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A socio-technical perspective on the application of green ergonomics to open-plan offices

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Abstract: Open-plan office (OPO) layouts emerged to allow organizations to adapt to changing workplace demands. We explore the potential for OPOs to provide such adaptive capacity to respond to two contemporary issues for organizations: the chronic challenge of environmental sustainability, and the acute challenges emerging from the great COVID-19 homeworking experiment. We apply a socio-technical systems perspective and green ergonomics principles to investigate the relationship between an OPO environment and the occupants working within it. In doing so, we consider the relevant technical and human factors such as green technology and employee green behavior. We also consider how a green OPO might provide non-carbon benefits such as improving occupant wellbeing and supporting the emergence of a green organizational culture. Our investigation highlights several avenues through which an OPO designed with green ergonomic principles could benefit occupants, the organizations they work for, and the natural environment of which they are a part and on which they depend. We find reason to suspect that green OPOs could play an important role in sustainable development; and offer a research agenda to help determine whether in fact OPOs are another example of how going green is good business.

Keywords: Open-plan office; socio-technical systems; green ergonomics; biophilic design; sustainable development; human factors.

1. Introduction

Government targets around Net Zero Emissions (S. J. Davis et al., 2018) demonstrate that sustainability is now a mainstream priority for organizations in most, if not all, sectors. For some time, sustainability was an alternative to traditional business practices. In recent years, however, evidence demonstrating the success of businesses engaging with the green agenda lend weight to the claim being green makes good business sense (Holme, Watts, & World Business Council for Sustainable Development, 2000). Moreover, scholars have begun to recognize that sustainability is an essentially *human* activity (see Pfeffer, 2010). In response to this imperative, modern businesses (and not just those on the green fringe) are publishing "Net Zero" (and, more recently, "Net Gain") ambitions and building action plans to ensure that they can adapt to a changing regulatory environment, one in which poor environmental management will carry tangible consequences. Board members, sensibly, want to avoid following in the footsteps of peers now facing criminal charges for failing to demonstrate effective governance (e.g., Campbell & Vladkov, 2021).

More recently still, the focus of business since 2020 is on the acute issue of COVID-19, and organizations globally are undergoing a rapid transformation in response to this pandemic. As countries around the world went into various forms of lockdown, organizations experienced a radical shift as office-based staff began working remotely in an effort to curb the virus' spread. This represents a sudden accelera-

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tion in the trend towards remote working (Global Workplace Analytics, 2017). The full implications of this mass remote-working experiment will emerge over time, and might include changes in employee office schemas, and how organizations use their office space. This includes those businesses following the trend of open-plan offices (OPOs) that emerged in the latter part of the 20th century (Davis, Leach, & Clegg, 2011). Bodin Danielsson and Bodin (2008) define such offices as shared rooms or spaces with more than four workstations and minimal partitions between occupants, which provide the capacity to accommodate large numbers of workers, and the flexibility to accommodate changing requirements.

An indirect effect of the COVID-19 pandemic, and in particular its effect on office-based work, could be in addressing the issue of OPOs compromising workers' access to appropriate workstations for focused work. In a pre-pandemic survey Leaman and Bordass (2007) found that workers in OPOs show a tendency to work from home when they require a quiet environment with minimal distractions. If COVID-19 is accelerating a transition to more digital ways of working, and with workers and organizations adapting to remote working and the use of “third places” (Oldenburg, 1989), then a company's office may similarly transition from being "the place where work happens" to "a place where some types of work happen".

In this article, we propose that OPOs sit at the confluence of organizations trying on the one hand to make meaningful steps towards reducing their environmental impact, and on the other hand adapting to post-pandemic ways of working. In imagining the OPO of the future, we consider how such a space could enable organizations to reduce their environmental impact, while simultaneously providing a working environment that supports the health, wellbeing, and productivity of employees.

We unpack this by first revisiting the main arguments for and against OPOs. Next, we review the field of green ergonomics, which focuses on developing human systems that integrate with the natural environment. We then consider the technical (e.g., how green OPOs help conserve, preserve, and restore nature), socio-technical (i.e., the interaction of workers with their work environment), and social (e.g. the green OPO as a way for a company to project its sustainability ambitions) aspects of OPOs as these pertain to sustainable development. Finally, we outline an agenda for future research in this area.

