural materials used in the room's furniture. The only window in the room was frosted to provide privacy from the adjacent open-plan office space. The room accommodating the regeneration pods (which was described in more detail in the Introduction) was located approximately 10 m away from the entrance of the meeting room and featured ceiling-to-floor windows providing views to outdoors.

To get from one room to the other, participants needed to return briefly to the main office space. This was a large open-plan area designed to accommodate approximately 300 employees (through a combination of desk space, secondary seating areas and informal meeting spaces), where small partitions (e.g. lockers, furniture), rather than interior walls were used to partition different working "neighbourhoods". A modest degree of biophilic design was implemented within this main space, limited to interior plants placed infrequently between neighbourhoods.

Participants

An e-mail list was used to contact approximately 200 employees who used the office as their primary working location with information about the study and an invitation to participate. Additionally, the lead researcher verbally communicated information about the study to others while working from the office. No tangible incentives were offered in return for participation. Rather than setting an *a priori* specification for minimum sample size, the aim was to recruit the maximum number of participants from the pool of regular employees.

In total, approximately 50 participants volunteered to participate in the study; however, not all of these attended their allotted experimental session. As such, the overall sample size comprised 32 employees. The sample consisted of 19 males and 13 females, and the mean age was 32.9 (range 24-46). A total of 17 participants were native speakers of English, whereas 15 participants spoke English as a second language. Efforts were made to balance these characteristics across the two experimental conditions; however, non-attendance to experimental sessions led to slight imbalances. As such, during the data analysis it was tested whether demographic characteristics should be included as covariates prior to running the main analyses.

Procedure

Depending on their availability, participants were asked to come to the enclosed meeting room for a 40-minute session on either a Thursday or Friday afternoon, with a starting time between 2:00 p.m. and 4:00 p.m. Participants either completed the procedure alone or with one other participant, again because of differing levels of availability.

Upon arrival to the meeting room, participants were asked to relax for five minutes to reduce the impact of prior experiences upon baseline measures. They were then asked to read a participant information sheet, and sign a consent form if they agreed to the terms of the study. At this point, they were given a paper questionnaire booklet and asked to fill in demographic information and the first round of subjective measures (T1).

Next, they were asked to complete three tasks, with a two-minute time limit for each. These tasks included a proofreading task and an arithmetic task, which were intentionally designed to be demanding in an attempt to replicate the type of stress an employee might experience during a difficult day at work. As a further ego-depletion manipulation, the first round of tasks also included a tracing task which, unbeknownst to the participants, was impossible to complete (adapted slightly from Lurquin, 2013; see supplementary materials). After the tasks were completed, participants were asked to turn to the next page in the questionnaire booklet to complete the second round of subjective measures (T2).

At this point, participants were instructed to take a 10-minute break and asked to "relax or unwind in your normal way", with the exception that they should not use their mobile phones or laptops during the break. Those in the treatment group were asked to walk the short distance to the regeneration pod for their break. Before starting their break, they were instructed to use their access card to initiate the acoustic soundscape through the overhead speakers. Those in the control group were asked to remain in the meeting room. In all cases, the lead researcher left the room with the questionnaire booklets and then notified the participant(s) when the 10 min had elapsed, so that the session could resume in the meeting room. Immediately after the break, participants completed the third round of subjective measures (T3). Finally, participants completed new versions of the arithmetic and proofreading task, followed by the fourth round of subjective measures (T4).

Once the booklet was completed, participation in the study was over, so participants were thanked for their time and debriefed about the nature of the unsolvable tracing task. Participants who were not assigned to the experimental condition were encouraged to use the restoration pods in future, so that they did not experience any disadvantage as a result of how the treatment was assigned.

Measures

Demographic information

Participants indicated their gender and year of birth. Additionally, they were asked to indicate whether English was their first language, as it was reasoned that this might affect performance on the proofreading task.

Subjective measures

To increase the sensitivity of participant's questionnaire responses, visual analogue scales were used within the questionnaire rather than numeric rating scales. Specifically, participants were instructed to use an "X" to mark the intensity with which they currently felt different emotions or sensations. In each case, the line for the scale was exactly 10 cm long, so a quantitative score for each measure was derived by using a ruler to calculate the exact point at which the X was drawn.

Specifically, on all four measurement occasions participants rated the extent to which they were currently experiencing four emotions (anxiety, calm, relaxed, tense), taken from the anxiety-comfort subscale of the multi-affect indicator (Warr, 2013). The scale ranged from "Not at all" to "Completely". Responses to "calm" and "relaxed" were reverse-scored, and subsequently the average of the four items was taken as the score for subjective *anxiety*. The four items showed high internal consistency (α = 0.84). At the same time points, one additional item was included for participants to rate their subjective *stress* levels, using exactly the same scale.

At T2 and T4 only, four items were taken from the NASA Task-Load index (NASA, 2019) to measure *perceived mental demand*, *temporal demand*, *perceived effort* and *frustration* experienced during the tasks that had just been completed. The scale for these items ranged from "Very low" to "Very high". The responses to these items were summated to attain a single score for *perceived task-load* between 0 and 40, and also showed good internal consistency (α = 0.79).

Task performance

A proofreading task and an arithmetic task were used to measure cognitive performance, as these approximately replicate real office activities, and have also been used previously to induce cognitive load (Jiang *et al.*, 2019).

The proofreading task was adapted slightly from previous studies (Brunye *et al.*, 2012), and can be considered a measure of verbal-semantic processing ability. Participants read a short passage of text, which they were told contained "numerous spelling errors, verb tense errors, and other typological errors" and were instructed to circle or underline any errors that they could identify. Each passage contained 16 errors in total: four simple local errors (misspellings of 1–2 syllable words), four complex local errors (misspellings of 3-4 syllable words), four simple global errors (homophones) and four complex global errors (subject-verb disagreement or verb tense mis-use). Both passages were adapted from Wikipedia entries and were approximately matched on both word length and the Gunning Fog Index of text readability (264 words and a Gunning Fog score of 17.5 for a passage on “air conditioning”, and 262 words and a Gunning Fog score of 18 for a passage on “solar energy”). Proofreading performance was scored as the number of errors correctly identified.

The second test was an adapted version of the Serial Sevens test (Hayman, 1942), designed as a measure of mental arithmetic. Whereas the original text requires participants to verbally perform serial subtractions in sevens from a starting number, in the present study the calculations were performed on paper using different numbers for serial subtractions. Participants were given ten questions to complete within two minutes, each involving five serial subtractions from a starting number. The starting number was a randomly generated three-digit (first 5 questions) or four-digit number (last 5 questions). The number to be serially subtracted was randomly chosen from 3 to 9 for the first seven questions, and from 10 to 20 for the last three questions (although multiples of 5 and 10 were not used). These measures ensured that the questions became increasingly difficult as the task progressed, and was matched in difficulty between the pre- and post-break tests. In total, there were five possible correct answers for each question, meaning that the maximum score was 50.

Results

All statistical analyses were performed using R Studio. The code that was used for the analysis, including the different packages that were used, is available as a supplementary file upon request from the primary author.

A series of analysis of variance (ANOVA) models were used to test the hypotheses. Two outcomes (perceived stress and anxiety) were measured at all four time points, so to analyse these outcomes 2 (Condition: Treatment vs Control) $\times$ 4 (Time: T1, T2, T3 and T4), mixed ANOVAs were performed (summary statistics shown in Table 1) and computed using Type III sum of squares because a significant interaction was expected. Generalised eta-squared (η^2_G) is reported as the measure of the effect size for predictors in these models and is interpreted by using Draper’s (2020) recommendations.

The other three outcomes (proofreading performance, arithmetic performance, perceived task-load) were measured at T2 and T4 only, and so baseline-adjusted analyses of co-variance (ANCOVAs) were used to test the hypotheses (summary statistics shown in Table 2). No interaction terms were included in these models, so test statistics were calculated using Type II sum of squares. Partial eta-squared (η^2_p) is reported as the measure of the effect size for predictors in these models and is also interpreted using Draper’s (2020) guidelines.

	F	η^2_G	p
Univariate model for subjective anxiety (N = 32)			
Condition	14.54	0.2	<0.0001
Time	18.11	0.23	<0.0001
Condition × Time	3.79	0.06	0.019
Univariate model for subjective stress (N = 32)			
Condition	1.43	0.03	0.24
Time	15.61	0.11	<0.0001
Condition × Time	7.31	0.06	0.0002

Notes: Effect size descriptors: *Small* ($0.02 < \eta^2_G < 0.13$), *Medium* ($0.13 < \eta^2_G < 0.26$), *Large* ($0.26 < \eta^2_G$)

Table 1. Summary of the mixed ANOVA models for subjective anxiety and stress

Testing potential confounds

Prior to the main analyses, the influence of three potential confounds (gender, age and whether or not English was the participant's first language) were assessed for each of the outcomes using *t*-tests and Pearson's correlation. The results confirmed that male participants in our sample scored significantly higher on the arithmetic task than the female participants ($M = 20$ vs $M = 14.54$; $p = 0.009$), and that the male participants also perceived lower task-load than the female participants ($M = 27.32$ vs $M = 30.43$; $p = 0.05$). As such, gender was included as a covariate in the models for arithmetic task performance and perceived task-load. Surprisingly, there was no significant effect of native language upon proofreading performance ($p = 0.54$). Neither were any of the other associations between potential confounds and outcome variables statistically significant (p-values > 0.05). Thus, the other models were fitted without the potential confounds to avoid over-parameterisation.

Mixed analysis of variances

In the model for anxiety, Shapiro–Wilks test and Levene's test were both non-significant, indicating that the assumptions of normality and homogeneity of variance had been met. However, Mauchly's test was significant ($p = 0.046$), indicating that the assumption of sphericity had been violated. As such, the degrees of freedom and p-values for the within-subject measures were corrected using the Greenhouse–Geisser method.

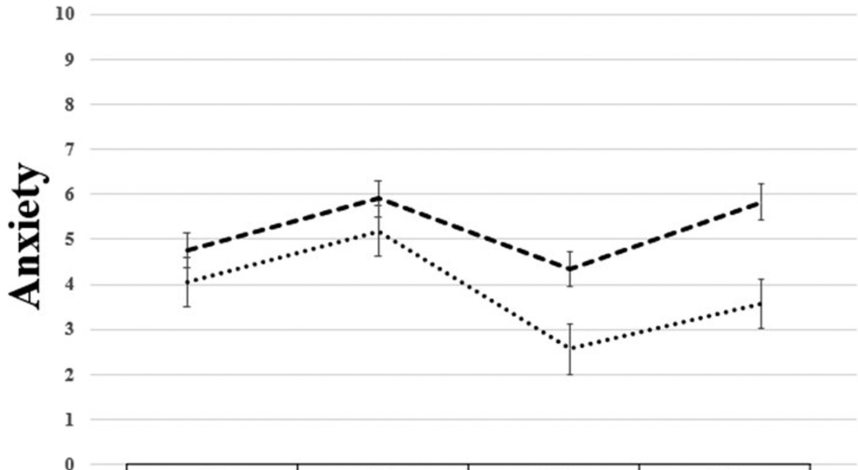
The results indicated significant moderate effects of both condition ($\eta^2_G = 0.2$, $p < 0.0001$) and time ($\eta^2_G = 0.23$, $p < 0.0001$). The interaction term was also significant with a small effect size ($\eta^2_G = 0.06$, $p = 0.019$), indicating that the effect of condition differed at different points in time. *Post-hoc* contrasts were tested using Tukey's procedure. The contrasts for time indicated a significant increase in anxiety from T1 ($M = 4.4$) to T2 ($M = 5.54$) ($p = 0.0007$), confirming that the manipulation (i.e. the completion of difficult tasks) had the intended effect. There was also a significant reduction in anxiety for both groups at T3 ($M = 3.45$) ($p < 0.0001$), confirming the general assumption that the 10-minute break would effectively reduce anxiety.

The interaction plot is shown in Figure 1, which reports the estimated means (including a 95% confidence interval) for both groups at each time point alongside the p-value of the difference test. As shown, there were no significant between-group differences at T1 or T2. At T3, perceived anxiety was significantly lower in the treatment group ($M = 2.56$) than the control group ($M = 4.34$) ($p = 0.01$). Similarly, anxiety was also significantly lower in the treatment group ($M = 3.56$) than the control group ($M = 5.83$) ($p = 0.0005$) at T4. As such, it was concluded that the regeneration pods were more effective at reducing anxiety than the meeting room, in support of *H1*.

Table 2. Summary of the baseline-adjusted ANCOVA models for proofreading performance, arithmetic performance and perceived task-load

	Model summary statistics			Adjusted means (95% CI)	
	F	η^2_p	p	Control	Treatment
Effect of condition *(Proofreading task)*	2.00	0.06	0.17	6.97 (5.5 – 8.43)	8.41 (6.95 – 9.87)
Effect of condition *(Arithmetic task)*	9.07	0.24	0.005	15.71 (13.74 – 17.68)	19.85 (17.88 – 21.82)
Effect of condition (*Perceived task-load)*	6.99	0.21	0.01	30.36 (28.46 – 32.27)	26.67 (24.69 – 28.64)

Notes: Effect size descriptors: *Small* ($0.01 < \eta^2_p < 0.06$), *Medium* ($0.06 < \eta^2_p < 0.14$), *Large* ($0.14 < \eta^2_p$)



	T1		T2		T3		T4	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Control - - - - - -	4.75 (4.04 – 5.45)	1.49	5.9 (5.2 – 6.61)	0.97	4.34 (3.64 – 5.05)	1.37	5.83 (5.13 – 6.54)	0.84
Treatment	4.05 (3.34 – 4.75)	2.02	5.19 (4.48 – 5.89)	1.73	2.56 (1.86 – 3.27)	1.45	3.56 (2.85 – 4.26)	1.08
p-value of contrast	0.86		0.84		0.01		0.0005	

Figure 1. The condition by time interaction for perceived anxiety, including the mean (plus 95% confidence interval) and standard deviation within each cell of the experimental design, as well as the *p*-value of the contrasts at each time point

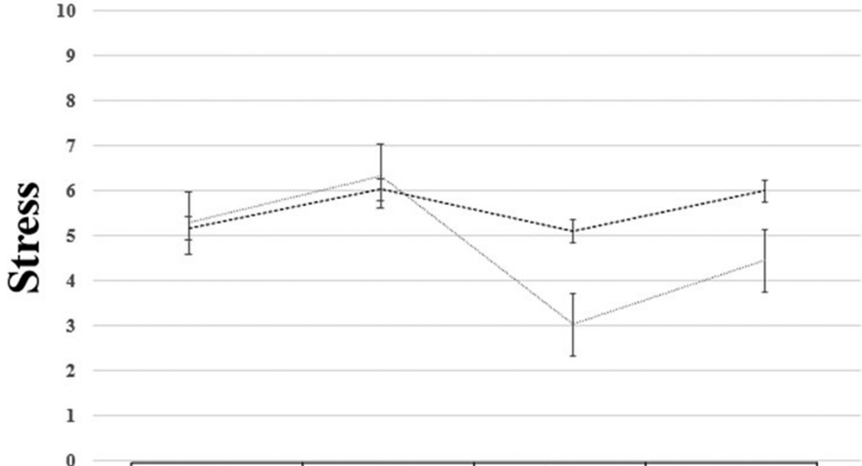
In the model for stress, Shapiro–Wilks test detected a violation of normality (p = 0.003). However, visual inspection of the Q-Q plot revealed an approximate normal distribution and sample size was equal across groups, so it was determined that the ANOVA would be robust to a small departure from normality. Levene's test and Mauchly's test were both non-significant, indicating that assumptions of homogeneity of variance and sphericity had been met.

The results indicated a non-significant main effect of condition ($\eta^2_G = 0.03$, $p = 0.24$). However, both the main effect of time ($\eta^2_G = 0.11$, $p < 0.0001$) and the condition by time interaction ($\eta^2_G = 0.06$, $p = 0.0002$) were statistically significant. Again, Tukey's test was computed to investigate the nature of the significant differences. For the main effect of time, perceived stress for all participants increased from T1 (M = 5.23) to T2 (M = 6.17) (p = 0.016), again confirming that the manipulation was successful. There was also a significant decrease in stress at T3 (M = 4.06) ($p < 0.0001$), again confirming the general assumption that a 10-minute break would effectively reduce stress.

The contrasts for the interaction, shown in Figure 2, were not significant at any of the four time points, although the between-group differences were larger and in the expected direction at both T3 (M = 5.09 for control vs M = 3.02 for treatment, p = 0.15) and T4 (M = 5.99 for control vs M = 4.44, p = 0.48). However, because these differences were not statistically significant, it could not be concluded that the regeneration pods were more effective at alleviating stress than the meeting room. Therefore, *H2* was not supported.

Baseline-adjusted analyses of co-variances

The baseline-adjusted ANCOVA models for *proofreading performance, arithmetic performance*, and *perceived task-load* all met the assumptions of normality, homogeneity of variance and homogeneity of regression slopes.



	T1		T2		T3		T4	
	M	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Control - - - - - -	5.17 (4.08 – 6.27)	1.71	6.02 (4.93 – 7.11)	1.65	5.09 (4 – 6.18)	1.99	5.99 (4.9 – 7.09)	1.62
Treatment	5.28 (4.19 – 6.37)	2.84	6.33 (5.24 – 7.42)	2.45	3.02 (1.93 – 4.12)	2.51	4.44 (3.35 – 5.53)	2.29
***p*-value of contrast**	1		1		0.15		0.48	

Figure 2.
The condition by time interaction for perceived anxiety, including the mean (plus 95% confidence interval) and standard deviation within each cell of the experimental design, as well as the p-value of the contrasts at each time point

The model for proofreading performance indicated that although the effect sizes were moderate, neither the effect of condition (η^2_p = 0.06, p = 0.17) nor baseline proofreading performance (η^2_p = 0.08, p = 0.13) was statistically significant. Although the estimated means indicated slightly higher post-break proofreading performance in the treatment group (M = 8.41) than the control group (M = 6.97), it could not be concluded that this difference was not because of chance. Therefore, *H3* was not supported.

In the model for arithmetic performance, there were strong effects of both condition (η^2_p = 0.24, p = 0.005) and baseline arithmetic performance (η^2_p = 0.51, $p < 0.0001$), but the effect of gender was not statistically significant (η^2_p = 0.03, p = 0.34). The analysis was repeated without the covariate, leading to slight increases in the effect sizes for condition (η^2_p = 0.26, p = 0.003) and baseline arithmetic performance (η^2_p = 0.57, $p < 0.0001$). The adjusted means for condition from the original model showed that the treatment group (M = 19.85) significantly outperformed the control group (M = 15.71) on the post-break arithmetic task. Therefore, *H4* was supported.

Finally, the model for perceived task-load also showed strong effects of both condition (η^2_p = 0.21, p = 0.01) and baseline perceived task-load (η^2_p = 0.46, $p < 0.0001$), and a non-significant effect of gender (η^2_p = 0.004, p = 0.74). Again, the analysis was repeated without the covariate and the effect sizes of condition (η^2_p = 0.23, p = 0.007) and baseline perceived task-load (η^2_p = 0.46, $p < 0.0001$) increased by a small amount. The adjusted means for condition from the original model showed that the treatment group (M = 26.67) reported significantly lower perceived task-load on the second round of tests than the control group (M = 30.36), providing support for *H5*.

Discussion

The purpose of this study was to investigate whether a 10-minute micro-break in a "regeneration pod" had greater benefits than a micro-break in an enclosed meeting room. Overall, the results provided support for three out of five hypotheses, and where between-group contrasts were non-significant the differences were in the expected direction.

In line with assumptions, the micro-break had stress- and anxiety-reducing effects for all participants, supporting previous suggestions that they are an effective way of managing stress throughout the working day (Sonnentag *et al.*, 2012; Wendsche *et al.*, 2016). However, these benefits were enhanced for those participants who took their break in the regeneration pods rather than the meeting rooms. These participants reported comparatively lower levels of anxiety, both immediately post-break and during a second round of challenging tasks. They also performed better on an arithmetic task, and reported that the tasks were less demanding. Overall, the results are in line with the wider literature on biophilic design, as well as recent studies which also demonstrated that "green" micro-breaks have unique benefits compared with micro-breaks in non-biophilic spaces (Jiang *et al.*, 2019; Lee *et al.*, 2015, 2018).

The findings can be interpreted with reference to ART (Kaplan, 1995). The completion of the challenging tasks (including the impossible tracing task) was attentionally demanding and led to increases in stress and anxiety. Attentional restoration appeared to occur more quickly amongst those who took their break in the regeneration pod rather than in the meeting room, as evidenced by comparatively higher post-break arithmetic performance and lower perceived task-load. Although the effect of stress was not statistically significant, the trend of lower perceived stress in the regeneration pods group suggests that these participants may also have experienced comparatively greater improvements in stress, in line with SRT (Ulrich *et al.*, 1991).

Uniquely, our results demonstrate that office spaces do not necessarily need to incorporate "nature in the space" biophilic design strategies (e.g. interior plants or direct views of nature) in order to be restorative. The regeneration pods looked out over a completely urban environment, with no plants in the user's direct line of vision. However, the construction used natural wooden materials, intentionally mimicked the refuge and complexity of nature, and allowed users to initiate an acoustic natural soundscape evoking the calming sounds of nature. Together, these features combined to form a restorative environment engendering similar benefits to those reported in spaces involving direct nature exposure. The finding that indirect nature evocation is also beneficial provides more flexibility for workplace designers seeking to use biophilic design strategies within offices. For example, in spaces where lush interior planting is deemed inappropriate, at least some of the benefits of biophilic design may still be derived through the use of wooden furnishings which mimic the spatial complexity of nature and/or acoustic soundscapes which enhance the immersive biophilic experience.

The results are especially relevant for the emerging practice of "activity-based" working, in which specific workspaces are designed for specific types of activity. Different workspaces within such offices are typically purely functional (e.g. spaces for collaborative work, spaces for focussed individual work); however, our results highlight that designing purpose-built spaces for restoration would also be a worthwhile investment. The effectiveness of the design can be enhanced through the biophilic strategies, providing opportunities for users to immerse themselves in "softly fascinating" environments while detaching themselves from work. In this way, organisations can empower their employees to proactively manage their stress throughout the working day.

The opportunity to conduct research on previously under-considered biophilic design strategies in a real office environment was certainly welcome and ensured that the findings have high external validity, owing to the fact that real members of the target population (i.e. working adults) were studied directly in the context of interest (a real office environment). However, the opportunistic field design also introduced largely unavoidable limitations which may have affected the internal validity of the findings.

Most notably, it was not possible to perfectly match possible confounds in the treatment and control conditions. Ideally, the exact same room would have been used for the treatment and the control conditions, with the only difference being the presence or absence of the regeneration pods, so that the physical features of the room (e.g. access to daylight, room height and size, room colours) were controlled across conditions. However, owing to the size of the pods and the complexity and cost associated with moving them, this was not possible. This also meant that treatment group participants had to walk a short distance before taking their break whereas control group participants remained still, which could also be a possible confound which affects the results. Therefore, it is not possible to fully conclude that the observed benefits were necessarily a result of the regeneration pods themselves.

On a similar note, even if the benefits could be attributed to the regeneration pods, the design of the study meant it was not possible to understand exactly which particular aspects of biophilic design (i.e. the wooden furnishings, the nature-mimicking design, the acoustic soundscape or some combination of the three) contributed most strongly to psychological restoration. Again, this was unavoidable because of practical constraints in separately partitioning and testing different combinations of these factors. However, in future it will be valuable to complement field studies with laboratory studies in which it easier to individually add or remove the environmental factors of interest. The recent study by Yin *et al.* (2019) demonstrates how this might be achievable through the use of virtual reality techniques. Possibly, research conducted using virtual reality could provide the initial validation for design techniques which are subsequently implemented and further tested in real workplaces.

A third limitation of the present study is that the potential sample was restricted to the regular users of the office. Amongst these, only a relatively small number volunteered to participate in the study, and so our analyses may have been underpowered to detect all significant differences between the groups. Indeed, this seems to be the most likely explanation as to why the between-group differences for perceived stress and proofreading task performance did not meet criteria for statistical significance. As such, it would be useful to repeat similar studies with larger samples in future.

Finally, and more generally, future research would also benefit from complementing subjective measures of stress with objective physiological measures, such as salivary cortisol, electrodermal activity and/or neurological activity. Indeed, in the present study there was an attempt to meet this need by asking participants to wear biometric sensors which continuously measured electrodermal activity, but unfortunately these data could not be used in the analysis because of missingness when the data were retrieved. By combining objective and subjective measures of the dependent variables, researchers will benefit from a more comprehensive understanding of exactly how individuals respond to different types of environment.

Conclusions

Employees who took a 10-minute break in a purpose-built biophilic “regeneration pod” reported post-break improvements in perceived anxiety, arithmetic performance and perceived task-load, relative to those who took a 10-minute break in an ordinary meeting room. The regeneration pods featured neither the integration of plants nor direct views of nature, but rather created a biophilic environment through the use of natural materials in a design which mimicked the spatial complexity of nature, coupled with an acoustic natural soundscape. The findings highlight the flexibility in the types of methods designers might use when crafting biophilic spaces within offices and demonstrate that these spaces could be highly valuable in enabling employees to proactively manage their stress levels throughout the working day.

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Appendix

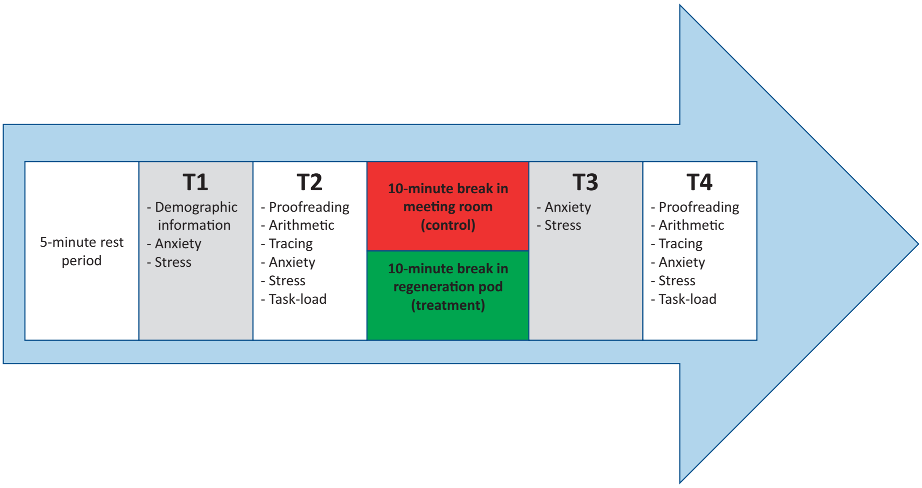

Figure A1. Order of the experimental procedure

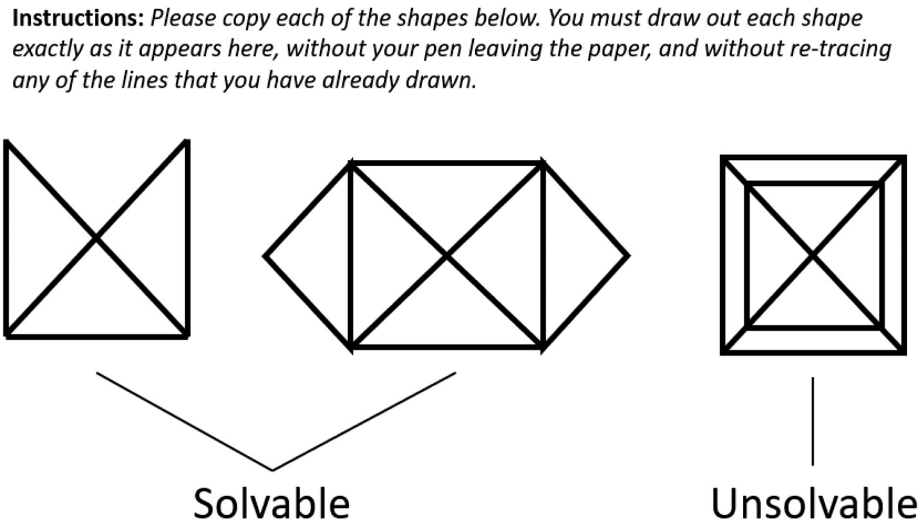

Figure A2.
Impossible tracing task presented to participants during the first round of tasks

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Salutogenic workplace design

A conceptual framework for supporting sense of coherence through environmental resources

Supporting sense of coherence

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Abstract

Purpose – The purpose of this paper is to identify and discuss opportunities for health promotion through the workplace environment, adopting a "salutogenic" perspective of health which more explicitly focuses on factors that support human health and well-being, as opposed to factors which cause disease.

Design/methodology/approach – In the introduction, the salutogenic model of health and the Environmental Demands-Resources model are discussed, providing a conceptual framework to represent the workplace environment as a composite of pathogenic "demands" and salutogenic "resources". Subsequently, a narrative review is performed to discuss the existing literature from the perspective of this novel framework, identifying environmental resources which might strengthen the three components of an employee's "sense of coherence" (comprehensibility, manageability and meaningfulness), an individual orientation associated with more positive health outcomes.

Findings – Comprehensibility can be supported by effectively implementing a clear set of rules governing the use of the workplace. Manageability can be supported through biophilic design solutions, and through design which supports social cohesion and physical activity. Meaningfulness can be supported by recognising the importance of personal identity expression and through design which reinforces the employees' sense of purpose.

Originality/value – The salutogenic perspective is a potentially valuable but relatively under-considered paradigm in workplace practice. The key contribution of this paper is to encourage researchers and practitioners to recognise the crucial role that an individual's sense of coherence plays in supporting higher levels of physical and mental health, so that they increase their ability to provide truly "healthy" workplaces, capable of promoting health as well as minimising the risk of disease.

Keywords Health promotion, Salutogenesis, Environmental demands, Environmental resources, Salutogenic design, Workplace environment

Paper type Conceptual paper

The emerging healthy workplaces movement is primarily concerned with the *pathogenic* (harm-causing) potential of the office environment. The quality of the indoor workplace environment may contain numerous contributors towards ill health (Al Horr *et al.*, 2016, for review), partly as a result of the cost reduction paradigm which pervades workplace practice, in which space efficiency is prioritised above occupant requirements (Haynes, 2007a). As such, recent certification schemes for optimising heath and well-being in the built environment (e.g. the WELL Building Standard; International WELL Building Institute, 2018) largely focus on improving indoor environmental quality through strategies such as the minimisation of airborne pollutants and by reducing various sources of environmental discomfort.

In this paper, we will argue that the mitigation of pathogenic environmental components is a necessary but not sufficient step towards the goal of providing truly healthy workplaces. We suggest that it is equally important to consider *salutogenic* (health-

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promoting) aspects of the workplace environment, to more suitably answer calls for more enabling paradigms in workplace practice (Haynes, 2007a). The distinction between harm-causing and health-promoting factors echoes the World Health Organisation's (1948) definition of health as a "state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity", and also has parallels with the distinction between "languishing" (the presence of mental illness) and "flourishing" (the presence of positive emotions) in the positive psychology movement (Keyes, 2002).

In recognition of the fact that the majority of workplace research has tended to be largely atheoretical and segmented by discipline (Sander *et al.*, 2018), we believe future research and practice should be more explicitly designed in accordance with relevant conceptual frameworks. Accordingly, in this paper, we explicate two conceptual frameworks to support understanding of the salutogenic potential of the workplace environment. First, we discuss the salutogenic model of health (Antonovsky, 1987), which has received good empirical support in healthcare disciplines. Second, we present the Environmental Demands-Resources (ED-R) model as a way of illustrating the pathogenic and salutogenic aspects of the workplace environment, and how they can be determined through the dynamic employee–workplace relationship.

Salutogenic approach to health care

According to the salutogenic model, the state of health is a continual process in which the individual is placed somewhere on the "*dis-ease* versus *health-ease*" continuum. Movement along the continuum occurs as a result of competing forces. Ubiquitous and unavoidable everyday stressors and hardships (termed *generalised resistance deficits)* contain the pathogenic potential to drive us towards ill health and disease. However, we are also able to draw upon resources at the individual or group level which enable us to effectively cope with or avoid these hardships (termed *generalised resistance resources*), preventing tension from being transformed into stress and thus containing the salutogenic potential to promote more positive health outcomes (Antonovsky, 1987).

To account for why some people are able to remain healthy even in the face of extreme hardships and major stressors, Antonovsky (1987) identified the "sense of coherence" (SOC) as the major individual difference factor which determines the extent to which resistance resources are effectively deployed in response to resistance deficits. The SOC is a global orientation reflecting the individual's perceptions regarding the extent to which the events occurring around them are structured, predictable, and explicable (*comprehensibility*); the extent to which the individual perceives sufficient resources to meet the challenges posed by these demands (*manageability*); and the extent to which the events are perceived as challenges worthy of investment and engagement (*meaningfulness*). These concepts are illustrated in Figure 1.

There is good evidence in the research literature to suggest that a stronger SOC (i.e. the perception that events are comprehensible, manageable and meaningful) is associated with greater resilience to stressors, more positive health behaviours, and better overall health across the lifespan (Braun-Lewensohn *et al.*, 2015; Koelen *et al.*, 2015; Idan *et al.*, 2015), meaning that individuals with a strong SOC have a lower all-cause mortality risk (Super *et al.*, 2014). From a mental health perspective in particular, individuals with a strong SOC tend to exhibit lower levels of depression, anxiety, and hopelessness, and higher levels of optimism, resilience and overall quality of life (Eriksson and Lindström, 2006, 2007).

Within the context of the built environment, researchers working within healthcare architecture have explicitly adopted the salutogenic paradigm and considered architectural strategies for strengthening patients' SOC (Golembiewski, 2010). However, salutogenesis has received relatively limited attention in the workplace literature, and existing discussions (Dilani, 2009; Ruohomäki, *et al.*, 2015) have adopted a more general approach and have not specifically considered how different workplace interventions might affect an individual's SOC. As such, the main aim of this paper is to address this gap in the knowledge base by identifying opportunities to improve comprehensibility, manageability and meaningfulness through the physical workplace. In the next section, we introduce a workplace-specific conceptual framework to guide this discussion, which illustrates the competing pathogenic and salutogenic aspects of the workplace environment.

The Environmental Demands-Resources model

The Environmental Demands-Resources (ED-R) model (Figure 2) is a domain-specific extension of the Job Demands-Resources model from the organisational psychology

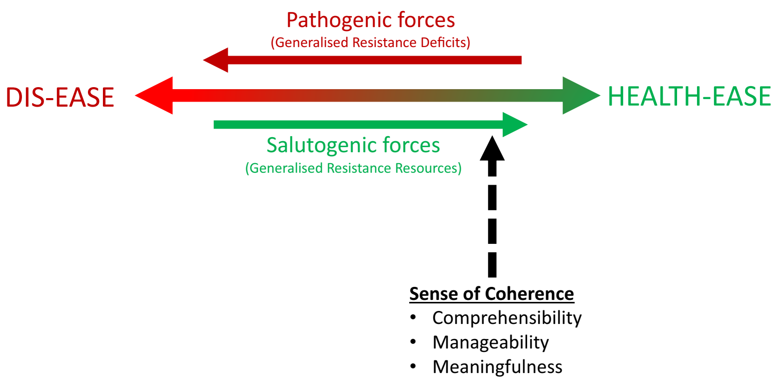

Figure 1.
The dis-ease health-ease continuum

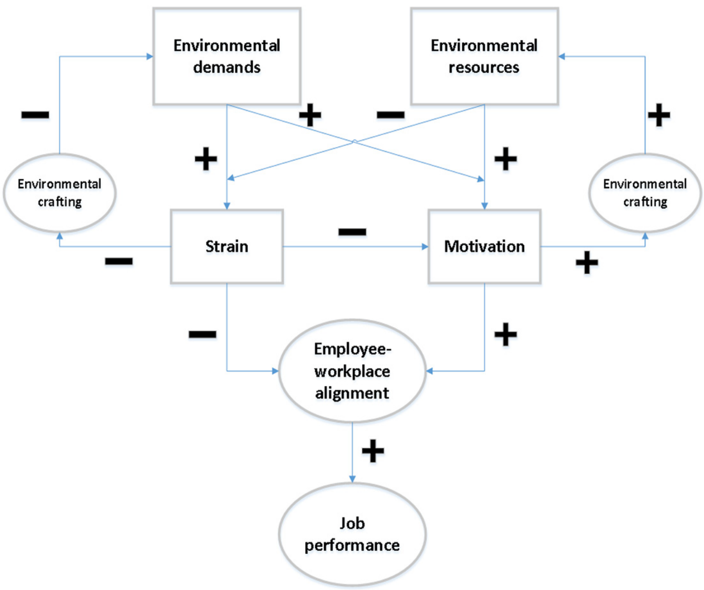

Figure 2.
The Environmental Demands-Resources model

tradition (Bakker and Demerouti, 2007a, 2007b). A key advantage of this framework in the present context is that it draws the same distinction as is made in salutogenic theory, between pathogenic ("demands") and salutogenic ("resources") forces which affect health.

Additionally, we present the ED-R framework separately here to address two major limitations in the workplace environment literature. First, whilst the majority of workplace environment research is atheoretical and limited to specific components of the environment (Sander *et al.*, 2018), the ED-R model is capable of conceptually representing the workplace environment in its entirety. Although some models representing the entire workplace environment do exist (Haynes, 2007b; Vischer, 2008), these are limited in that the authors acknowledge the reciprocal nature of the relationship between employee and workplace but do not illustrate in their models the process by which this reciprocity occurs. As such, the second limitation addressed by the ED-R model is the explicit representation of the dynamic employee–workplace relationship.

Briefly, the ED-R model posits that the workplace environment is a complex psychophysical system encompassing not only the objective physical stimuli within the workplace but also the ways in which these stimuli are subjectively perceived by the individual occupants. These stimuli can be broadly separated into "environmental demands" and "environmental resources", depending on how they affect the employee.

Environmental demands are the pathogenic aspects of the workplace environment, which cause physiological and/or psychological "strain" and impede an individual's progress towards hihe/sher goals. In the face of environmental demands, additional effort must be exerted to achieve the same outcome, leading to lower overall job performance. Environmental demands can be likened to Herzberg's (1966) "hygiene factors", in that their presence causes stress and dissatisfaction but their absence does not necessarily support the highest levels of functioning.

Conversely, environmental resources are the salutogenic components of the workplace environment, which enable the individual to cope with the demands (environmental or otherwise) experienced throughout the working day. The presence of environmental resources improves psychological comfort by supporting fundamental psychological needs (Sander *et al.*, 2018; Vischer, 2008) and has a positive impact on overall job performance by aiding recovery from stress, stimulating engagement and/or improving motivation. These are similar to Herzberg's (1966) motivators, in that the absence of these features does not directly cause stress, but their presence is necessary to support high levels of motivation.

The presence of environmental demands and resources within a workplace is not static, and can be significantly altered by "environmental crafting" behaviours. This term refers to any action performed by the individual with the explicit aim of improving the workplace environment (i.e. by minimising demands and/or increasing resources). Organisational policies regarding location of work (e.g. through policies relating to desk assignment and teleworking) and office protocols (through policies relating to desk personalisation and personal comfort devices) can either facilitate or impede the process of environmental crafting. In this way, the reciprocal nature of the employee-workplace relationship is illustrated, recognising that employees are not simply passive recipients of environmental conditions.