2. Factors to be considered in OPOs

In this section, we discuss the pros and cons of OPOs, before turning our focus to look at issues of place attachment in OPOs, as well as how multiple stakeholders can compete for spaces in shared offices. Finally, we look to the impact of OPOs on occupant behavior.

2.1 Pros and cons of OPOs

Outcomes of empirical studies into physical work environment such as OPOs presents a tension (Elsbach & Pratt, 2009). Specifically, OPOs can be profitable and yet detrimental for organizations (Ayoko & Ashkanasy, 2020). For example, advocates of OPOs believe that they stimulate cooperation, social relations, communication, feed-

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back, solidarity, teamwork, and knowledge-sharing between workers while helping to inculcate a commitment to organizational values (McGuire and McLaren, 2009; Kaarlela-Tuomaala, Helenius, Keskinen, & Hongisto, 2009). Results from this stream of studies also suggest that OPOs facilitate work satisfaction, creativity (Marmot & Eley, 2000) and reduce overhead costs (Oommen, Knowles & Zhao, 2008).

In contrast, another stream of studies suggests that OPOs lead to distraction and lack of privacy (Lee and Brand, 2005; Perrin Jegen & Chevret, 2016). In this regard, Lee and Brand (2005) investigated employees' perceptions of physical work environment. Results from employees in five different American organizations showed that perceived distraction levels in the workplace is negatively relate to satisfaction with the physical work environment. Similarly, these authors found that the perceived levels of personal control over the physical work environment (i.e., the opportunity to influence aspects of one's environment such as thermal condition or lighting) is positively related to the physical environment and job satisfaction.

Additionally, Perrin et al. (2017) found that employees' satisfaction depends on the general ambient sound, on noise management, and on the physical positioning of workstations. Furthermore, they found that employees are least satisfied in administrative open-plan spaces. Brennan, Chugh and Kline (2002) corroborate this, finding that moving to an OPO increased employees' physical stress, decreased satisfaction with the physical environment, reduced team member relations, and lowered perceived job performance. Also, noise in OPOs can have detrimental effects on performance, fatigue, and motivation, the extent of which varies with the level of cognitive processes and hearing status a task requires (Jahncke & Halin, 2012).

In terms of interactions, we are aware that OPOs may also trigger conflict and similar difficulties (Ayoko & Hartel, 2003; Bodin Danielsson, Bodin, Wulff, & Theorell , 2015). In particular, Bodin Danielsson and her team found a significant influence of office type on workplace conflicts among women (not among men), which persisted after adjusting for noise disturbances. They conclude that other environmental factors inherent in this office layout might thus account for the existence of conflicts. One such explanation is that proximity between workstations escalates cognitive workload and decreases privacy (De Croon, Sluiter, Kuijer, & Frings-Dresen, 2005). In contrast, Davis, Leach and Clegg (2020) note that open-plan layouts can facilitate serendipitous discussions and meetings that might otherwise not occur, and that personal autonomy could moderate whether an OPO environment is seen as distracting or enriching.

Researchers have also found that the air quality, noise (Kaarlela-Tuomaala et al., 2009; Boden Danielsson & Bodin, 2008; Jensen et al., 2005; Brennan et al., 2002), ergonomic conditions, and lack of privacy are significant predictors of psychological well-being (see also Herbig, Schneider, & Nowak, 2015). Studying noise impact in open-plan working environments in China, Zhang and her colleagues (2012) show that acoustic environment evaluations significantly correlate with fatigue, depression, and hypersensitivity to loud sounds. The authors also found significant correlations between job satisfaction and evaluation of various acoustics-related factors. For example, Jahncke and Halin (2012) found that noise negatively impacts Swedish students' cognitive performance and motivation (as well as fatigue) in laboratory study.

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In their research, Herbig and her colleagues (2015) also demonstrate that stressors and environmental satisfaction mediate the effect of office space occupation on employee health, but this relationship is not mediated by psychosocial work resources. Moreover, employees had higher mental and physical health in private offices compared to OPOs. In fact, these authors report a negative relationship between the number of persons per enclosed office space with health; and psychosocial work stressors had the strongest impact on health (see also Bodin Danielsson and Bodin, 2008; Pejtersen, Feveile, Christensen, & Burr, 2011). In addition to air quality and noise and privacy, Bae and colleagues (2017) found that indoor air quality, furnishings, electric lighting, daylighting, and vibration/movement ranked highest on influencing employees' health.