Importantly, it should be noted that specific features are not *inherently* demanding or resourceful but are rather perceived as such at the level of individual, relative to the effect on goal-directed behaviour. Depending on the task being performed and the individual's personal characteristics, the same aspect of the environment might exert a very different effect. This element of inter-individual non-uniformity is represented in the model through the concept of *employee–workplace alignment,* which refers to the extent to which the characteristics of the workplace environment are aligned to the needs of the individual (i.e. the relative presence of environmental demands and environmental resources). This reflects growing recognition amongst workplace researchers regarding the importance of need-supply fit (Gerdenitsch *et al.*, 2018; Haynes, 2008; Vischer, 2008).

Overall, the ED-R model predicts that job performance will be the highest when the workplace environment is free of demands and abundant in resources, relative to the needs of the individual occupant. Thus, effective workplace interventions are those which lead to an overall reduction in demands and/or increase in resources. In this paper, we focus in particular on the role of environmental resources.

Aims and purpose

Drawing upon the two conceptual frameworks presented, the main aim of this paper is to identify opportunities for salutogenesis in the workplace environment. Specifically, we perform a narrative review to identify potential interventions for strengthening employees': comprehensibility; manageability; and meaningfulness, through targeted interventions in the workplace environment. We do not intend to provide an exhaustive list of all the workplace interventions that might affect an individual's SOC, but rather we aim to re-interpret the existing research within the promising yet relatively under-considered salutogenic paradigm, to encourage researchers and practitioners to consider opportunities for improving the workplace beyond just the mitigation of pathogenic aspects of the environment.

Methodology

As a first step, we carried out a search of the literature in Google Scholar using a combination of the keywords: salutogenic design, salutogenic workplace, salutogenic architecture, sense of coherence, comprehensibility, manageability and meaningfulness. The results were then reviewed to identify previous studies which adopted a salutogenic approach to workplace practice. However, only two relevant papers (Dilani, 2009; Ruohomäki *et al.*, 2015) were identified in this manner. Whilst these were valuable from a conceptual perspective, they did not support the primary aim of this paper in relating specific workplace interventions to different components of the individual's SOC.

As such, we performed a subsequent search of the literature in Google Scholar, in which the scope was widened to any studies concerning the effects of the workplace environment on employee well-being and productivity. A variety of keywords were used, including indoor air quality, thermal comfort, luminous environment, natural light, acoustic environment, background speech, noise, office layout, workplace strategy, biophilic design, workplace well-being and productivity. Where suitable articles were identified, the reference list was scanned to identify additional research studies relevant to the topic which may have been missed during the primary search process.

The significantly broader scope meant that more than 500 primary research articles were identified. We reviewed the abstracts for each paper, and passed the papers for further analysis if the content was judged to be in accordance with the themes of salutogenesis, comprehensibility, manageability, and meaningfulness (even if the researchers did not explicitly use these terms). Given that the majority of workplace research has focused solely on pathogenic factors, the majority of papers were excluded at this stage, leaving approximately 75 papers to be analysed in more depth. The papers were divided into the separate themes of comprehensibility, manageability and meaningfulness, and then further sub-divided into different types of interventions within each area.

The narrative review that follows is the result of this endeavour. It was not our intention to provide a systematic analysis of each paper that was identified, but rather to adopt an exploratory approach and creatively re-interpret the existing research from the salutogenic perspective, to provide a state-of-the-art summary of the role of salutogenic resources in the workplace environment.

Results

Comprehensibility

Comprehensibility concerns the individual's ability to understand and make sense of external events. In a highly comprehensible office, the stimuli within the workplace environment are ordered, predictable and explicable.

Workplaces lose their sense of comprehensibility when there is a mismatch between the employee's expectations for the workplace and the way in which the workplace is actually used. When aspects of the workplace environment are difficult to predict or control, they become even more demanding. For example, background speech is a common concern in open-plan offices and has been found to be especially disruptive if it is unpredictable or judged to be inappropriate for the context (Emberson *et al.*, 2010; Glass and Singer, 1972; Graeven, 1975). The inability to control such events leads to a motivational deficit termed "learned helplessness", where the employee simply succumbs to the demands of the environment and stops trying to craft effective responses, resulting in depressive symptoms and low productivity (Evans and Stecker, 2004).

Possibly, the development of clear and explicit workplace rules could mitigate such issues. This would provide employees with unambiguous information about the types of environmental stimuli which can be reasonably expected at their workstation, allowing them to develop appropriate crafting strategies if the conditions are judged to be unsuitable. Indeed, recent case studies exploring the transition to "activity-based" workplaces, where employees are not given assigned desks but are instead encouraged to move flexibly between different functional zones within the workplace to complete different types of activities (Wohlers and Hertel, 2017), have highlighted the rule-development process as a key determinant of the eventual workplace effectiveness.

Certain steps need to be taken to ensure these rules are effectively implemented, as employees often resist new workplace concepts (Appel-Meulenbroek *et al.*, 2011; Babapour *et al.*, 2018; Rolfö *et al.*, 2017). It has been demonstrated that employees derive the greatest benefits from their workplace when they perceive a high level of "fit" with their own working style (Gerdenitsch *et al.*, 2018). As such, to reduce the risk of resistance it is crucial to actively involve the workplace users in the development of rules governing the use of the workplace. Indeed, in one case study it was demonstrated that non-compliance with rules occurred as a result of their ambiguity, but subsequently involving users in the design process and making the co-created rules more explicit resulted in increased acceptance of the new working style and higher compliance with the rules, and lower levels of demands experienced in the new workplace (Babapour and Rolfö, 2018; Rolfö, 2018).

Finally, it is also crucial to recognise the role of "place attachment" during any change management procedures. Employees automatically form emotional bonds with the physical workplace as a result of the routinised interactions that occur there (Inalhan and Finch, 2004), and the workplace can even come to form part of the employee's personal identity (Inalhan, 2009). During workplace re-location or renovation, disruption to place attachment can occur, prompting the loss of psychological comfort and increasing the likelihood of resistance to change. To mitigate this disruption, Inalhan (2009) also highlighted the crucial importance of occupant engagement prior to and during the move. If the intervention involves a change to working style (e.g. from fixed-location to location-independent), it can also be useful for change managers to explicitly help employees to forge new working identities which are more aligned to the new style (Skogland, 2017).

Manageability. Manageability concerns the extent to which individuals perceive sufficient resources to deal with demands. When the office is highly manageable, the employee has developed the personal competencies and/or crafting strategies to effectively cope with the various demands (environmental and non-environmental) that they experience at work. Concerning psychosocial factors, there is good evidence to suggest that the deployment of job resources effectively buffers the impact of job demands on strain (Bakker and Demerouti, 2007a, 2007b). While this pathway has not been explicitly explored from the perspective of the ED-R model, past research has yielded several examples in which environmental resources can act in a similar manner.

First, there is significant evidence to suggest that "biophilic design" solutions (e.g. the direct physical presence of nature in the workplace, the indirect evocation of nature through biomorphic forms and patterns, or design which mimics the spatial configurations found in nature; Ryan *et al.*, 2014) enable employees to more effectively cope with workplace stressors. For example, demonstrated benefits of biophilic design have included fewer reported health ailments, higher satisfaction with the workplace environment, improved attentiveness, improved information management and processing, greater attention capacity, higher self-rated productivity and reduced stress (Lohr *et al.*, 1996; Kaplan, 1993; Nieuwenhuis *et al.*, 2014; Raanaas *et al.*, 2011; Smith and Pitt, 2009).

To account for such findings, it has been suggested that the benefits of nature arise due to the inherent stress-reduction properties of natural features (Ulrich *et al.*, 1991), and that the "softly fascinating" properties of nature engender micro-restorative experiences which enable the depleted cognitive resource for directed attention to recover (Kaplan, 1993, 1995). The benefits of nature also extend to non-stressed and non-depleted individuals, termed an "instorative" effect (Beute and de Kort, 2014). Thus, there is good evidence to conclude that biophilic design functions as a salutogenic resource, enabling the individual to more effectively cope with and recover from stressors in the workplace environment.

A second way in which the workplace environment can enhance employee's resources for coping with demands is through design strategies which promote social cohesion. Social support helps employees to effectively mitigate workplace stress (Viswesvaran *et al.*, 1999), and workplaces with strong perceived social support are associated with higher job satisfaction, higher morale, lower absenteeism, and reduced turnover intentions (Lowe *et al.*, 2003). As such, social support has been identified as a key resource which can be supported (or restricted) through the workplace environment (Morrison and Macky, 2017).

Architectural configurations which promote proximity (e.g. removal of interior walls, removal of partitions between workstations) tend to facilitate higher levels of work-related and social interactions (Appel-Meulenbroek, 2014). However, this may come at a cost, as higher-density workplaces are also associated with increased distractions, increased physical discomfort, increased perceptions of crowding, and lower overall environmental dissatisfaction, (Aries *et al.*, 2010; Duval *et al.*, 2002; May *et al.*, 2005). Indeed, this "privacy-communication trade-off" has been highlighted as a key issue in modern open-plan offices (Kim and de Dear, 2013).

Again, the solution to the problem might be found through the activity-based working office concept. Rather than trying to balance requirements for communication and privacy at a single workspace, employees in activity-based workplaces are able to craft the environment that is appropriate for their needs at the time (i.e. by choosing to work in a collaborative area or a private area). Support for social cohesion can be further enhanced through the provision of spaces which are purposefully designed for social activity (e.g. shared lunch areas, games rooms) and organisational policies which encourage employees to take breaks from their desks and use these spaces.

Finally, it would also be useful to consider strategies for promoting physical activity through the workplace environment, given that physical fitness can act as a mechanistic buffer which helps individuals to deal more effectively with stress (Rook *et al.*, 2018). The requirement for desk-based work tends to increase sedentary behaviour, in turn increasing the likelihood of musculoskeletal symptoms and heightening the risk of health issues such as Type 2 diabetes, cardiovascular illness and certain forms of cancer (Karakolis and Callaghan, 2014; Owen *et al.*, 2008). In this way, poor ergonomic support contributes to poor health both by increasing physical strain and by restricting one of the ways in which individuals can effectively buffer this strain.

To combat this, organisations could consider the use of fixed-height seated and standing desks, desktop height-adjustment stands or desks which are able to be adjusted between seated and standing positions. Indeed, it has been showed that such interventions can be effective in reducing sedentary behaviour, physical discomfort and musculoskeletal pain symptoms (Karakolis and Callaghan, 2014; Makkonen *et al.*, 2017; Straker *et al.*, 2013). Additionally, it may also be beneficial to use behavioural prompts within the workplace environment (e.g. posters, information leaflets) to encourage physical activity, although the evidence base for the effectiveness of such interventions to date is mixed (Malik *et al.*, 2014). Possibly, such interventions could be made more effective if delivered using the principles of well-supported models of health behaviour change (e.g. the Transtheoretical Model of Behaviour Change; Prochaska and Velicer, 1997).

Meaningfulness. Meaningfulness concerns the extent to which experienced demands are perceived as challenges worthy of investment and engagement. Antonovsky (1987) considered meaningfulness to be the strongest and most important aspect of SOC, and recent evidence confirms the notion that it plays a crucial role in fostering employee health and happiness. Higher work meaningfulness is associated with higher job satisfaction and overall well-being, reduced absenteeism, more intrinsic work motivation and a stronger sense of overall life meaningfulness (Arnold *et al.*, 2007; Dik and Steger, 2008; Duffy and Sedlacek, 2007; Kamdrom, 2005; Wrzesniewski *et al.*, 1997). It has been suggested that interventions to improve work meaningfulness should focus on ensuring work activities are congruent with the individual's values, and/or linking mundane work activities to distal outcomes that are personally meaningful (Dik *et al.*, 2013).

One way to promote this through the workplace environment is to support personal identity expression. In offices where it is permitted, up to 90 per cent of employees decorate their workspace with items and/or photographs with rich personal significance, particularly those which reflect personal relationships with family and friends (Wells and Thelen, 2002). This personalisation behaviour is a strong contributor of workplace well-being, particularly for women (Wells, 2000). Interview data have confirmed that the behaviour is at least partially motivated by the desire to give a sense of meaning to the workplace (Brunia and Hartjes-Gosselink, 2009). In this way, personalisation should be viewed as a form of environmental crafting in which employees surround themselves with visual cues serving as reminders of the personal meaningfulness of their (possibly mundane) work, with important implications for well-being.

Whilst activity-based working has been presented as a solution which might help to support the needs for comprehensibility and manageability, there is a risk that its implementation might inadvertently have a negative impact on meaningfulness, because personalisation is typically prohibited in these offices (to prevent employees from reserving workspaces which they are not using). Indeed, it has been demonstrated that employees in activity-based offices often rebel against such policies and persist with personalisation and other forms of territorial behaviour (Skogland, 2017), highlighting its central role in promoting well-being at work. It may be especially important for those employees who are more location-dependent and unable to experience the benefits of switching between different workspaces (Hoendervanger *et al.*, 2016). As such, organisations making the transition to activity-based working should consider whether the proposed benefits outweigh the potential harm associated with restricting personalisation and should also consider whether personal identity expression can be supported in any other ways.

Second, employers could also support meaningfulness through aspects of workplace design which remind employees of their sense of purpose within an organisation. The importance of creating a purpose-driven organisational culture is being increasingly recognised (Dik *et al.*, 2013), and while there are presently limited studies investigating the relationship between corporate branding strategy and employee well-being, it is certainly feasible that this could be a worthwhile area for practitioners to consider. Khanna *et al.* (2013) created a framework for aligning corporate branding and real estate strategies, involving the development of brand values, the clear identification of internal and external stakeholders, and the creation of an action plan to communicate these values to the stakeholders through corporate real estate strategies. Possibly, explicit integration of organisational purpose into this strategy could help organisations to foster meaningfulness through corporate branding.

Discussion

In this narrative review, we responded to the call for a more enabling workplace paradigm (Haynes, 2007a) by elucidating a salutogenic approach to the workplace environment. First, we distinguished between the (pathogenic) demands which cause disease and the (salutogenic) resources which promote health, and provided evidence to show that the effectiveness of resource deployment is determined by the individual's SOC (Antonovsky, 1987). Next, we presented the ED-R model as a representation of the same distinction specifically within the context of the workplace environment, including an illustration of the dynamic relationship between the workplace environment and the employee.

Finally, we performed a narrative review in which we creatively re-interpreted the existing evidence base from salutogenic theory, focusing specifically on environmental resources which could strength the three components of the individual's SOC: comprehensibility, manageability, and meaningfulness. Although previous theorists have discussed a salutogenic approach to the workplace (Dilani, 2009; Ruohomäki *et al.*, 2015), this is the first attempt to specifically relate workplace interventions to the SOC. The non-exhaustive list of identified interventions is shown in Figure 3.

From a theoretical perspective, it will be necessary in future research to empirically test the conceptual frameworks used in our discussion. To our knowledge, the salutogenic approach has not been explicitly adopted in any previous workplace intervention studies, and so the various predictions that were made during the view remain to be empirically verified in future research. That is, it would be beneficial for researchers to explore whether specific interventions do help to strengthen comprehensibility, manageability and/or meaningfulness, as expected, and confirm that this in turn leads to more positive health outcomes. Similarly, the prediction that increasing environmental resources will lead to improved job performance also remains to be empirically verified. Research in this area would help to determine the effectiveness of the ED-R model as a tool to guide workplace practice.

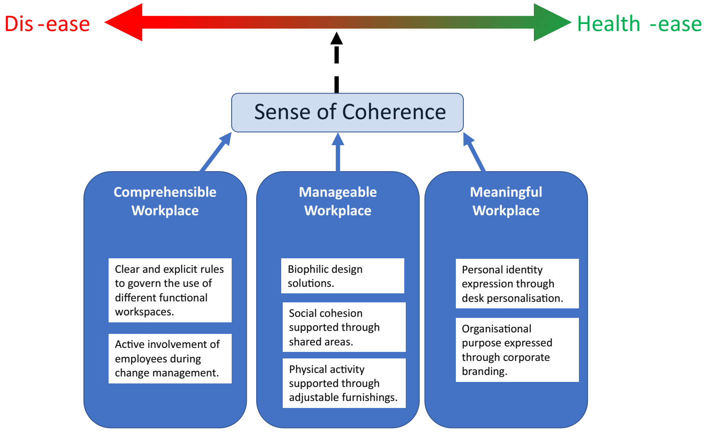

Figure 3.
A non-exhaustive list of workplace interventions to support sense of coherence

Additional research is also needed to support evidence-based practice in workplace optimisation. In particular, we believe further research is needed to guide the effective implementation of activity-based working, given its increasing popularity and potential for mitigating several of the environmental demands which tend to arise in traditional open-plan offices. Of crucial importance is how best to manage the trade-off between flexibility and territoriality in the workspace, given that the provision of increased flexibility is typically accompanied by restrictions on personalisation. If no benefit is perceived to activity-based working, employees often persist with discouraged territorial behaviours (Skogland, 2017). As such, it would be useful for researchers to consider strategies for supporting identity expression in non-territorial offices. For example, studies might test the use of digital photo frames so that personal photographs could be easily set up at each new workstation, and/or the personalisation of group areas rather than individual workspaces.

It would also be useful to give further consideration to the types of functional spaces that should be included in activity-based offices, and the relative proportion of the overall office that should be devoted to each. In addition to the common functional distinction between spaces for "communication" or "concentration", an emerging trend is for offices to also include "restorative" spaces for employees to recover from stress (Morgan Lovell, 2019). In future research, it will be useful to explore how these environments should best be designed and managed, and how effective they are in promoting recovery from work stress. In particular, the demonstrated restorative and instorative benefits of nature (Beute and de Kort, 2014; Kaplan, 1995; Ulrich *et al.*, 1991) lead to the suggestion that biophilic design principles should be applied in such areas. For example, a recent study demonstrated that a workplace "micro-break" was more effective in aiding recovery from work strain when employees had views of nature rather than urban views (Lee *et al.*, 2018).

The results of these research efforts will have important implications for workplace practice and provide a conceptual framework to guide effective workplace interventions. In particular, we believe the ED-R model serves as a useful guide for understanding the overall workplace environment as a composite of pathogenic demands and salutogenic resources, and understanding employees' behaviours as being motivated by the reduction of demands and/or the increase in resources. By viewing the workplace environment in this manner, two overarching possibilities for workplace improvements become apparent. First, physical alterations can be made to the workplace aimed at reducing the presence of demands (e.g.

increasing ventilation rate to improve air quality) and increasing the presence of resources (e.g. bringing plants into the indoor environment). Second, changes can be made to the ways in which the physical workplace is able to be used, to give employees the autonomy to craft a suitable environment on an ongoing basis (e.g. through the selection of different workspaces in activity-based offices).

Conclusion

In conclusion, we have argued that the minimisation of pathogenic aspects of the workplace environment is a necessary step in office improvements, but not sufficient to fully optimise the workplace. Equal consideration must be given to opportunities for promoting salutogenic resources in the workplace environment, as these can strengthen the individual's SOC and help them to respond to stressors in a more positive and adaptive way, with beneficial health and well-being outcomes in the long term. The truly healthy office should not only be free of factors which cause disease, but should also be ordered and consistent (*comprehensible*), rich enough in resources to enable the employees to effectively deal with stressors (*manageable*), and a place where employees are able to recognise their sense of personal and/or organisational purpose (*meaningful*).