2.2 OPOs and place attachment

Lewcika (2011) points out that employees have emotional bonds with their workplaces, which suggests that place attachment may be an important factor for OPOs. Scannell and Gifford (2010) define place attachment as a positive affective relationship between an individual and a specific place, which includes an individual's desire to stay close to that place, and the memories, knowledge and meaning about that place. Place attachment is a common feature in indigenous cultures, which confirms the validity of this construct (see Yunkaporta, 2019). Applied to the office context, and in support of this notion, Fried (2000) found that moving to a new workspace or changing an existing workspace can cause people with high place attachment to suffer emotionally and physiologically.

One way to minimize the negative impact of relocating an employee from a place to which they are attached is by promoting employee personalization and ownership of their workspaces. This attempts to redirect any attachment away from the space itself, and towards features they can move from one space to another if required. Another way of thinking about this would be to allow employees to have "psychological ownership" of, or "territoriality" towards, their workspaces. Brown, Lawrence, and Robinson (2005) describe territoriality as an individual's expression of their behaviors and or feelings of ownership toward a physical or social object (p. 578). For example, OPO occupants can demarcate the boundaries of their workspace with office plants (Knight & Haslam, 2010; Wells, 2000). Research shows further that workspace personalization can improve psychological wellbeing and satisfaction, especially when this encourages a sense of control and strengthens place attachment (Averill, 1973).

Ayoko and Ashkanasy (2019) note that there are different ways to manage the challenges confronting OPO design. For example, architects and acoustic engineers can use sound masking or acoustic tiling to minimize the noise in workstations at the construction stages, which can neutralize background noise (Haapakangas & Hongisto, 2008) in OPOs. Similarly, covering surfaces and partitions with sound-absorptive materials can minimize speech sound levels (cf. Venetjoki, Kaarlela-Tuomaala, Keskinen, & Hongisto, 2006), while higher dividing panels to separate workspace, or working in enclosed offices, can also serve as an effective improvement measure (Zhang, Kang & Jiao, 2012). Additionally, owing to prevalence of

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video conferencing, employees are more likely to use headphones as standard equipment, affording the capability to filter out ambient noises when they need to concentrate on a particular task.

To manage privacy in OPOs, Ayoko and Ashkanasy (2019) suggest that additional side/private rooms can provide employees working on complex task or needing to move away from stressful situations the ability to withdraw and complete tasks needing privacy or high concentration (Jensen, Potts, & Jensen, 2005). Also, flexible furniture should be considered as part of the solution for managing privacy issues (see Cangelosi and Lemoine, 1988).

2.3 Multiple stakeholders and competing goals in commercial buildings

Alignment between building stakeholders is critical for sustainable retrofits and for maximizing a building's economic, environment, and social value (Stephan & Menassa, 2014). This is important because dynamic stakeholder opinions and value maximization perceptions may culminate into conflicting requirements that have the potential to deter the adoption of truly sustainable retrofit choice. Consistent with this idea, Stephan and Menassa found that strong connections among stakeholders can accelerate the interactions necessary to achieve alignment on sustainability issues. In addition, networks with stakeholders that experience comparable perceptions of values and modest confidence levels may trigger alignment and polarization of stakeholders towards a unified retrofit objective.

Regarding energy consumption, buildings are a major source of global demand for energy and materials that produce greenhouse emission gases (GHG). Indeed Yudelson (2010) estimates activities in buildings consume up to 70% of total US electricity production and generates about 40% of non-industrial waste. In the US alone, approximately 60% of all current construction projects are retrofit projects—and the World Green Building Council projects the market share of green retrofit projects will dramatically increase between 2020 and 2050 (Laski & Burrows, 2017). This means building stock is a key target for energy-efficient retrofits to substantially reduce the overall building carbon footprint and extend its life span (cf. Oreszczyn and Lowe, 2010). According to Stephan and Menassa (2014), there are two issues associated with existing building stakeholders that are critical in shaping the direction for sustainable retrofits project and whether the economic, environmental, and social benefits can be achieved. First, how stakeholders perceive value regarding the retrofit; and second, how early involvement in the project can help to close the gaps in the perception between a variety of stakeholders to come to design solutions.