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Environmental demands and resources: a framework for understanding the physical environment for work

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Abstract

Purpose – The purpose of this paper is to explore the extent to which Job Demands-Resources (JD-R) theory (Demerouti *et al.*, 2001; Bakker and Demerouti, 2017) is an appropriate conceptual framework for understanding the physical environment for work.

Design/methodology/approach – A conceptual analysis of the multidisciplinary workplace literature was performed to assess the core propositions of JD-R theory as they relate to the workplace environment.

Findings – The analysis confirms that the workplace environment can be viewed as a composite of environmental demands (which instigate a health impairment process) and environmental resources (which trigger an engagement process). Employees proactively try to improve the suitability of their workspace through environmental crafting, motivated by minimising demands and maximising resources.

Originality/value – The application of JD-R theory to the workplace environment fills a gap in the literature for a framework which captures the dynamic nature of the employee-workplace relationship.

Keywords Workplace, Theory, Health, Productivity, Environmental psychology, Workplace psychology

Paper type Conceptual paper

Modern corporate real estate practice operates predominantly under a cost reduction paradigm, in which efficiency (i.e. optimising the use of the space) is generally prioritised over effectiveness (optimising the extent to which employees are able to carry out their work) (Harris, 2019; Haynes, 2007). This is exemplified by recent workplace trends such as the transitions from private to open-plan offices and from assigned seating arrangements to flexible working practices, which are both motivated at least in part by the desire to achieve greater space efficiency

However, there are increasing concerns that this trade-off has led to unhealthier working environments. Modern open-plan offices are associated with lower environmental satisfaction, poorer health and lower productivity amongst their users (Bodin Danielsson and Bodin, 2008, 2009; Bodin Danielsson *et al.*, 2014; Kim and de Dear, 2013). Moreover, the purported benefits of these offices (e.g. improved interpersonal communication and collaboration, greater autonomy over working location) have typically not been supported (Bernstein and Turban, 2018; Engelen *et al.*, 2018; Kaarlela-Tuomaala *et al.*, 2009; Kim and de Dear, 2013; Pejtersen *et al.*, 2006).

As such, it has been argued that the cost reduction paradigm should be supplanted by a new approach which recognises that employees are crucial assets whose value can be amplified through the provision of more supportive working environments (Haynes, 2007). To achieve this, workplace research and practice should be guided by a clear conceptual framework which represents the relationship between the employee and the

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myriad environmental factors which detract from or support healthy and productive work. However, the extant workplace environment literature is segmented by specialism and largely atheoretical (Ashkanasy *et al.*, 2014; Sander *et al.*, 2018). The limited use of theory, when translated into practice, raises the risk of iatrogenesis (i.e. well-intentioned interventions which inadvertently do more harm than good), owing to insufficient understanding of the complexity of the entire employee–workplace ecosystem.

To address the need for a suitable conceptual approach, in this paper we present a new theoretical framework for the workplace environment, termed the Environmental Demands-Resources (ED-R) model. This novel framework can be considered to be a domain-specific extension of one of the most popular and influential models of work stress from the organisational literature, the Job Demands-Resources (JD-R) theory (Demerouti *et al.*, 2001; Bakker and Demerouti, 2017), as well as serving as a standalone framework to represent the complex employee-workplace relationship.

Job Demands-Resources theory

The core proposition of JD-R theory is that all jobs share common factors associated with human wellbeing and functioning. These characteristics can be conceptualised as *job demands* ("aspects of the job that require sustained physical or mental effort and are therefore associated with certain physiological and psychological costs"; Demerouti *et al.*, 2001, p. 501) or *job resources*:

> [. . .] aspects of the job that may do any of the following: (a) be functional in achieving work goals; (b) reduce job demands and the associated physiological and psychological costs; (c) stimulate personal growth and development (Demerouti *et al.*, 2001, p. 501).

It has been noted that the distinction between demands and resources can often be ambiguous (e.g. a lack of resources might be construed as a demand), and so a general rule has been proposed that demands are those characteristics which are always appraised negatively, whereas resources are appraised positively (Schaufeli and Taris, 2014).

Job demands and resources influence work outcomes through two mediating pathways. First, chronic job demands and a scarcity of job resources instigate the process of exhaustion. The presence of demands requires the employee to expend higher levels of energy to achieve work-related goals, with insufficient time for recovery. Concurrently, the absence of job resources leads to a state of disengagement in which the employee loses the motivation to continue expending effort to overcome the demanding circumstances. The combination of exhaustion and disengagement is symptomatic of burnout and is also associated with other physical and mental health impairments (Demerouti *et al.*, 2001; Bakker and Demerouti, 2017).

Conversely, the presence of job resources triggers the separate pathway of work engagement. Job resources are intrinsically motivating because they satisfy fundamental human needs. This leads to a state of engagement characterised by vigour, dedication and absorption, which is in turn associated with positive outcomes such as positive affect, extra-role performance and higher productivity (Demerouti *et al.*, 2001; Bakker and Demerouti, 2017).

Whilst certain demands and resources might be intrinsic to the job itself, employees may also be able to use *job crafting* strategies to maximise resources and minimise demands. Job crafting refers to the proactive steps taken by employees to alter the nature of their work (*task crafting*), the relationships they have with colleagues and clients (*relationship crafting*) and/or the way in which they appraise their work (*cognitive crafting*) (Wrzesniewski and Dutton, 2001). Essentially, the purpose of job crafting is to reduce demands and to increase resources (Tims *et al.*, 2012).

Despite the fact that an unfavourable work environment was highlighted as a potential job demand in the original conceptualisation of the JD-R model (Demerouti *et al.*, 2001), very few studies have explicitly considered environmental factors as potential job demands or resources (for exceptions, see Hakanen *et al.*, 2005; Morrison and Macky, 2017). Instead, job demands and resources have typically been conceptualised as personal, social or organisational factors. Similarly, there has been limited consideration of the crafting strategies employees might use with respect to the workplace environment.

Therefore, the purpose of this paper was to address these gaps by performing a conceptual analysis of the workplace environment literature, considering the extent to which the propositions of JD-R theory are logically supported in the novel domain of the workplace environment. Specifically, the conceptual analysis was guided by the following three research questions: "Which aspects of the workplace environment can be conceptualised as job demands?"; "Which aspects of the workplace environment can be conceptualised as job resources?"; "Which environmental behaviours at work can be conceptualised as examples of job crafting?"

Methodology

To perform the conceptual analysis, we followed a slightly adapted version of the phases Jabareen (2009) proposed for the development of conceptual frameworks. JD-R theory had already provided us with *a priori* assumptions about the nature of the concepts and their interrelationships, as described in the previous section. Therefore, rather than "discovering" the concepts by reviewing the literature, we aimed instead to evaluate their logical consistency. As such, the three-phase approach to the conceptual analysis was as follows:

(1) map the disciplines and topics comprising the multidisciplinary workplace environment literature;

(2) extensively read and categorise the literature; and

(3) evaluate the logical consistency of the proposed concepts.

To map the relevant workplace environment disciplines, we used the model proposed in the recent review by Forooraghi *et al.* (2020), which largely corresponds with the factors discussed in previous reviews of the multidisciplinary workplace literature (Al Horr *et al.*, 2016a, 2016b). Accordingly, the workplace environment is conceptualised as a series of factors arranged into three higher-order categories:

(1) indoor environmental quality (IEQ; the physical conditions inside the building, e.g. indoor air quality, thermal environment, luminous environment, acoustic environment);

(2) spatial factors (the arrangements and nature of the office furnishings, e.g. interior design and spatial layout); and

(3) socio-spatial factors (the interaction between the office space and its users, e.g. perceived privacy, perceived territoriality, perceived autonomy).

For the second phase, the aim was to understand how each environmental factor related to occupants' health, well-being and/or productivity within offices. To identify the relevant literature, we used keyword searches within Scopus (search terms shown in Table 1) to identify studies relating to employee health, well-being and/or productivity within each workplace environment discipline. To identify further suitable papers which may have been

Table 1. Results of the conceptual analysis of the multidisciplinary workplace environment literature; the three right-hand columns present an initial typology of environmental demands, environmental resources and examples of environmental crafting

Workplace environment factor	Keyword search[1]	Environmental demands	Environmental resources	Environmental crafting
Indoor air quality	"indoor air quality" OR "indoor air pollutants" OR "ventilation rate" OR "air quality"	CO_2; CO; O_3; VOCs; $PM_{2.5}$; PM_{10}; NO_2; humidity; unpleasant odours	Pleasant fragrances	–
Thermal environment	"thermal comfort" OR "temperature" OR "thermal sensation" OR "thermal satisfaction"	Thermal discomfort (too cold); thermal discomfort (too warm)	Thermal alliesthesia	Cooling fan; personal heater
Acoustic environment	"acoustic comfort" OR "noise" OR "background speech" OR "irrelevant speech" OR "speech distraction" OR "psychoacoustics"	Too loud; too quiet; annoying non-speech sounds; annoying speech	Valuable speech (work-related); valuable speech (non-work-related)	Headphones; time crafting; spatial crafting
Luminous environment	"lighting" OR "light quality" OR "daylighting" OR "access to daylight" OR "natural light" OR "access to natural light"	Insufficient light; glare; insufficient access to daylight	Interest-evoking lighting	–
Spatial layout	"office layout" OR "office design" OR "workplace layout" OR "workplace design" OR "workspace layout" OR "workspace design")	Perceived crowding; lack of privacy; auditory distractions; visual distractions; isolation	Valuable social interactions (work-related); valuable social interactions (non-work-related)	Time crafting; spatial crafting
Biophilic design	"biophilic design" OR "biophilia" OR "interior plants" OR "indoor plants" OR "nature-based design" OR "nature views" OR "views of nature"	–	Interior plants; interior water features; design which evokes nature	–
Aesthetic design	"aesthetic design" OR "aesthetics" OR "beauty"	–	Aesthetically pleasing design	–
Ergonomic design	"ergonomics" OR "ergonomic quality" OR "furniture"	Uncomfortable furniture; requirement for prolonged period of sitting	–	–
Privacy/crowding	"privacy" OR "crowding" OR "density"	Lack of visual privacy; lack of auditory privacy; perception of crowding	–	–

(continued)

Table 1.

Workplace environment factor	Keyword search[1]	Environmental demands	Environmental resources	Environmental crafting
Autonomy/ control	"autonomy" OR "individual environmental control" OR "local environmental control" OR "personal comfort system" OR "personal comfort device" OR "activity-based working" OR "non-territorial office" OR "flexi office" OR "flexible working" OR "agile working"	Lack of autonomy; lack of control	–	Cooling fan; personal heater; headphones; time crafting; spatial crafting
Territoriality/ ownership	"psychological comfort" OR "territoriality" OR "appropriation" OR "ownership" OR "personalisation" OR "personalization"	–	Perceptions of ownership; Perceptions of belongingness	–

Notes: [1]The titles, abstracts and keywords of research articles were searched with the keywords. All factor-specific search strings were followed by "AND TITLE-ABS-KEY ("wellbeing" OR "well-being" OR "health" OR "productivity" OR "job performance") AND TITLE-ABS-KEY ("workplace" OR "office" OR "workspace")) ". To prioritise review papers published since 2010, we added "AND DOCTYPE (re) AND PUBYEAR > 2009" to the search string in a second round of searches missed by the initial searches, we also scanned the reference lists and citing articles of the papers which had been identified. The primary author scanned the titles and abstracts of the articles within the search results before reading the full text of relevant articles. This resulted in a database of 433 research articles which the primary author read in full.

Finally, the third phase was addressed by identifying, categorising and integrating common concepts across the disciplines. Specifically, we assessed the extent to which our *a priori* assumptions about the applicability of JD-R theory to the workplace environment were valid. This was done by assessing the extent to which the content of the papers aligned to the conceptual framework of demands, resources and crafting behaviours. For the purposes of this paper, the articles listed in the Results section are those which were subjectively judged to best exemplify these concepts for each workplace environment discipline. Because of the very broad scope, we prioritised systematic review papers published in the past decade where possible, although these were not available for all disciplines, and so field studies and laboratory studies were also included where the findings were generalisable to real office environments.

Overall, the conceptual analysis process yielded an initial typology of "environmental demands", "environmental resources" and "environmental crafting" strategies (Table 1).

Results

Which aspects of the workplace environment can be conceptualised as job demands?

The defining characteristic of a job demand is that its presence requires that the employee expends additional energy to achieve the same goal (Demerouti *et al.*, 2001). There is a similarity here with Vischer's (2007) concept of "workspace stress", defined as the degree to which users have to compensate for adverse environmental conditions and expend additional energy to achieve work-related goals. Essentially, this can be caused by physical discomfort (health impairments, ranging from mild disturbance to more serious problems) and/or functional discomfort (interference with the successful completion of work-related activities) (Vischer, 2008).

Clear contributors towards physical and functional discomfort were identified across each of the three higher-order workplace categories. In terms of IEQ, several review papers highlight common airborne pollutants within offices which are associated with the development of "sick building syndrome" symptoms (e.g. headaches, tiredness, respiratory irritation), such as particulate matter (Nezis *et al.*, 2019) and volatile organic compounds (Tsai, 2018). If humidity is low, these symptoms are exacerbated (Wolkoff, 2018). In this way, polluted indoor air results in a mental state which makes the completion of work-related activities more difficult, contributing to psychological stress as well as impairments to physical health.

Characteristics of the luminous and thermal environment can also cause discomfort. Visual discomfort and eyestrain can be caused by lighting configurations providing insufficient light and/or producing the sensation of glare (Carlucci *et al.*, 2015). Additionally, limited access to daylight causes diminished alertness and cognitive response (Aries *et al.*, 2013) because the regulation of circadian rhythms (which govern the sleep-wake cycle) depends upon the stimulation of a certain type of photoreceptor which is maximally sensitive to a wavelength contained within natural daylight but not typically in artificial light (Lucas *et al.*, 2014). In terms of the thermal environment, temperature complaints are common within offices and are also associated with lower productivity (Rupp *et al.*, 2015).

With respect to purely spatial factors, the greatest potential contributor towards physical discomfort is the ergonomic design quality. For example, the development of musculoskeletal symptoms in the spine and neck has been associated with non-adjustable seating arrangements, poor posture and a close keyboard position to the body (Jun *et al.*, 2017). Another issue is the requirement for prolonged sitting at work. High sedentary behaviour contributes to musculoskeletal pain, as well as the development of even more serious health impairments such as Type 2 diabetes, cardiovascular diseases and certain types of cancer (Owen *et al.*, 2009).

Finally, in terms of socio-spatial factors, the literature highlights a worsening of various forms of discomfort in open-plan offices. In particular, distraction by speech is a very common complaint within open-plan offices (Bodin Danielsson and Bodin, 2009). For this reason, occupants of open-plan offices report approximately tenfold more acoustic complaints (Pejtersen *et al.*, 2006) and a doubling in the amount of time wasted owing to noise (Kaarlela-Tuomaala *et al.*, 2009) compared with those in enclosed offices. Open-plan offices are also associated with lower perceived acoustic and visual privacy (Bodin Danielsson and Bodin, 2009; Kim and de Dear, 2013) and higher perceptions of crowding (Sundstrom *et al.*, 1980). In turn, this contributes to higher levels of emotional exhaustion (Laurence *et al.*, 2013).

In sum, there is evidence to conclude that numerous disparate aspects of the workplace environment are unified by the fact that they cause physical or functional discomfort. Borrowing terminology from the JD-R model, we refer to these as *environmental demands*. These demands directly or indirectly impair physical or mental health, triggering a pathway labelled "strain". In the face of demands, employees must exert increased physical and/or psychological effort to achieve the same outcomes. Hence, chronic exposure to environmental demands increases the likelihood of physical and mental health deficits, burnout and low productivity. Thus, the first proposition (P1) of the JD-R model as it applies to the workplace environment can be stated as follows:

P1. The physical workplace environment contains "environmental demands" which instigate a health-impairment process and have a negative impact on job performance.

Which aspects of the workplace environment can be conceptualised as job resources?

Job resources stimulate work engagement by supporting fundamental psychological needs, thereby buffering the impact of job demands on strain (Demerouti *et al.*, 2001). This is similar to Vischer's (2008) concept of psychological comfort, which relates to aspects of the environment which engender perceptions of belonging, territoriality and ownership in the workplace. The concept can be further extended to other psychological needs, such as the "sense of coherence" (i.e. the extent to which one's environment is perceived as comprehensible, manageable and meaningful) which underpins the salutogenic theory of health promotion (Antonovsky, 1996).

The clearest examples of environmental resources come from features of interior design. In particular, the integration of nature and natural analogues into the indoor built environment ("biophilic design") makes the workplace more manageable by enabling employees to cope more effectively with stress. Exposure to nature instigates a "restorative" process characterised by reduced stress and the recovery of depleted attentional resources (Hartig *et al.*, 2014) and also has "instorative" benefits which arise even when cognitive resources are not depleted (Beute and de Kort, 2014). As such, when nature is integrated into the workplace environment, employees experience benefits including reduced stress, higher productivity and improved overall wellbeing (Gillis and Gatersleben, 2015).

Personally meaningful artefacts also serve as environmental resources, as high job meaningfulness is associated with higher job satisfaction and motivation and lower absenteeism and turnover intentions (Dik *et al.*, 2013). Indeed, personalisation serves to foster positive emotions, accelerate personal identity expression and imbue the workplace with a sense of meaning (Ashkanasy *et al.*, 2014; Brunia and Hartjes-Gosselink, 2009; Wells, 2000). In offices with low privacy, employees who personalise their desk are at lower risk of experiencing emotional exhaustion than those who do not (Laurence *et al.*, 2013).

The "look and feel" of the workplace may have a similar effect, through the mediating pathway of positive affect. Indeed, philosophers of architecture recognise that the aesthetic appreciation of architectural objects gives rise to an extended range of psychological states (Fisher, 2016). Although studies quantifying the correlates of aesthetic appreciation in the workplace are rare, there is evidence to suggest that creativity tends to be higher in aesthetically interesting spaces (McCoy and Evans, 2002) and that judgments of aesthetic quality contribute to overall workplace environment satisfaction (Bodin Danielsson, 2015). Hence, artefacts or design features judged to be "beautiful" may also function as environmental resources.

Beneficial psychological states can also be elicited by certain aspects of IEQ. For example, exposure to pleasant fragrances tends to induce positive affect, which in turn leads to more optimistic goal-setting, more cooperative conflict resolution and higher task performance (Baron and Bronfen, 1994; Baron and Thomley, 1994). Positive affect might also be elicited through acoustic soundscapes playing sounds from natural environments (e.g. birdsong, rippling water) (Benfield *et al.*, 2014), thermal environments which elicit pleasurable sensations ("thermal alliesthesia") rather than neutrality (Parkinson and de Dear, 2014) and lighting configurations which are sufficiently non-uniform to be characterised as interesting (Veitch, 2001). However, supporting evidence for these additional strategies remains relatively scant at present.

Finally, socio-spatial characteristics can also indirectly support traditional job resources (e.g. co-worker and supervisor support) by facilitating interpersonal communication. However, improvements in interpersonal relations are not typically observed following a transition to open-plan spaces (Bernstein and Turban, 2018; Kaarlela-Tuomaala *et al.*, 2009; Kim and de Dear, 2013; Morrison and Macky, 2017; Pejtersen *et al.*, 2006), so the challenge remains for workplace practitioners to develop effective strategies for increasing the likelihood of interpersonal contact and interaction but at no expense to individual privacy.

In sum, although the evidence base requires further development, there is good evidence that at least some aspects of the workplace environment independently support work engagement by supporting fundamental psychological needs. We conceptualise these elements as *environmental resources*. The absence of environmental resources does not directly cause strain, but rather their presence triggers a separate motivational pathway which improves motivation and buffers the impacts of demands (environmental or otherwise) on strain. In this way, environmental resources support physical and mental health, helping employees to work more productively.