2.4. Shared offices

There is evidence that physical and social factors presented in the environment shape and enable human behavior (Giles-Corti & Donovan, 2002), and that modifying these factors has the capacity to trigger enduring behavioral changes in employees (Bandura, 1974). As an example, the availability of informal discussion space in shared offices is linked with less sitting time—but only when employees have a high degree of control and autonomy on sitting and standing in the workplace (Kim, Can-

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dido, Thomas, & de Dear, 2016). More importantly, such needs to be combined with a high degree of organizational support and behavioral autonomy to arrant low level of sitting time at work. Other issues that might impact the amount of time occupants spend sitting in OPOs include the spatial layout and arrangement of working stations and shared spaces (i.e., grouped, single, multiple) (cf. Colenberg, Appel-Meulenbroek, Romero Herrera, & Keyson, 2021). This demonstrates how the social and physical environment can influence behavioural adaptation.

Furthermore, it is critical that work design, described as the content, structure and organization of the tasks, roles, and responsibilities of work, aligns to the physical work space (Bankins, Tomprou, & Kim, 2021; Parker, 2014). In this respect, Ward and Parker (2020) argue that since physical environments are part of work design, modelling the relationships between workspace and work outcomes should include these factors. Elements of workspace can enable people to do their job in ways that utilize positive aspects of their work design to promote sustained performance. Ward and Parker conclude that workspace can foster social support and promote feelings of control/autonomy.

As working arrangements become more flexible and remote working becomes more common, the risk of social isolation rises (Lashani & Zacher, 2021). To this point, coworking spaces can minimizes such isolation because they offer more than a workplace; they offer community. Using a person-environment fit approach, these authors examined how the congruence between workers' needs and supplies by coworking spaces relate to job satisfaction and intent to leave. Specifically, they identified five needs (i.e., community, collaboration, amenities, location, and cost), and hypothesized community as the central need. These authors concluded that needs-supplies fit regarding community was related to job satisfaction and intent to leave in coworking spaces. Overall, these findings highlight the importance of community fit in coworking and offer insights for workers and entrepreneurs in this area.

2.5. Summary of OPO issues

In the foregoing discission, we examined the pros and cons of OPOs, including the paradoxical situation that arises when the benefits of OPOs (e.g., costs, collaboration) are set against the cost (e.g., noise, distraction) and the effects that ensue when employees experience a loss of place attachment. Brown and his co-authors (2005) argue humans are naturally territorial, with a tendency to redress a perceived loss of territory in OPOs through behavior, which can be disruptive or counterproductive. Such issues become critical in the context of modern offices where there can be multiple stakeholders in a shared workspace. In the following section, we deal more specifically with how these factors impact green ergonomics.

3. Green ergonomics

Ergonomics (also known as "Human Factors") is a systems-oriented scientific discipline focusing on the interaction between humans and other elements within a system, with the intent to optimize human outcomes and overall system performance (International Ergonomics Association, 2000). This manifests in evaluating and de-

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signing work environments, ways of working, and equipment so that these enable a user to perform their tasks effectively, reliably, and safely. Similarly, an ergonomic approach to the built environment, including offices, requires designers to consider the technical aspects of the space, as well as how the space supports users as they perform their tasks (Attaianese & Duca, 2012).

As with many disciplines, ergonomics is adapting to the imperative of sustainable development (Steimle & Zink, 2006). Accordingly, contemporary research and practice contributes to a growing literature that considers how ergonomics can integrate sustainable development alongside existing priorities such as safety (Thatcher, Zink, & Fischer, 2019). Within this literature, Thatcher (2013) argues that green ergonomics has a specific focus on the environmental impact of work systems. The emerging effects of climate change such as more frequent extreme weather events, are having a direct and multiplicative impact on work. For example, extreme weather is contributing to landslips that interrupt rail networks in the United Kingdom, while also changing the conditions in which track workers travel to site to repair and to maintain this damage, and the workload of signalers that need to manage the remainder of the network (Network Rail, 2021). This example demonstrates how climate change impacts what work people do, how they do it, and the conditions in which they do it, emphasizing the fact that human activity is nested within a wider ecosystem (Curtis, Fair, Wistow, Val, & Oven, 2017).