> *P2*. The physical workplace environment contains "environmental resources" which instigate a motivational process, buffer the impact of demands on strain and have a positive impact on job performance.

How can we understand employees' environmental behaviours at work?

Job crafting refers to proactive changes employees make to increase their job resources and decrease their job demands (Tims *et al.*, 2012). Many workplace behaviours can be understood in this manner; as a particular type of coping behaviour in which the employee actively improves the suitability of the external environment to make it more aligned to their preferences and requirements (i.e. by reducing environmental demands and/or increasing environmental resources). When the autonomy to do so is restricted, the "learned helplessness" response can occur, in which the individual simply succumbs to the inappropriate conditions instead of trying to improve them, resulting in depressive symptoms and poorer work performance (Evans and Stecker, 2004). Hence, it is crucial to consider the different crafting strategies an employee might effectively use within the workplace.

Wessels *et al.* (2019) distinguish two types of job crafting relating to the workplace environment. *Spatial crafting* refers to decisions over where to complete work, including different types of workspace within the office and which could also extend to spaces outside of the office (e.g. home office, café). *Time crafting* refers to decisions over when to complete work, recognising that the same environment might be more or less suitable (because of the presence or absence of colleagues) at certain times of the day. Enhancing time-spatial job crafting is one of the major justifications for non-territorial working policies such as "activity-based working", in which employees are expected to regularly use different workspaces for different activities (Veldhoen, 2008).

In practice, however, the evidence base for activity-based working is equivocal (Engelen *et al.*, 2018) and a significant proportion of employees retain a territorial working style (Skogland, 2017). Here, it can be recognised that a conflict exists between what Elsbach and Pratt (2007) refer to as the instrumental and symbolic functions of the workplace. If the employees already perceive low demands at their primary workspace, then attempts to encourage them to switch workstations conflict with their wish to maintain familiar and psychologically comfortable workspaces. Hence, supporting time-spatial job crafting may not always have the anticipated benefits.

In addition to spatial and time crafting, the literature also reveals the existence of crafting strategies motivated by improving conditions in the immediate local environment, by improving design and/or by reducing discomfort. For example, just as the artefacts of personalisation can be conceptualised as environmental resources, so too can the process of personalisation be understood as an example of crafting. Acoustic disturbances can be reduced through the use of personal headphones (Oseland and Hodman, 2018) and thermal discomfort can be mitigated through the use of personal fans or heaters (Liu *et al.*, 2013) or even desk chairs with built-in heating and cooling mechanisms (Kim *et al.*, 2018).

In summary, various workplace behaviours are directly motivated by the desire to create a more suitable working environment (by mitigating environmental demands and/or enhancing environmental resources). Examples might include moving to a new working location, changing the time at which one works and/or altering the local environmental conditions at the workspace. Collectively, these can be referred to as *environmental crafting*.

P3. To the extent that they are able to do so, employees will use crafting behaviours to minimise demands and maximise resources in the workplace environment.

Discussion

In this paper, we performed a conceptual analysis of the multidisciplinary workplace literature, using indicative studies to demonstrate that the core concepts of JD-R theory (Demerouti *et al.*, 2001; Bakker and Demerouti, 2017) are also applicable to the workplace environment. Therefore, a domain-specific version of the theory presented separately as the ED-R model (Figure 1) is judged to be a suitable conceptual framework to represent the complex and dynamic nature of the employee–workplace relationship.

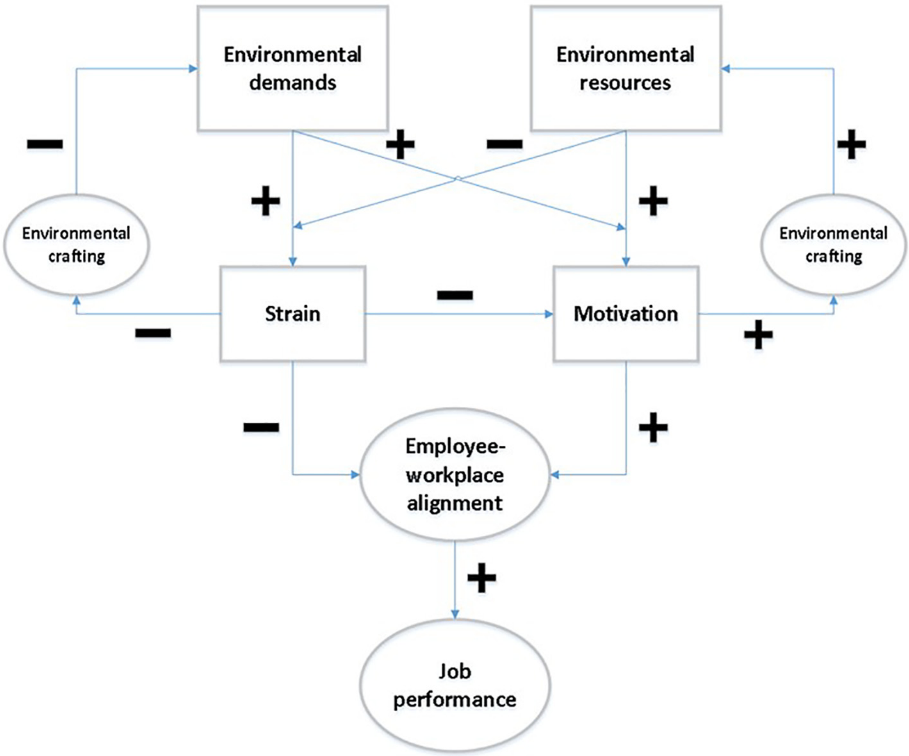

Figure 1.
The environmental demands-resources (ED-R) model

Specifically, the analysis showed that the workplace environment is as a composite of environmental demands, which instigate a health impairment process (through physical and/or functional discomfort) and negatively impact job performance and environmental resources, which trigger a motivational process (through psychological comfort) and positively impact job performance. While certain environmental demands and resources are outside the control of the employees, employees can improve the workplace through environmental crafting behaviours (i.e. minimising demands and/or maximising resources).

The presence of demands and resources (relative to the idiosyncratic needs of each employee) determines the overall level of *employee-workplace alignment*. This is a similar concept to "functional and psychosocial congruence" (Heerwagen *et al.*, 1995), "need-supply fit" (Gerdenitsch *et al.*, 2018; Wohlers *et al.*, 2019), "work pattern-office type (mis)fit" (Soriano *et al.*, 2018) and one component of "person-environment fit" (a broader concept which also includes congruence with the broader psychosocial and organisational environment; Edwards and Billsberry, 2010). In line with the ED-R model, previous studies have confirmed a significant positive association between perceptions of alignment and productivity (Gerdenitsch *et al.*, 2018; Soriano *et al.*, 2018; Wohlers *et al.*, 2019).

Practical implications

From a practical perspective, a major implication of ED-R theory is recognising the myriad environmental forces acting upon individuals in the workplace environment. Consequently, practitioners should perform more comprehensive evaluations of demands, resources and crafting opportunities within the workplace environment, to get a truer understanding of workplace effectiveness. The tentative typology presented in Table 1 provides a starting point for understanding the different factors which should be assessed.

The assessment of environmental demands and resources can also improve workplace intervention delivery. Broadly, the ED-R model suggests that the provision of more effective workplaces relies on a combination of three broad strategies. Two of these are practitioner-led, top-down strategies: the mitigation of environmental demands (e.g. creating silent working areas) and the enhancement of environmental resources (e.g. placing interior plants within the office). The third strategy is to facilitate the user-directed, bottom-up process of environmental crafting (e.g. implementing flexible working policies).

Finally, both prior to and after the intervention has occurred, a comprehensive evaluation of environmental demands, environmental resources and perceptions of overall employee–workplace alignment should occur. This will minimise the risk of iatrogenesis and help to ensure that the intervention really did have the intended effect.

Limitations and suggestions for future research

The strengths and limitations of the ED-R model are largely shared with the JD-R model (Schaufeli and Taris, 2014). The main strength of the model is its flexibility. Any aspect of the environment can be included in the model as a demand or resource, any subjective or objective measure of well-being or productivity can be included as a component of overall job performance and a range of organisational behaviours can be interpreted as examples of environmental crafting. In this way, the model encourages researchers and practitioners to adopt a holistic view of the entire workplace environment and the employees' responses within it.

However, this generalisability comes at the cost of limited specificity, so additional frameworks will be needed to explain the numerous individual relationships contained within the model in more detail and with greater predictive power. Indeed, more research is needed in general to validate the propositions of the ED-R model. At present, no predictions are made about the strength of the relationship between each demand or resource and overall job performance. Possibly, trying to quantify these relationships might be further complicated by the fact that there is still limited insight into the combined effects of different aspects of the environment, as the vast majority of prior research has attempted to isolate the effects of just one or two components at a time. As such, it remains unclear whether multiple demands and/or resources will be additive or multiplicative in their effects.

It will be important to develop research into exactly which demands are most detrimental and which resources are most conducive to job performance. The limited extant literature highlights the importance of supporting productivity by ensuring that distractions in the workplace environment are minimised (Roskams and Haynes, 2019a). However, it is possible that different types of employee will require different types of intervention, so more field-based research is needed at a greater variety of workplaces to better inform the evidence-based approach to practice.

There is also an asymmetry in the strength of evidence for different aspects of the model. The existence of environmental demands is clearly supported by numerous systematic reviews, but the evidence in support of certain environmental resources (with the exception of biophilic design) is more tentative and based on individual studies. This will also be important to address in future research. A truly "healthy" workplace entails not only the mitigation of harm-causing "pathogenic" factors but also the enhancement of health-promoting "salutogenic" factors (Heerwagen *et al.*, 1995; Roskams and Haynes, 2019b). It would be valuable in future research to investigate exactly which environmental resources are most useful for buffering the impact of job demands on strain and which are most useful for promoting work engagement.

Finally, it should be recognised that organisations will continue to be motivated by cost-reduction concerns and so the provision of workplaces which are entirely free of demands and resource-abundant may not be possible. Hence, the most pressing concern for researchers and practitioners is to explore the most effective ways to resolve the inherent tensions of shared modern offices. How can requirements for privacy and quiet work be best supported within open-plan spaces? If personal identity expression needs to be restricted in non-territorial offices, can psychological comfort be maintained in other ways? Do personal comfort systems enable users to improve their individual comfort without the risk of adversely affecting co-workers? The answers to these types of question will be crucial for helping practitioners to understand how to provide more effective workplaces while still meeting organisational requirements for efficiency.

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Associations between job satisfaction, job characteristics, and acoustic environment in open-plan offices

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ABSTRACT

This study aimed to investigate the associations between physical acoustic factors, job characteristics, and job satisfaction. Acoustic measurements and questionnaire surveys were conducted in 12 open-plan offices. Active noise levels ($L_{Aeq,8\text{-}hour}$), reverberation time (T_{20}), and speech privacy-related measures such as $D_{2,S}$ and $L_{p,A,S,4m}$ were measured at each office. A total of 324 employees then completed the online questionnaire surveys. The questionnaire assessed perceived speech privacy, noise disturbance, job characteristics, and job satisfaction. The measures of job characteristics involved skill variety, task identity, task significance, and autonomy. The results showed that active noise level ($L_{Aeq,8\text{-}hour}$) was negatively correlated with job satisfaction. Also, job satisfaction showed a negative correlation with speech privacy, whereas the relationship between job satisfaction and noise disturbance was not significant. It was also observed that the relationship between task identity and job satisfaction was moderated by the active noise level and speech privacy.

1. Introduction

Open-plan offices were introduced in the 1950s and have become popular from the early 1970s [1]. This type of office is cost-effective to create and be rearranged to meet the changing needs of groups and whole departments [1,2]. In addition, it allows better access to daylight than a conventional arrangement [3]. Moreover, it has been known to help co-workers be near to each other and have efficient communication [4–6]. However, a growing number of studies have demonstrated that such office environments have negative impacts on employees in many ways [7,8]. Contrary to the original argument that open-plan office promotes efficient communication between co-workers [4], some researchers have reported that it does not facilitate communication among co-workers because employees are likely to feel such offices prohibit confidential conversations [9–11]. Adverse impacts of open-plan offices on employees' perceived satisfaction have also been reported. Brennan et al. [1] compared traditional offices to open offices during relocation and found that satisfaction with the physical environment, team member relations, and perceived job performance decreased after the relocation. It was also reported that poor physical environments (e.g., lighting, temperature, and noise) reduced job satisfaction of employees in open-plan offices [12,13]. In particular, lack of perceived privacy and increase of noise distractions have been observed in open-plan offices [14–16].

1.1. Design parameters of open-plan office

Several studies have proposed design guidelines of open-plan offices for designers as well as acousticians. Kjellberg and Landstrom earlier recommended general strategies to deal with major noise sources in the offices [17] and highlighted the effects of noise on occupants' perception and performance [18]. Later Bradley [19] investigated the effect of office design parameters on Speech Intelligibility Index (SII) using a mathematical sound propagation model. The office design parameters were ceiling absorption, partition height, partition absorption, workstation plan size, floor absorption, screen transmission loss, ceiling height, lighting fixture, speech level, and making noise level. Among the parameters, the ceiling absorption, partition height, and workstation plan size were most important in improving speech privacy. Recently, Rindel and Christensen [20] confirmed that the ceiling absorption was critical in improving speech privacy in open-plan offices in terms of speech privacy-related measures in ISO 3382-3. A laboratory

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experiment [21] also showed that the Speech Transmission Index (STI) decreased with increasing masking sound level, partition height, and room absorption. Different types and levels of speech maskers were also adopted as a design parameter to improve speech privacy in the offices [22,23]. Other researchers [24] have also considered several features of open-plan offices to maximise employees' productivity and satisfaction as well as to fulfil the following needs: physical and task needs (e.g., furnishing, storage), privacy needs (e.g., partition shape and height, workstation size), and recognition needs (e.g., space for displaying personal items). For example, more than 80% of interviewees answered that they preferred increases of partition height and degree of enclosure [25]. Recently, Lee and Aletta [26] developed key performance indicators of acoustic environments including space planning principles. Duval et al. [27] highlighted that higher-density might harm employees' satisfaction although further investigation with empirical evidence is needed. Newsham et al. [28] also found that workstation size significantly increased the risk of dissatisfaction with privacy and acoustics. Moreover, Yildirim et al. [29] reported higher satisfaction with a workspace from those with higher partitions, implying better privacy led to higher satisfaction. Haapakangas et al. [30] suggested that quiet workspaces in open-plan offices might provide better coping and improve the work environment.

1.2. Effects of acoustics environment of open-plan offices on occupants

Research has demonstrated that poor acoustic quality of open-plan offices causes employees' disturbance, and adversely affects work performance, job satisfaction, and health. Boyce [31] found that more than half of the survey respondents in open-plan offices reported disturbance caused by telephone ringing, conversation, and some machinery noises. Kraemer [32] demonstrated significant noise disturbance in open-plan offices by highlighting the increase of noise disturbance with decreasing masking sound level. Kaarlela-Tuomaala et al. [33] found that the negative acoustic environment in the open-plan offices increased disturbance, concentration difficulties, and the use of coping strategy from the longitudinal study during relocation. Haapakangas et al. [34] investigated the relationships between an acoustic measure (distraction distance) and perceived disturbance using data from 21 open-plan offices. The study found that increasing distraction distance was associated with an increase in noise disturbance. Smith-Jackson and Klein [35] carried out a laboratory study to examine how irrelevant speech in open-plan offices contributed to employees' mental workload, performance, stress, and fatigue. They found that irrelevant speech had impacts on performance (e.g., false alarms and completion rates) and workload. Di Blasio et al. [62] also highlighted the negative effect of irrelevant speech on work performance, mental health and well-being in shared and open-plan offices based on the questionnaire survey. Similarly, a Swedish laboratory study [36] showed the high noise level condition resulted in lower performance, higher tiredness, and lower motivation with work. Furthermore, the poor acoustic environment of open-plan offices may adversely affect employees' health [32,37]. Danielsson and Bodin [38] showed that employees in open-plan offices had the lowest health status and those working in the medium-sized open-plan offices had second-lowest job satisfaction. In addition, Pejtersen et al. [39] found that sickness absence significantly increased in open-plan offices compared to other office types such as private offices. More recently, Lee et al. [40] conducted questionnaire surveys in open-plan offices to examine the effects of noise on job satisfaction and health problems. They found that employees' health symptoms were associated with perceived speech privacy and self-rated job satisfaction.

1.3. Job satisfaction and job characteristics

Given that job satisfaction is one of the crucial factors affecting organisations' outcome [41], many researchers have described the term in their own words. Hoppock [42] described it as any combination of psychological, physiological and environmental circumstances that cause a person truthfully to say, 'I am satisfied with my job'. Besides, Spector [43,44] defined it as the extent to which people like (satisfaction) or dislike (dissatisfaction) their jobs. There has been a lot of research on job satisfaction in relation to job design and job characteristics. Substantial research has reported that enriched and complex jobs improved employees' job satisfaction. More specifically, the job characteristics model of Hackman and Oldham [45], developed based on earlier methodologies [46,47], proposed that positive work outcomes (e.g., high job satisfaction) are obtained once employees experience the fulfilment of three critical psychological states (e.g., experienced meaningfulness of the work). Later, several studies supported this job characteristics model by reporting positive correlations between job characteristics and job satisfaction [48]. However, it is still unknown how the association between job characteristics and job satisfaction is affected by the acoustic environment in open-plan offices and only few studies have examined this issue. Sundstrom et al. [49] analysed subjective ratings of employees' environmental satisfaction, job satisfaction, and job performance before and/or after office renovation into an open-plan office. A significant relationship between noise disturbance and employees' dissatisfaction with the job was found. Based on this finding, the study hypothesised a model between environmental features (e.g., noise), environmental satisfaction, job characteristics, and job satisfaction. The model showed mutual impacts between environmental satisfaction and job characteristics. However, the associations were not empirically validated. Recently, Lee et al. [40] highlighted that speech privacy was associated with self-rated job satisfaction. However, only subjective ratings of acoustics (e.g., speech privacy and noise disturbance) were used in the questionnaire surveys and physical acoustic data was not introduced. Lee et al. [40] also noted that there was a need for further consideration into non-acoustic factors such as job characteristics in explaining employees' job satisfaction.

1.4. The aims

This study aimed to investigate the relationships between acoustic factors, job characteristics, and job satisfaction of employees in open-plan offices through the data collected by questionnaire surveys and acoustic measurements in the open-plan offices. The acoustic factors covered both physical acoustic environments as well as perceptions of acoustics in order to broaden the understanding of the relationship between the physical and perceived acoustic environment and job satisfaction. Furthermore, moderation effects of acoustic and non-acoustic factors on the relationship between job characteristics and satisfaction were examined.

2. Methods

2.1. Sites

As listed in Table 1, questionnaire surveys and acoustic measurements were conducted at 12 open-plan offices. Among them, six offices (offices #1–#6) were located within the same building of a construction company. Those offices were chosen to investigate the perceived acoustic environment and job satisfaction of employees who are working in almost identical environmental

Table 1
Characteristics of the participated offices.

Offices	Floor plan	Floor area [m^2]	Ceilingheight [m]	Partition height [m]	Number of workstations	Estimated percentages of Occupied workstations [%]	Employees' duties
#1	Rectangular	418	2.4	1.2	74	90–100	Design
#2							Sales planning and support
#3							Technical support
#4							Technical support
#5							R&D
#6							IT support
#7	Rectangular	150	3.0	–	30	90–100	Network Operations Centre
#8	Non-rectangular	570	3.0	–	90	65–75	Consulting
#9	Rectangular	415	2.7	1.1	150	50–60	Call-center
#10	Non-rectangular	680	2.7	1.1	90	75–85	HR; finance; other administrative teams
#11	Rectangular	250	2.5	1.1	70	70–80	Finance; quotes
#12	Non-rectangular	650	2.5	1.1	140	70–80	Call-center; planners

conditions. The offices in the building were a mixture of R&D, design, sales, technical support, and IT support. Each office had 74 workstations which were almost always occupied. They were located on different floors with the same floor design, finishing materials, and workstation arrangement; thus, similar acoustic environments were expected across the floors. On the other hand, the other six offices were branches of an energy service company located in different buildings. Office #7 was a Network Operations Centre (NOC) where the employees were mainly communicating on the phone. There were 30 workstations in the office which were nearly always occupied. The employees in office #8 were mostly consultants; there were 90 workstations in this area and approximately 60 employees occupied the space. Office #9 was a call centre where 150 workstations were located and around 80 callers mainly communicated on the phone. The employees in office #10 were in human resources, finance, and various administrative teams. There were 90 workstations and around 70 were occupied. Around 50 of 70 workstations were occupied in office #11 and the employees in this area were mainly in finance and quotes teams. In office #12, there were 140 workstations and around 100 employees were working on call-handling. Most offices were in rectangular shapes except for offices #8, #10, and #12. Floor areas varied from 150 to 680 m^2, while ceiling heights ranged between 2.4 and 3.0 m. Partitions with heights of 1.1 and 1.2 m were installed between workstations in 10 offices. The pictures of the offices are presented in Fig. 1.

2.2. Participants

A total of 324 employees took part in the questionnaire surveys. As listed in Table 2, more than a half (61.4%) were between 18 and 35 years old, 30.2% of them were between 36 and 50 years old, and 8.3% were between 51 and 64 years old. No respondent was more than 65 years old. In addition, 67.3% were males and 31.2% were females. Five respondents reported that they preferred not to answer on their gender identity.

2.3. Acoustic measurements

Active noise levels were measured in an occupied condition for eight hours using sound level meters (B&K Type 2236) with half-inch free-field microphones (B&K Type 4188). Single measurements were conducted in the rectangular offices because the workstation arrangements were almost the same, whereas three sound level meters at different workstations were placed in the non-rectangular offices. The measurements were carried out on weekdays during the working hours from 09:00 to 17:00 (A-weighted equivalent sound pressure levels, $L_{Aeq,8\text{-hour}}$). One minute equivalent sound pressure levels ($L_{Aeq,1\text{-min}}$) were then stored to obtain sound profiles.

Additional measurements were performed at night-time when people were absent in order to determine room acoustics [50] and speech privacy-related measures [51]. The night-time measurement was conducted at one of offices #1–#6 because all the offices had almost identical acoustic conditions when they were vacant. During the measurements, the air conditioner was operated as during typical working hours. An omni-directional source was adopted as a sound source and half-inch microphones were used to record the signals. Measurements were carried out along a line which crossed over workstations. Two measurements were conducted in two different zones in the non-rectangular offices with different workstation arrangements, while one measurement was done in the rectangular offices with similar workstation arrangements. The sound source was placed at the end of the line at a height of 1.2 m and microphones were located at the position of each workstation, 1.2 m above the floor. From the measurements, reverberation time (T_{20}) and speech privacy-related measures were determined. The speech privacy-related measures included spatial decay rate of speech ($D_{2,S}$), A-weighted sound pressure level of speech at a distance of 4 m ($L_{p,A,S,4m}$), distraction distance (r_D), and background noise level ($L_{p,A,B}$).

2.4. Questionnaire

The questionnaire measured speech privacy, noise disturbance, job characteristics, and job satisfaction. First, the following question was used to assess perceived speech privacy: "How much do you hear the content of following sounds?" Two options (colleagues chatting and telephone conversation) were given and each option was rated using 5-point scales (1 = "*None*" ~ 5 = "*All*"). Second, perceived disturbance caused by different noises was assessed using 7-point scales (1 = "*Not at all*" ~ 7 = "*Extremely*"). Haapakangas et al. [34] introduced the proportions of highly disturbed by noise (%HD) with a cut-off point of 75 on a scale from 0 to 100. Similarly, the %HD was computed in this study by computing the percentage of the responses exceeding the cut-off point (i.e. 6 and 7 on the 7-point scale). Third, four job characteristics (skill variety, task identity, task significance, and autonomy) were measured by the Job Diagnostic Survey (JDS) developed by Hackman and Oldham [52]. Skill variety, task identity, and task significance were to measure the 'psychological states of the experienced meaningfulness of the work', and autonomy was to measure the 'psychological states of the experienced responsibility for outcome of the work' [52]. The following instruction was given: "Please

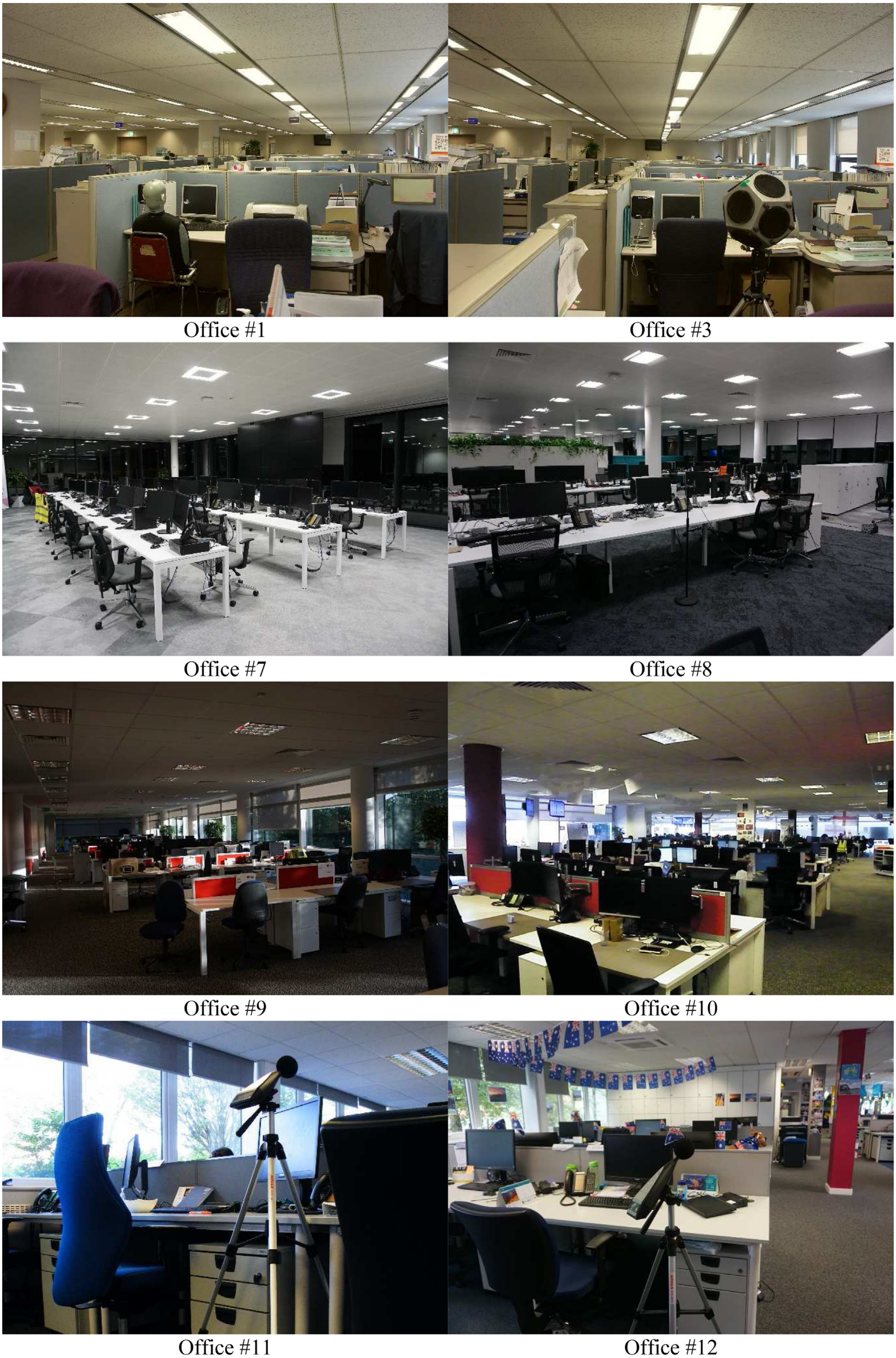

Fig. 1. Pictures of the offices.

Table 2
The number of survey respondents from each office.

Offices	Age			Gender			
	18–35	36–50	51–64	Male	Female	Prefer not to answer	*Total*
#1	15	7	–	17	5	–	*22*
#2	14	11	1	23	3	–	*26*
#3	15	11	2	18	10	–	*28*
#4	18	6	3	25	2	–	*27*
#5	15	6	2	22	1	–	*23*
#6	12	7	2	18	3	–	*21*
#7	5	5	3	6	6	1	*13*
#8	21	13	2	28	8	–	*36*
#9	12	10	2	11	13	–	*24*
#10	13	10	3	9	13	4	*26*
#11	25	3	3	21	10	–	*31*
#12	34	9	4	20	27	–	*47*
Total	*199*	*98*	*27*	*218*	*101*	*5*	*324*

choose the number indicating whether each statement is an accurate or inaccurate description of your job." and each statement was rated using 7-point scales (1 = "*Very inaccurate*" ~ 7 = "*Very accurate*"). A total of eleven statements (three for measuring each of skill variety, task identity, and autonomy, and two for task significance) were used to measure the job characteristics. Fourth, job satisfaction was measured with the Global Job Satisfaction (GJS) developed by Pond and Geyer [53]. Following the instruction ("Please indicate your agreement with the following statements."), three statements were given with 7-point scales (1 = "*Strongly disagree*" ~ 7 = "*Strongly agree*") for assessing job satisfaction. Lastly, the questionnaire also contained some question items concerning personal details such as age, gender, and self-reported noise sensitivity. In particular, noise sensitivity was measured using 6-point scales (1 = "*Strongly disagree*" ~ 6 = "*Strongly agree*") given to five statements which followed the instruction "Please indicate your agreement with the following statements." Table 3 shows the sample question items used in the questionnaire survey and their Cronbach's alpha. The Cronbach's alpha ranged between 0.71 and 0.91, indicating internal consistencies of the questions.

2.5. Procedure

Employees of the 12 offices were invited to participate in the online survey. Survey invitations were sent via email with information of the study and only those who reported they did not have any hearing disability were invited to take part in the survey. At the first page of the online survey, the study information and a consent form were presented on the screen and it proceeded only when the participants agreed with the consent. If for any reason during the questionnaire, they needed to leave the website, their answers were deleted. The responses were stored only after the participants filling in all required fields and clicking the 'submit' button. This study was ethically approved by the School of the Arts Committee on Research Ethics, University of Liverpool (Approved on the 23.04.2018, Ethics application No. 3079).

2.6. Data analysis

The data were analysed using SPSS version 24.0 and AMOS version 24.0. Since the survey responses were measured using different numerical scales as they were adopted from the existing measures, all of the data were translated to the minimum score of 0 to the maximum score of 100. It was assumed that the categories divide the range from 0 to 100 in equally spaced intervals. Each category was positioned on a scale from 0 to 100 using a simple equation: $\text{category}_i = (i\text{-}1)^*100/(m\text{-}1)$, where i is the number of category and m is the number of the categories. For example, the translated scores using seven categories from 1 to 7 are 0, 17, 33, 50, 67, 83, and 100. Shapiro-Wilk normality test showed that $L_{\text{Aeq,8-hour}}$ and speech privacy were not normally distributed. Thus, Spearman rank correlation coefficients were computed to examine the bivariate correlations between the variables. The independent samples t-tests were performed to compare groups (e.g., differences between the low and high skill variety groups' job satisfaction). Main effect of the offices on the $L_{\text{Aeq,1-min}}$ was assessed

Table 3
Sample question items for measuring each scale and Cronbach's alpha. The number in the bracket indicates the number of questions used to measure the scales.

Scale	Range	Sample question items (sub-scale)	Cronbach's alpha
Job satisfaction (3)	1 = strongly disagree, 7 = strongly agree	I find real enjoyment in my work.	0.90
Job characteristics (11)	1 = very inaccurate, 7 = very accurate		
Skill variety		The job requires me to use a number of complex or high-level skills.	0.71
Task identity		The job is arranged so that I can do an entire piece of work from beginning to end.	0.75
Task significance		The job is one where a lot of other people can be affected by how well the work gets done.	0.76
Autonomy		The job gives me considerable opportunity for independence and freedom in how I do the work.	0.81
Acoustic perceptions (5)			
Speech privacy	1 = none, 5 = all	How much do you hear the content of following sounds? (e.g., colleagues chatting)	0.88
Noise disturbance	1 = not at all, 7 = extremely	How disturbing do you find the following noises in your office? (e.g., colleagues chatting)	0.85
Noise sensitivity (5)	1 = strongly disagree, 6 = strongly agree	I am sensitive to noise.	0.89

Table 4
Results of the confirmatory factor analysis (CFA).

Factor	Question item	Factor loading	AVE	CR
Job satisfaction	Enthusiasm about my work	0.777	0.759	0.904
	Enjoyment in my work	0.898		
	Satisfaction with my present job	0.930		
Skill variety	Variety in my job	0.785	0.562	0.792
	Requirements of complete/high-level skills	0.638		
	Simpleness/repetitiveness of the job	0.815		
Task identity	Whole/identifiable piece of work	0.792	0.599	0.871
	Chance to completely finish the work I begin	0.692		
	Arranged to do an entire piece of work from beginning to end	0.831		
Task significance	A lot of other people can be affected	0.755	0.625	0.769
	Significance and importance in the broader scheme	0.820		
Autonomy	Autonomy in my work	0.666	0.604	0.820
	Independence/freedom in how I do the work	0.839		
	Chance to use my personal initiative/judgment	0.740		

using a one-way analysis of variance (ANOVA) because the $L_{Aeq,1\text{-}min}$ were normally distributed. Finally, the structural equation modelling (SEM) method was used to test the effects of moderating variables (e.g., low and high speech privacy) on the relationships between the latent variables (job characteristics and job satisfaction). Before testing the path model, validity and reliability of the items were assessed using Confirmatory Factor Analysis (CFA). As summarised in Table 4, convergent validity was assessed via factor loadings and Average Variance Extracted (AVE), and reliability was examined via Composite Reliability (CR). All factor loadings were statistically significant ($p < 0.01$) and greater than 0.6, which were acceptable values. Hair et al. [54] suggested cut-off values for AVE (0.5) and CR (0.7) to explain adequate convergence and good reliability. The calculated AVE ranged from 0.56 to 0.76 and the reliability estimates measured via CR ranged from 0.79 to 0.90. Moreover, Fisher's r to z transformation [55] was used to compare correlation coefficients. This study considered p values of<5% ($p < 0.05$) as statistically significant.

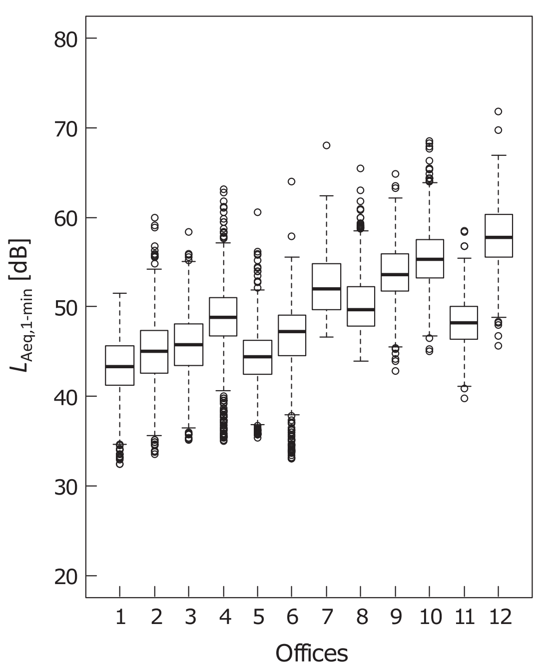

Fig. 2. Boxplots of the active noise levels ($L_{Aeq,1\text{-}min}$) for eight hours in the 12 offices. The box plot shows the median (bold line), the first quartile (lower border of the box) and the third quartile (upper border of the box); the whiskers indicate 1.5 times the interquartile range above and below the 75th and 25th percentiles. The circles indicate the outliers.

3. Results

3.1. Descriptive results

3.1.1. Offices

Fig. 2 shows the boxplots of the active noise levels during working hours ($L_{Aeq,8\text{-}hour}$) measured at each office. The mean of $L_{Aeq,8\text{-}hour}$ of the offices ranged between 44.7 and 60.3 dB. In particular, the active noise levels from the offices in the same building (#1–#6) varied between 44.7 and 51.2 dB, showing a good agreement with a previous study [33]. This result implies that active noise levels vary according to the employees' jobs and working environments even though room acoustic conditions are almost identical. On the other hand, the other offices (#7–#12) had slightly greater noise levels, varying from 49.1 to 60.3 dB. This might be because the working environments and job characteristics of these offices were different from those of offices #1–#6. For example, the employees were mainly communicating on the phone in offices #7, #10, and #12. In addition, offices #7–#12 had higher ceiling heights and more reflective materials on walls than the others. The result of ANOVA confirms that the $L_{Aeq\text{-}1min}$ values were statistically different across the offices [$F(8640, 17) = 942.774$, $p < 0.01$]. *Post hoc* comparisons via Tukey's test indicated that the $L_{Aeq\text{-}1min}$ values of the offices #1–6 were significantly lower than those of the offices #1–7 except for the office #4 which was not different from the office #11. Among the offices #1–6, three non-significant differences were found (#2 and #3, #2 and #5, and #3 and #6) because they have almost identical environmental conditions. On the other hand, the $L_{Aeq\text{-}1min}$ values of the offices #7–12 were all statistically different.

Room acoustics and speech privacy-related measures are listed in Table 5. Offices #1–#6 showed a shorter reverberation time (T_{20}) than offices #7–#12 due to the lower ceiling height and smaller room volumes. The $D_{2,S}$ results, varying from 4.2 to 7.9 dB, were quite small because the partition heights were not high. Offices #1–#6, the second measurement line of office #8, and office #9 showed smaller $D_{2,S}$ values due to the stronger reflections from columns and windows. Results of $L_{p,A,S,4m}$ were opposite; offices #1-#6 showed larger value than the other offices similarly due to the sound reflections from the room boundaries. $L_{p,A,S,4m}$ of offices #7–#12 varied from 45.8 dB to 49.4 dB showing, a quite small variation. Offices #1–#6 showed the largest r_D because of the lowest background noise level ($L_{p,A,B}$), whereas office #7 with the largest background noise level showed the smallest r_D.

3.1.2. Perceptions and job characteristics

The mean perceived speech privacy, %HD, and job satisfaction ratings are listed in Table 6. Speech privacy ratings ranged from

Table 5
Acoustic parameters measured from each office. T_{20} was averaged over 500 Hz and 1 kHz octave bands.

Offices	T_{20} [s]	$D_{2,S}$ [dB]	$L_{p,A,S,4m}$ [dB]	r_D [m]	$L_{p,A,B}$ [dB]
#1–#6	0.30	5.7	51.9	16.5	33.9
#7	0.44	7.4	48.6	9.7	40.3
#8	0.54, 0.52	7.9, 4.2	48.3, 49.4	10.8, 10.8	38.5, 39.2
#9	0.45	5.7	47.9	12.2	36.5
#10	0.43, 0.42	6.9, 7.2	47.3, 47.8	12.2, 15.0	35.5
#11	0.46	7.9	47.2	12.0	34.8
#12	0.34, 0.37	7.0, 7.7	47.6, 45.8	12.7, 10.6	35.6, 37.7

Table 6
Mean ratings of perceptions and job characteristics.