Green ergonomics applies ergonomic principles, perspectives, and methods to support sustainable development. This rests on several key fundamental assumptions: (1) the earth is effectively a closed system, where disruption in one area will lead to disruptions elsewhere in the system; (2) humans are a component of nature and are vulnerable to variations in the health of their environment; and (3) that human activity can positively or adversely impact the environment. According to Thatcher (2013) green ergonomics has two functions with respect to this bi-directional relationship between nature and humans. First, to facilitate human activity that makes a positive contribution by conserving, preserving, restoring, and regenerating nature. Second, by leveraging the relationship between humans and the natural environment to support human wellbeing and effectiveness.

In the context of sustainable development, green ergonomics is rooted in the concept of the "triple bottom line" (Zink, Steimle, & Fischer, 2008). This concept advocates the view that genuine sustainability meets environmental, social, and economic needs. Accordingly, the goal of green ergonomics is to design systems that are efficient and effective when viewed from ecological, economic, and social perspectives. Thus, green ergonomics can make a valuable contribution towards sustainable development by focusing on the interaction between people and the built environment. In this regard, Thatcher, Garcia-Acosta, and Morales (2013) propose four design principles that serve as a basic framework for green ergonomics, which we interpret in the context of office design from the perspective of office workers.

Principle 1 is that green ergonomics should promote eco-efficiency, eco-effectiveness, and eco-productivity. In short, to ensure work systems minimize residual energy, allow for sources of energy to replenish, and in such a way that the

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balance between inputs and outputs is sustainable. In the context of office workers, design aligning to this principle minimizes the energy workers require to complete their tasks (e.g., demand on cognitive resources to filter extraneous noise), and provides sufficient access to restoration (e.g., through the provision of quiet spaces and elements of biophilic design) so that the interaction between workers and their workspace is sustainable.

Principle 2 holds that green ergonomics should promote ecological resilience by preserving the capacity of the workplace environment to absorb disturbances without change to its structure or function (i.e., the emergent dynamic stability that is a characteristic of complex adaptive systems; Lansing, 2003). In complex adaptive systems that feature dynamic interdependencies among independent components, such as organizations (Eidelson, 1997), stability is an emergent process. That is, the system finds a balance not through top-down design, but bottom-up through the dynamic interaction of components as they exchange energy and matter. By virtue of their design, OPOs may facilitate this more effectively than other office layouts by providing greater flexibility for components to interact freely (i.e., without top-down constraints). For example, an OPO layout enables individuals, groups, and teams to move around and find a location that satisfies idiosyncratic needs (e.g., proximity to certain amenities, access to natural light, noise levels).

In Principle 3, Thatcher and his co-authors (2013) maintain that green ergonomics should accommodate indigenous/vernacular solutions to local problems. This implies understanding local requirements using a participative approach to arrive at an optimal design solution, and satisfying those requirements using local resources. For example, a green ergonomics approach to office fit out would include consultation with users regarding their requirements for office furniture, and contracting local manufacturers to provide this, ideally using local materials. As with the previous principle, the nature of OPO design enables users to adapt their space to meet local requirements.

Finally, in Principle 4, green ergonomics acknowledges the interaction between natural systems and design. At one end of a spectrum, design can have harmful effect on the natural environment by consuming more natural resources than it requires, producing excess waste, and failing to support the restoration of those natural resources. Moving on from this end of the spectrum, sustainable design aims for a neutral impact and acknowledges the inherent uncertainty of complex systems by taking a precautionary stance (Orr, 2002). At the other end of this spectrum, regenerative design strives for a net positive effect on the natural environment by restoring, renewing, or revitalizing the natural resources it consumes (Cole, 2012). This stance advocates against activity with the potential for widespread harm due to systemic risks, such as those that exist in conditions of uncertainty (Taleb, Read, Douady, Norman, Bar-Yam, 2014). For example, where the specific impact of high levels of carbon emissions on the ecosystem is unknown, the precautionary stance is to avoid increasing such emissions, which includes through the design and use of the built environment.

A green ergonomic perspective thus considers the interaction between human, technological, and natural systems. From this perspective, OPOs aligning to green

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ergonomic principles might constitute effective working environments that support worker, organizational, and ecological requirements. In the next section, we develop this idea a step further, and explore how such green OPOs can be exemplars of sustainable development from two different perspectives: (1) technical and (2) socio-cultural.

4. The Technical Approach to Green Ergonomics

The focus on this perspective is on how ergonomic design and evaluation might be used to conserve, preserve, and restore nature. The UN estimates 28% of global CO_2 emissions derive from building operations, and 6.6% from commercial buildings.[1] With approximately half of service sector organizations' environmental impact (Junnila, 2004) coming from building operations, the carbon intensity of an office is a prime target for companies seeking to align themselves with sustainable development. Lighting and heating/cooling are the major sources of demand, and their direct link to the basic needs of building occupants highlights the potential contribution of a human-centered design response. Ergonomics uses a variety of methods such as task analyses, people flow, usability testing and human error analyses (Stanton, Hedge, Brookhuis, Salas, & Hendricks, 2004) to design and evaluate work systems through prototyping, and post occupancy reviews for continuous improvement (Preiser, 1995). Thus, under the technical perspective, a green ergonomic approach applies these same methods to identify and to realize opportunities to effectively reduce energy consumption within OPOs.

We propose two technically oriented avenues through which green OPOs could integrate into a company's broader sustainability agenda: (1) minimizing the environmental impact from the physical office; and (2) enabling employees to reduce their environmental impact. From a technical systems perspective, this focuses on infrastructure and technology in an OPO, and how occupants interact with these features.

4.1.Minimizing the environmental impact of the physical office

The essential idea underpinning the technical approach is the assumption that a general trend towards designing more sustainable (e.g. energy efficient) technology exists. If we view this progress from the perspective of socio-technical systems thinking, however, the net contribution of green technology on the environmental impact of an office might depend upon the extent to which green technology fulfils user requirements and preferences. Green office technology can thus serve as a tangible and engaging demonstration of an organization's investment in sustainable development (Cox, Higgins, Gloster, Foley, & Darnton, 2012). Notably, however, deploying green office technology without a clear understanding of ergonomics will likely fail to promote efficiency, effective, and satisfying use on behalf of office workers (Martin, Legg, Brown, 2013).

[1]See https://www.climatewatchdata.org/

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Green ergonomics can also help reduce the energy consumption in an office through a detailed understand of user behavior. For example, providing the necessary lighting and environmental comfort to building occupants is a primary driver of the energy consumption of an office (Omer, 2008). Moreover, providing high levels of artificial light not only necessitates a larger carbon footprint, but can lead to negative OPO occupant outcomes, such as difficult sleeping and lowered vitality (Peeters, Smolder, Vogels, & de Kort, 2021). Ergonomists can investigate user activity within the office and form a detailed understanding of user requirements. Interrogating these requirements from an energy-efficiency position can subsequently identify opportunities to reduce energy consumption.

Using such understanding, de Bakker, Aarts, Kort, and Rosemann (2018) distinguished task, surrounding, and background areas in an OPO. By providing focused illumination in task areas, and lower levels of lighting in surrounding and background areas, these researchers reduced lighting-related energy consumption by 25% without disrupting user comfort. This is a clear example of how an ergonomic appreciation of work design (Ward & Parker, 2020), namely how and where people work can rationalize energy use without compromising the conditions that facilitate task performance and meeting comfort needs for ambient lighting (Loe, 2009). Other lighting interventions consistent with a green ergonomics approach including maximizing the availability of natural light, providing artificial light only in areas or conditions where natural light is insufficient (i.e. daylighting, Leaman & Bordass, 2007), and using light-reflecting finishes on surfaces (Makaremi, Schiavoni, Pisello, Asdrabali, & Cotana, 2017).