Offices	Speech privacy	%HD	Job satisfaction	Job characteristics			
				Skill variety	Task identity	Task significance	Autonomy
#1	43.2	15.8	71.4	**75.8**	75.5	77.6	65.8
#2	**43.1**	23.1	69.8	71.4	79.1	77.2	72.0
#3	45.1	25.0	72.5	74.5	**79.3**	81.4	72.4
#4	45.3	19.2	64.5	66.3	76.9	76.2	71.3
#5	48.8	**5.0**	65.6	67.1	71.4	**66.5**	**56.7**
#6	45.9	5.3	**73.9**	73.9	73.9	75.9	61.5
#7	49.5	33.3	64.4	68.5	**54.6**	76.9	68.1
#8	49.4	22.6	69.2	72.5	72.2	81.0	75.9
#9	44.9	**43.5**	64.7	75.0	70.0	**87.8**	**82.5**
#10	**59.9**	29.2	53.7	59.0	62.7	74.7	62.5
#11	52.3	20.0	61.8	53.8	63.9	73.5	63.7
#12	48.6	30.6	**53.3**	**53.2**	61.9	78.3	62.5

43.1 to 59.9, where the minimum and maximum ratings were from offices #2 and #10, respectively. The %HD varied from 5.0 (office #5) to 43.5 (office #9). The mean job satisfaction ratings ranged from 53.3 to 73.9 where the minimum and maximum ratings were from offices #12 and #6, respectively. The participants from the IT support team (office #6) showed the highest job satisfaction rating, whereas those from the call-centre (office #12) had the lowest rating. Skill variety ranged from 53.2 to 75.8 across the 12 offices, where the minimum and maximum ratings were from offices #12 and #1, respectively. Task identity ranged from 54.6 (office #7) to 79.3 (office #3) and five offices showed lower ratings than the mean of the whole. Task significance ranged from 66.5 (office #5) to 87.8 (office #10), while autonomy varied from 56.7 (office #5) to 82.5 (office #9).

3.2. Relationships between acoustic factors and job satisfaction

Table 7 shows the correlations between perceived speech privacy, %HD, active noise level ($L_{Aeq,8\text{-}hour}$) and job satisfaction. It was found that job satisfaction was significantly correlated with perceived speech privacy and $L_{Aeq,8\text{-}hour}$, whereas the relationship between %HD and job satisfaction was not significant. This indicates that the increase of speech privacy and active noise level led to a decrease in job satisfaction. It was also observed that $L_{Aeq,8\text{-}hour}$ showed a significant correlation with %HD, indicating the impact of active noise level on perceived noise disturbance.

3.3. Moderation effects on job satisfaction

The structural equation modelling (SEM) was computed to assess the effects of the moderating variables on the path between job characteristics and job satisfaction. In order to test the moderation effects, multi-group analyses were carried out. The participants were grouped into 1) low and high active noise level ($L_{Aeq,8\text{-}hour}$) groups, 2) low and high speech privacy groups, 3) low and high noise disturbance groups, and 4) low and high noise sensitivity groups. Table 8 shows the standardised estimates of the paths from the four job characteristics (skill variety, task identity, task significance, and autonomy) to job satisfaction across the moderating variables. First, job characteristics showed weaker relationships with job satisfaction for those with high active noise levels ($L_{Aeq,8\text{-}hour}$) except for autonomy which showed the opposite tendency. However, only the path between task identity and job satisfaction showed a significant difference among the four paths. It implies that the influence of task identity on job satisfaction became weaker in the offices with a high noise level. Second, job satisfaction's relationships with skill variety, task identity, and autonomy became stronger with higher speech privacy but only that with task identity significantly increased. In contrast, the associations between job satisfaction and task significance were almost the same for the low and high speech privacy groups. This presents that the effect of task identity on job satisfaction is stronger in better speech privacy conditions. Third, the impact of job characteristics on job satisfaction was not significantly changed across the level of noise disturbance. For instance, the association between task identity and job satisfaction was weakened for those with high noise disturbance but the difference between the groups was not significant. This result confirms that noise disturbance might not moderate the associations between job characteristics and job satisfaction. Fourth, for the low and high noise sensitivity groups, job satisfaction's paths with skill variety and autonomy remained the same. The effect of task identity on job satisfaction

Table 7
Correlation coefficients between acoustic parameters, acoustic perceptions, and job satisfaction ($^{**}p < 0.01$ and $^{*}p < 0.05$).

	Speech privacy	%HD	$L_{Aeq,8\text{-}hour}$ [dB]	Job satisfaction
Speech privacy	1	0.077	0.483	-0.608^{*}
%HD	0.077	1	0.734^{**}	-0.476
$L_{Aeq,8\text{-}hour}$ [dB]	0.483	0.734^{**}	1	-0.734^{**}
Job satisfaction	-0.608^{*}	-0.476	-0.734^{**}	1

Table 8
Standardised estimates of the structural equation models showing the effects of the moderating variables on the paths from job characteristics to job satisfaction (**$p < 0.01$; *$p < 0.05$). Underlined estimates showed there were significant differences between the compared groups.

	Acoustic factors						Non-acoustic factor	
	$L_{Aeq,8\text{-}hour}$		Speech privacy		Noise disturbance		Noise sensitivity	
	Low	High	Low	High	Low	High	Low	High
Skill variety – job satisfaction (RMSEA = 0.020; GFI = 0.965; CFI = 0.986; χ2/df = 1.667)	0.76**	0.61**	0.60**	0.72**	0.70**	0.73**	0.70**	0.70**
Task identity – job satisfaction (RMSEA = 0.016; GFI = 0.977; CFI = 0.993; χ2/df = 1.436)	<u>0.64**</u>	<u>0.35**</u>	<u>0.33**</u>	<u>0.59**</u>	0.49**	0.47**	0.51**	0.43**
Task significance – job satisfaction (RMSEA = 0.021; GFI = 0.984; CFI = 0.993; χ2/df = 1.721)	0.54**	0.39**	0.43**	0.42**	0.41**	0.45**	0.32**	0.53**
Autonomy – job satisfaction (RMSEA = 0.016; GFI = 0.977; CFI = 0.993; χ2/df = 1.434)	0.48**	0.53**	0.46**	0.52**	0.49**	0.48**	0.50**	0.50**

was slightly declined, while that of task significance increased. However, Fisher's r to z transformation showed that there was no significant difference between groups for all measures, indicating that self-reported noise sensitivity does not have any moderation effect on the relationship between job characteristics and job satisfaction.

4. Discussion

4.1. Physical acoustic environments and subjective acoustic perceptions

Sundstrom et al. [49] previously highlighted the potential contribution of the physical environment to perceived noise disturbance and job satisfaction in a conceptual model. In particular, they proposed a hypothetical model, indicating the relationship between physical environment conditions and environmental satisfaction. In order to validate their model, the present study investigated the relationships between acoustic measures and perceived noise disturbance as a form of percentage of highly disturbed by noise (%HD) by assuming that the acoustics is one of the physical environmental conditions. Confirming the hypothesis, it was found that active noise level ($L_{Aeq,8\text{-}hour}$) was highly correlated with %HD. However, other speech privacy-related measures in the ISO 3382-3 did not show any significant correlation with %HD. This result is not consistent with the finding of Haapakangas et al. [34], in which most speech privacy-related measures (r_D, $L_{p,A,S,4m}$, and $L_{p,A,B}$) were significantly correlated with %HD. The disagreement may be attributed to the ranges of acoustic environments of the open-plan offices. Haapakangas et al. [34] studied 21 open-plan offices with greater variations of acoustics; for instance, r_D ranged from 2.5 m to 14 m. It was observed that job satisfaction ratings had negative correlations with $L_{Aeq,8\text{-}hour}$ and perceived speech privacy, indicating that lower active noise level and less speech privacy are helpful to improve job satisfaction. This is consistent with existing findings which reported the negative correlation between noise exposure level and job satisfaction [56]. Moreover, those with high active noise levels showed a weakened association between task identity and job satisfaction (Table 8), supporting the hypothesis of Sundstrom et al. [49].

Lee et al. [40] reported that job satisfaction was significantly influenced by perceived speech privacy. The present study confirmed this by showing the significant correlation between speech privacy and job satisfaction. In addition, this study showed that speech privacy had some moderation effects on the paths between job characteristics and job satisfaction. Particularly, the association between task identity and job satisfaction became significantly stronger with high speech privacy. However, the percentage of highly disturbed by noise (%HD) did not have any significant effect on job satisfaction. Moreover, noise disturbance did not have any moderation effect on the paths between job characteristics and job satisfaction. These results are in line with previous findings in which the inverse relationship between noise disturbance and job satisfaction was not very strong or not statistically significant [40,49]. In their path model, Lee et al. [40] found a non-significant association between noise disturbance and job satisfaction ($\beta = -0.19$) and Sundstrom et al. [49] also reported a weak correlation between noise disturbance and job satisfaction ($r < 0.20$). Both studies suggested that further evaluation of job characteristics may yield a better understanding of the link between noise perception and job satisfaction. However, the present study found that job satisfaction was not well explained by noise disturbance and job characteristics. In addition, noise disturbance did not have any significant moderation effect on the paths between job characteristics and job satisfaction. These results imply that perceived satisfaction cannot be predicted only by noise and thus, better understanding would be obtained with other environmental variables covering both physical and subjective data [49].

4.2. Job characteristics and job satisfaction

Lee et al. [40] discussed that there is a need for further investigation into the diverse components of job characteristics and their mutual associations with job satisfaction and acoustic factors. The present study tested how the relationships between job characteristics and job satisfaction were affected by moderating variables such as acoustic and personal factors. It was observed that the impact of task identity on job satisfaction significantly changed across the groups with low and high speech privacy ratings and active noise levels. Task identity represents "the degree to which the job requires completion of a whole and identifiable piece of work [45]". This dimension also evaluates how much employees do a job from beginning to end and clearly identify the result of their efforts [57]. Its significant changes may imply that this particular job characteristics index has more sensitive links to acoustic environments. Furthermore, Loher et al. [48] earlier reviewed 28 studies on the relationship between job characteristics and job satisfaction, and reported that the sample-weighted correlation coefficient between job characteristics index and job satisfaction was about 0.39. In the present study, the standardised estimates of the path from task identity to job satisfaction were 0.33 and 0.35 for those who perceived low speech privacy or high active noise level, respectively. The estimates significantly increased with improvements in speech privacy (i.e. high speech privacy) and active noise level (i.e. low active noise level). This tendency agrees well with Locke [58] who earlier emphasised that "dissatisfaction accompanies unpleasant or stressful physical working conditions, but employees take favourable working conditions for granted and experience positive gains in satisfaction only through other job characteristics such as job autonomy or task variety [49,58]". In agreement with Locke [58], job characteristics did not have significant impacts on job satisfaction with poor physical conditions of office environments. In other words, the impacts of job characteristics on job satisfaction became significant in the offices with favourable acoustic conditions. Moreover, noise sensitivity did not have any moderation effect on the association between job characteristics and job satisfaction. It is in agreement with Lee et al. [40] who also reported a non-significant impact of noise sensitivity on job satisfaction in their path model. However, they found an interaction effect of noise sensitivity on the influence of speech privacy on job satisfaction. Employees who had high noise sensitivity reported lower job satisfaction when speech privacy was poor, indicating noise sensitivity would be an appropriate measure to predict acoustic-related responses. The present study followed the idea of job satisfaction defined in earlier studies [42–44]. As Hoppock [42] stated, job satisfaction is a combination of psychological, physiological and environmental circumstances affecting a person to say that he/she is satisfied with his/her job. The present study particularly focused on the environmental circumstance by assessing the acoustic environment and examined how it is associated with the way the employees like (satisfaction) or dislike (dissatisfaction) their jobs [43,44]. To measure this, the present study used the Global Job Satisfaction which assesses respondents' job satisfaction in general. Since there are different kinds of questionnaires on job satisfaction designed for various purposes, future research may consider using these instruments depending on its research aim. For instance, some questionnaires (e.g., Job Descriptive Index [59]) examine specific dimensions (e.g., satisfaction with coworkers, pay, promotional opportunities etc.) considering them as crucial determinants of job satisfaction.

4.3. General discussion

Limitations in the present study can be supplemented in future research. First, the variation of the partition heights in the present study was smaller compared to previous studies. For example, Virjonen et al. [60] studied open-plan offices with partition heights ranging from 1.2 m to 1.7 m and Utami et al. [61] estimated how privacy and disturbance in open-plan offices were affected by partitions with different heights ranging from 1.25 m to 1.85 m. Given that the speech privacy-related measures in the present study, in particular, $D_{2,S}$ and r_D, showed a small range, the offices with various partition heights and speech privacy conditions could be examined. Second, the acoustic parameters did not correspond to each participant; thus, future research could obtain physical data and predict how the acoustic environment at each workstation associates with individuals' subjective responses. This study found that acoustic factors are limited to fully explain job satisfaction. Therefore, additional physical environmental variables (e.g., temperature and lighting) would be helpful to further explain job satisfaction. Third, Hackman and Oldham [45] introduced five core dimensions (skill variety, task identity, task significance, autonomy, and feedback from the job itself) to measure the critical psychological states and later added two supplementary dimensions (i.e. feedback from agents and dealing with others). Given that the present study only used four out of the five core dimensions measuring two critical psychological states, the use of the full scale would be helpful to extend the understanding of the associations between the concerned variables.

In the present study, the $D_{2,S}$ values were quite small due to the low partition heights (<1.2 m). In addition, the offices #9–#12 had only front partitions and the offices #7 and #8 did not have any partition between workstations. Consequently, perceive speech privacy ratings were not satisfactory and it resulted in a decrease of job satisfaction. Several studies [19–21] have demonstrated the importance of the partition height to improve physical and perceptual speech privacy. Thus, the offices of the present study could adopt this strategy to enhance speech privacy. The offices #1–#6 with identical environments showed a variation of active noise levels, which led to fluctuations of perceptual ratings such as speech privacy and noise disturbance. Thus, noise masking system could be introduced in the offices #1–#6 in the future.

5. Conclusions

The relationships between physical and subjective acoustic factors, employees' job characteristics, and perceived job satisfaction have been investigated through the acoustic measurements and questionnaire surveys. The moderation effects on the relationship between job characteristics and job satisfaction have also been examined. Several acoustic parameters showed significant correlations with job satisfaction. In particular, job satisfaction showed negative correlations with active noise level for 8 h ($L_{Aeq,8\text{-}hour}$) and perceived speech privacy. On the other hand, noise disturbance (%HD) did not have a significant influence on job satisfaction. The active noise level was highly correlated with %HD, implying its significant impact on noise disturbance. Active noise level and speech privacy showed significant moderation effects on the relationship between task identity and job satisfaction. Future research is required to further understand job satisfaction by considering other environmental variables.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apacoust.2020.107425.

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3

JOB DEMANDS-RESOURCES MODEL

Its applicability to the workplace environment and human flourishing

Michael Roskams, Eileen McNeely, Dorota Weziak-Bialowolska, and Piotr Bialowolski*

1 Background

The job demands-resources (JD-R) model (see Figure 3.1; Demerouti, Bakker, Nachreiner, & Schaufeli, 2001; Bakker & Demerouti, 2014, 2017) is one of the most popular and influential models of work stress in the literature. The model can be summarised in a series of simple yet compelling propositions. All jobs share common characteristics that can be classified as 'demands' or 'resources', based on their effect on an employee. Demands instigate a health impairment process characterised by strain and exhaustion, eventually leading to burnout and other negative work outcomes. Resources stimulate work engagement, leading to higher motivation and other positive work outcomes. As such, the challenge for those tasked with job design is to minimise demands whilst maximising resources.

The JD-R model has become immensely popular in the two decades following its inception, inspiring hundreds of empirical articles and being used within thousands of organisations worldwide (Demerouti, Bakker, & Xanthopoulou, 2019). As a result of its broadness and generalisability, it has been found to be equally applicable across a range of ostensibly diverse professional environments (Demerouti et al., 2019). The strength of the model lies in its ability to move beyond surface-level differences and identify the common characteristics that are universally associated with work outcomes.

The chapter is structured as follows. Firstly, the JD-R model is outlined in more detail. Secondly, a domain-specific extension of the JD-R model, termed the environmental demands-resources (ED-R) model, is presented and evaluated. Finally, the chapter concludes with a discussion of how the ED-R model ties in with theories of human flourishing and can be used to support a *salutogenic* (i.e., health-promoting) approach to well-being in the workplace.

1.1 Outline of the JD-R model

The JD-R Model assumes that every job shares common risks and opportunities for impaired or enhanced well-being and functioning. These characteristics can be divided into two broad categories: *job demands* and *job resources*.

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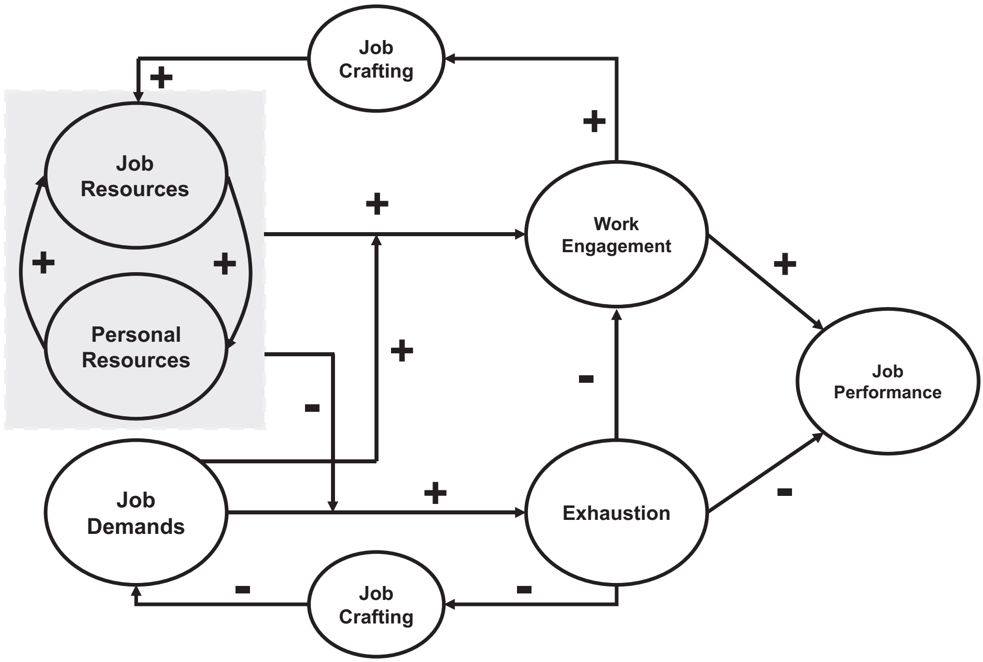

Figure 3.1 The job demands-resources model (Bakker & Demerouti, 2014)

Job demands are defined as "those physical, social, or organizational aspects of the job that require sustained physical or mental effort and are therefore associated with certain physiological and psychological costs" (Demerouti et al., 2001, p. 501). Importantly, demands should be valued negatively by the employee (as opposed to difficult but positively valued challenges, which provide an opportunity to develop mastery and personal growth; Schaufeli & Taris, 2014). Examples of such demands might include an irregular work schedule and demanding interactions with clients, amongst others.

Conversely, job resources are defined as "those physical, social, or organizational aspects of the job that may do any of the following: (a) be functional in achieving work goals; (b) reduce job demands and the associated physiological and psychological costs; (c) stimulate personal growth and development" (Demerouti et al., 2001, p. 501). Examples here could include organisational factors such as supervisor support and goal clarity, but they can also be widened to include personal resources such as resilience and interpersonal skills (Xanthopoulou, Bakker, Demerouti, & Schaufeli, 2007).

Job demands and resources affect numerous work outcomes through two mediating pathways. First, the process of *exhaustion* is instigated by high demands and few resources. Chronic job demands require the employee to expend high levels of energy to achieve their work-related goals, with insufficient time for recovery. Eventually, this leads to a state of exhaustion. Similarly, a lack of job resources leads to a state of disengagement whereby the employee loses the motivation to expend effort to complete work. The combination of exhaustion and disengagement is symptomatic of burnout, which is in turn associated with various negative outcomes (e.g., absenteeism, impaired physical and mental health).

Whilst the absence of job resources causes demotivation, their presence can trigger a separate pathway termed *work engagement*. Job resources are intrinsically motivating because they satisfy fundamental human needs, thus engendering an engaged state of mind characterised by vigour (i.e., high levels of energy and mental resilience whilst working), dedication (i.e., a sense of significance, enthusiasm and challenge), and absorption (i.e., high levels of focus and feeling engrossed in one's work). In turn, work engagement is then associated with numerous positive outcomes (e.g., higher productivity, extra-role performance, positive affect at work).

Finally, the JD-R model also highlights the role of *job crafting*, which refers to proactive strategies taken by employees to alter the nature of their work (*task crafting*), their relationships with colleagues and clients (*relationship crafting*), and/or their appraisal of their work (*cognitive crafting*) (Wrzesniewski & Dutton, 2001). When given the autonomy to do so, employees can thereby attempt to reduce perceived job demands and enhance job resources, thereby making the work more enjoyable and meaningful.

Altogether, the JD-R model has received good empirical support in the literature. Synthesising the large evidence base, different meta-analyses have confirmed the positive associations between job resources and work engagement (Christian, Garza, & Slaughter, 2011; Crawford, LePine, & Rich., 2010; Halbesleben, 2010) and between job demands and burnout (Alarcon, 2011; Crawford et al., 2010). Furthermore, research also supports the propositions that work engagement is positively associated with dedication and commitment (Halbesleben, 2010; Christian, Garza, & Slaughter, 2011), whereas burnout is negatively related (Alarcon, 2011). A meta-analysis including only longitudinal research also supports the claims of the model (Lesener, Gusy, & Wolter, 2019), providing more rigorous evidence to suggest that the concepts are causally related to one another, as opposed to being merely associated.

Overall, therefore, the JD-R model is a simple, yet effective, framework for representing the nature of work. In particular, it highlights three ways in which jobs can be adapted to improve employee well-being and productivity: (i) through the mitigation of job demands; (ii) through the enhancement of job resources; and (iii) through the facilitation of job crafting.

2 Applicability to workplace studies

Although the original conceptualisation of the JD-R model by Demerouti et al. (2001) acknowledges that an unfavourable physical work environment could be considered a job demand, the empirical JD-R literature has largely neglected the role of the physical environment as a potential source of job demands and resources (instead focusing on personal, social, and organisational factors). Correspondingly, the physical environment literature has tended to suffer from a lack of theory, where individual studies are typically segmented by discipline and unconnected to any conceptual framework (Ashkanasy, Ayoko, & Jehn, 2014; Sander, Caza, & Jordan, 2018; Weziak-Bialowolska, Dong, & McNeely, 2018).

However, research from a variety of built environment disciplines (e.g., indoor environment quality, environmental psychology, corporate real estate, facilities management) clearly demonstrates that many aspects of the workplace environment have the same effects as other job demands and resources, and that many common behaviours within the workplace can be considered as examples of crafting. This can be presented separately as the ED-R model (see Figure 3.2).

2.1 Environmental demands

Environmental demands can be defined as aspects of the workplace environment that require an additional and sustained exertion of physical and/or mental effort, resulting in physiological and/or psychological strain.

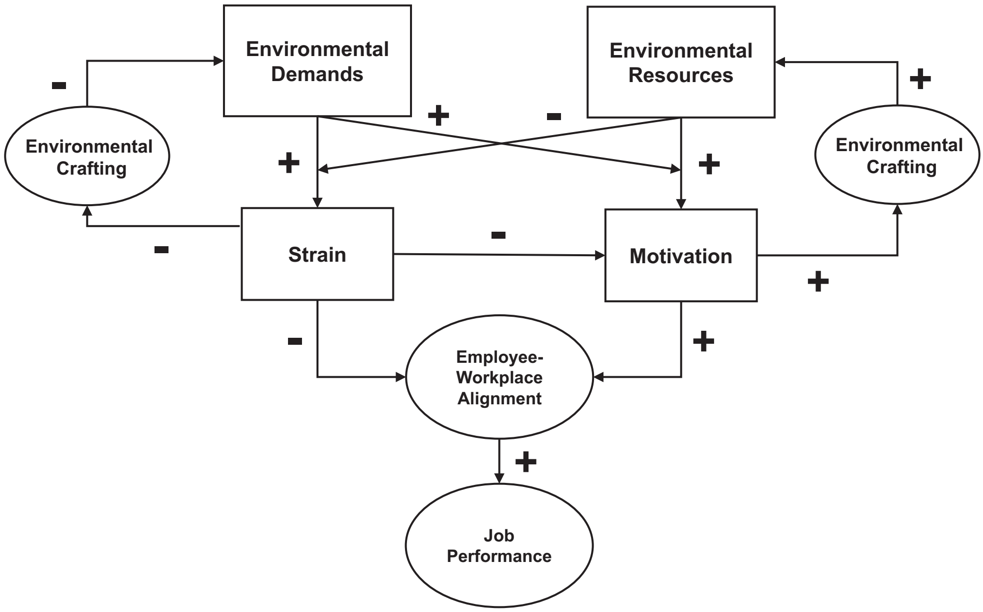

Figure 3.2 The environmental demands-resources model (Roskams & Haynes, 2019)

For example, polluted indoor air can be considered an environmental demand, as it has a negative impact on cognitive performance (Allen et al., 2015; Satish et al., 2012, Zhang, Wargocki, Lian, & Thyregod, 2016) and contributes to the development of 'sick building syndrome' symptoms, such as headaches, tiredness, and respiratory difficulties (Seppänen, Fisk, & Mendell, 1999; Tsai, Lin, & Chan, 2012). Other environmental factors which could deplete employees' energetic reserves might include uncomfortable temperatures (Rupp, Vásque, & Lamberts, 2015; Wyon & Wargocki, 2006), inadequate lighting (Boyce et al., 2006), and insufficient exposure to daylight (Jamrozik et al., 2019) (see also Chapter 13 The Theory of Attractive Quality).

Environmental demands may be particularly prevalent in modern open-plan offices, compared with traditional private offices. In shared workspaces, employees are frequently exposed to distraction by irrelevant background speech (Bodin Danielsson & Bodin, 2009; Haapakangas, Hongisto, Eerola, & Kuusisto, 2017; Mak & Lui, 2012), leading to an estimated tenfold increase in acoustic complaints (Pejtersen, Allermann, Kristensen, & Poulsen, 2006) and a doubling in the amount of time wasted due to noise (Kaarlela-Tuomaala, Helenius, Keskinen, & Hongisto, 2009) relative to enclosed offices. Open-plan offices also increase perceptions of crowding and low privacy (Sundstrom, Burt, & Kamp, 1980), leading to emotional exhaustion (Laurence, Fried, & Slowik, 2013) and lower job satisfaction (Weziak-Bialowolska et al., 2018) amongst employees.

2.2 Environmental resources

Environmental resources can be defined as aspects of the workplace environment whose presence is associated with an enhanced ability to cope with demands and/or higher levels of work engagement.

For example, certain features of the workplace environment are effective in promoting recovery from stress. In particular, 'biophilic' design strategies (i.e., the integration of nature and natural analogues into the indoor built environment; see also Chapter 15 The Biophilia Hypothesis) have received significant research attention, building upon research that demonstrates that exposure to nature reduces psychological and physiological stress (Hartig, Mitchell, de Vries, & Frumkin, 2014). When nature is brought into the office environment, most typically through interior plants, benefits include not only lower subjective stress but also higher health and job satisfaction, improved information processing and management, greater attention capacity, and higher self-rated productivity (Kaplan, 1993; Lohr, Pearson-Mims, & Goodwin, 1996; Nieuwenhuis, Knight, Postmes, & Haslam, 2014; Raanaas, Evensen, Rich, Sjøstrøm, & Patil, 2011; Smith & Pitt, 2009). In line with the definition that resources should be inherently engaging, biophilic design has also been observed to have an *instorative* effect (i.e., a positive impact on energy even in the absence of prior ego depletion; Beute & De Kort, 2014).

The objects of workspace personalisation also serve as important environmental resources. Up to 90% of employees personalise the workspace with personally meaningful objects, such as photos of loved ones or artwork, if they have an opportunity to do so (Wells & Thelen, 2002). This imbues the workplace with a sense of meaning (Brunia & Hartjes-Gosselink, 2009) and helps to accelerate the development of personal identity in the workplace (Ashkanasy et al., 2014). In this way, the objects of personalisation act as visual stimuli which remind the employee of the deeper purpose of their work, which in turn helps to foster engagement and increased effort in the face of demands.

2.3 Environmental crafting

Finally, there is also good evidence to suggest that many behaviours within the workplace can be understood as examples of *environmental crafting*, in that they are directly motivated by a desire to improve one's working environment, through the mitigation of demands and/or the enhancement of resources.

For example, if they have the ability to do so, employees act in various ways to reduce discomfort in the workplace environment. In response to the demand of distracting background noise, it is common for employees to use headphones to improve acoustic comfort (Oseland & Hodsman, 2018). In response to the demand of uncomfortable temperatures, employees might use personal fans or heaters to improve thermal comfort (Rupp et al., 2015). If the workplace environment is perceived as stale and corporate, then the act of personalisation is another example of environmental crafting, motivated by the desire to have easy access to resources at one's workspace.

Employees working in offices with flexible working arrangements often have an even greater ability to craft their working environment. By providing more freedom over where and when to work (referred to as *spatial crafting* and *time crafting*, respectively; Wessels et al., 2019), employees become better able to ensure that their working environment has few demands and abundant resources.

2.4 Relationship to human flourishing

Overall, the presence of demands and resources (relative to each individual's idiosyncratic needs and preferences) determines the level of 'alignment' between the employee and the workplace. In turn, more aligned workplaces will have a more positive impact on human flourishing (see also Chapter 14 Flourish Theory). As such, the ED-R model can be used to support a regenerative culture of well-being within organisations, in line with wider initiatives towards sustainable development goals (McNeely, 2018; Serafeim, Rischbeith, & Koh, 2020; Wahl, 2016).

Essentially, flourishing can be understood as a state of fulfilment which arises when universal human needs are met. Specifically, the concept of human flourishing is conceptualised as a general construct with five distinct but interrelated components: life satisfaction and happiness; mental and physical health; meaning and purpose; character strengths; and close social relationships (VanderWeele, 2017; VanderWeele, McNeely, & Koh, 2019). By systematically identifying and mitigating demands whilst enhancing resources, an environment more conducive to flourishing is provided.

Indeed, the ED-R model is congruent with more general frameworks for human flourishing within organisations. For example, the SHINE (Sustainability and Health Initiative for Net-Positive Enterprise) model (see Figure 3.3) developed at the Harvard T.H. Chan School of Public Health draws from a rich bank of literature in the social, psychological, management, and health sciences to identify key elements associated with human need fulfilment, resiliency, work performance, and engagement (Braunchli, Jenny, Fullemann, & Bauer, 2015; Grossmeier et al., 2020; Jenny, Bauer, Vinje, Vogt, & Torp, 2017; Kaufman, 2020; Medvedev & Landhuis, 2018; Roskams & Haynes, 2019, Weziak-Bialowolska, Bialowolski, Leon, Koosed, & McNeely, 2020c). These key elements support flourishing precisely because they constitute specific resources or assets needed for employees to mitigate demands. The data thus far confirm the importance of these work arrangements for driving performance at work and overall flourishing in life and therein reaffirm the overall premise of the ED-R model (Bialowolski, McNeely, VanderWeele, & Weziak-Bialowolska, 2020; Gale, Mordukhovich, Newlan, & McNeely, 2019; Weziak-Bialowolska, Koosed, Leon, & McNeely, 2017; Weziak-Bialowolska et al., 2018; Weziak-Bialowolska, McNeely, & VanderWeele, 2019a; Weziak-Bialowolska, Bialowolski, & McNeely, 2019c, 2020a; Weziak-Bialowolska, Bialowolski, Sacco, VanderWeele, & McNeely, 2020b; Weziak-Bialowolska et al., 2020c).

Most importantly for this chapter, the SHINE model highlights the importance of physical working conditions as a key component of a regenerative work environment (alongside more general psychosocial job characteristics). In line with the salutogenic perspective and towards the overall aim of providing jobs which enhance rather than detract from well-being, the ED-R model can be used for the specific purpose of optimising the workplace environment.

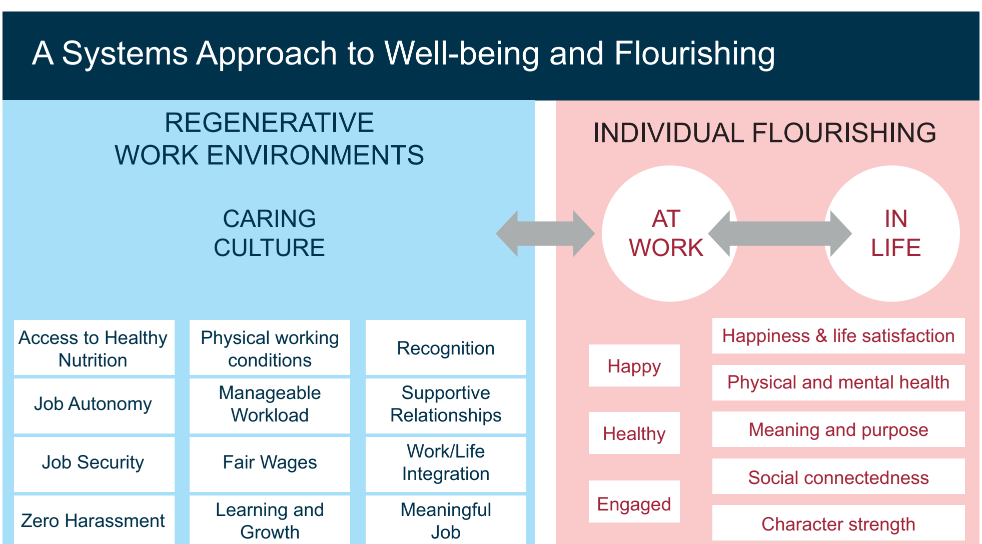

Figure 3.3 SHINE work and well-being model

3 Methodological/research approaches

A variety of research methodologies can, and should, be used to empirically validate the propositions of the ED-R model. The model is in a nascent stage, and it will be necessary to confirm the assumed relationships between environmental demands and strain, between environmental resources and motivation, and between employee-workplace alignment and flourishing.

Firstly, recognising the fact that the majority of workplace environment research has focused largely on pathogenic factors, more research is needed to test the relationship between different environmental resources and different components of flourishing. The flourishing index (FI), which is embedded in the overarching SHINE model and has shown good psychometric properties (Weziak-Bialowolska et al., 2019a; Weziak-Bialowolska, McNeely, & VanderWeele, 2019b), can be a suitable tool for this type of research. Using this framework, research(ers) would assess the ways in which a comprehensive, yet not exhaustive, set of different workplace demands and resources can affect general life satisfaction and happiness, mental and physical health, meaning and purpose, social connectedness, and character strengths of overall flourishing.

Secondly, researchers must resist the urge to restrict their inquiries solely to their own specialisms and instead to consider the entirety of environmental forces acting upon office occupants. A workplace intervention might successfully achieve a reduction in one environmental demand but inadvertently increase other demands and/or decrease resources, resulting in a worse working environment. The need to evaluate a comprehensive set of workplace factors across various work settings prompted the development of the SHINE model. To advance knowledge in the field, researchers should apply a consistent and broad set of workplace factors in longitudinal cohorts and use rigorous methods, such as pre-/post-intervention studies, ideally with a control group, to test assumptions of causality within the ED-R model. Further, qualitative techniques such as interviews and focus groups might be useful for identifying important demands or resources which have not yet been considered by the researchers.

Finally, to provide practitioners with more useful insight, it would be important to link employees' perceptions with objective assessments of environmental conditions. By comparing subjective and objective data, it would help confirm which conditions are associated with better or worse outcomes, such as work performance, engagement, and flourishing. The challenge for the aggregation of both subjective and objective information is that both environmental conditions and subjective perceptions are liable to momentary fluctuation, which can result in a lack of concordance or measurement accuracy of the intended condition or outcome. For example, the perception of poor air quality could be missed by employees completing a survey shortly after a momentary mechanical failure of the ventilation system. Instead, it may be more suitable to use either longitudinal survey data linked with continuous objective measurements of working conditions or repeated random experience sampling to assess employee-workplace interactions on a moment-by-moment basis (e.g., Roskams & Haynes, 2020).

4 Limitations

The ED-R model shares the limitations of the JD-R model (e.g., Schaufeli & Taris, 2014). Specifically, the generalisability of the model comes at the cost of limited specificity; no predictions are made within the ED-R model about the strength of the relationships between different demands, resources, and outcomes. It also remains unclear whether combinations of different demands and/or resources are additive or multiplicative in their effects. Hence, whilst the ED-R model can be viewed as a comprehensive meta-theory for the workplace environment, it would also be necessary to apply other frameworks, such as the SHINE model, to explain the numerous specific factors and relative relationships in the model with greater detail and predictive power.

5 Theory relevance to practice

This chapter explored the conditions for 'healthy work' by exploring the JD-R model in relation to the workplace environment and then examining how this approach aligns with the more general SHINE model for flourishing at work. Evidence-based approaches to workplace practice should be contextualised within these theoretical frameworks and explicitly guided towards connecting workplace resources directly to performance and overall flourishing.

Specifically, workplace practitioners can apply the ED-R model to practice by implementing top-down strategies such as identifying and mitigating environmental demands (e.g., monitoring and reducing airborne pollutants) and increasing the presence of environmental resources (e.g., using biophilic design within the office). This process can be supported by a typology of environmental demands and resources, derived from previous research (see Roskams & Haynes, 2021). Practitioners should have a good understanding of the various environmental factors which may impact an employee's well-being and productivity and aim to ensure that the workplace is designed and maintained in such a way that it will continue to provide physical, functional, and psychological comfort for users.

However, it should also be recognised that significant inter-individual variability exists between different individuals and different types of work, and the strategies required to provide an optimal working environment may vary depending on these circumstances. Interventions delivered at the group level are likely to be welcomed by some employees but considered unhelpful by others. Hence, the top-down strategies should be complemented with bottom-up, user-directed strategies designed to facilitate the individual process of environmental crafting (e.g., implementing flexible workplace policies). This will allow the workplace users themselves to ensure that their working environment is free of demands and abundant in resources.

By applying these strategies, the hidden arrangements at work which give rise to both harms and benefits can be made visible. The approach presented in this chapter emphasises a holistic model of well-being in which work systems can be optimised to address specific human needs, such as social connectedness, or designed to affect multiple outcomes simultaneously. By uncorking the user experience of work in relation to their well-being, it becomes possible to gain new insights and opportunities to build a regenerative workplace that fits with the goals of sustainability and societal well-being.

6 Further reading

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