Another opportunity to reduce energy consumption that links to user requirements is the provision of heating, ventilation, and air conditioning (HVAC)—which accounts for as much as 40% of building energy consumption (US Department of Energy, 2011). Like most organisms, humans are reactive to the temperature of their environment. In built environments, thermal comfort is a function of environmental (air temperature, humidity, local air velocity, thermal radiation) and occupant variables (clothing insulation, metabolism; Fanger, 1970). As a systems-based discipline, ergonomics focuses on the interaction between people and their environment, and a green ergonomics approach considers the potential for this interaction to improve environmental outcomes. For example, how to orient and operate HVAC units in an OPO to meet user requirements and to regulate heat in an open space more effectively, while simultaneously reducing overall energy consumption. By coordinating multiple HVAC units and understanding the impact of solar radiation, building managers can maintain thermal comfort throughout an OPO while also reducing heating-related energy consumption by 21% (Nagarathinam, Doddi, Vasan, Sarangan, Ramakrishna, and Sivasubramaniam, 2017).

Automated building services, such as lighting and environmental control, may offer another technically sufficient way to reduce the energy consumption of an office (e.g., see Vaidya et al., 2004). If this is done in a way that is insensitive to user requirements and preferences, however, such as by failing to provide adequate thermal comfort, there could be unintended consequences. For example, users can manipulate

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the sensors that input into automated building services, which may move the energy efficiency of the office away from the technical ideal (Vaidya et al., 2004).

Accordingly, Leaman and Bordass (2007) note that the environmental performance of green buildings can be fragile, owing to the complexity of their design. Green ergonomics could moderate this fragility by effectively considering the interaction between the human and technical components of an OPO to facilitate emergent stability. With early integration and demonstrating an understanding of user needs and behavior, green ergonomics could help to design OPOs that require less energy altogether (Martin, Legg, & Brown, 2013), while preserving the autonomy of individuals to make some adjustments (Huang, Robertson, & Chang, 2004). For example, by designing a layout that enables occupants to optimize their exposure to natural light, ventilation, and solar radiation and minimize the need for artificial light and HVAC systems.

The foregoing examples demonstrate some ways through which green ergonomics can apply a thorough understanding of user requirements, and how users interact with building technologies to reduce the energy consumption of an OPO. In the next section, we move on to consider how green ergonomics can address the human factor in an OPOs environmental impact.

4.2 How the technical approach to designing OPOs can help employees to limit their environmental impact

The American Physical Society (2008) found that building energy consumption often exceeds projections made during the design process. Other findings demonstrate that buildings designed with green intent (i.e., to minimize environmental impact), vary considerably post-occupancy and in some cases perform worse than conventional buildings (Khoshbakht, Gou, Xie, He, & Darko, 2018; Kim & Kim, 2020). As an explanation for this, Leaman and Bordass (2007) suggest projections might fail to accurately consider the dynamics of user behavior. More specifically: how user behavior varies at the inter- and intra-individual levels (i.e., from one moment to the next), and deviates from processes-as-designed. Ergonomics considers user variability as a design parameter (Attaianese & Duca, 2012), and could identify and proactively address issues that might undermine the potential of green technology.

By focusing on the interaction between users and other parts of a system, ergonomics offers an ideal perspective to understand whether office workers can leverage the technical potential of green technology. In this regard, Zibarras and Ballinger (2011) note that environmental initiatives often focus on introducing green technology, such as energy-efficient IT, video-conferencing, and low-energy lighting. While these and other technologies provide the potential to reduce the environmental impact of an office, realizing this potentially depends on occupant/user behavior. This directly relates to the concept of employee green behavior (EGB), which Ones & Dilchert (2012, p.87) define as "scalable actions and behaviors that employees engage in or bring about that are linked with, and contribute to, environmental sustainability". Unsworth, Davis, Russell and Bretter (2021) argue researchers and practitioners should consider EGB from a systems perspective. Tools such as the Leadership in Energy and

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Environmental Design (LEED) rating system support this view; and consider the ergonomic features of office equipment (Attaianese & Duca, 2012). While the technical potential of green technologies is important, a green ergonomic approach would select the most appropriate technologies by considering user characteristics, such as tasks, priorities, and skills (Charytonowicz, 2007). Such a detailed understanding of user requirements can feed into a user-centered design process to optimize the green performance of technology provided in a green OPO (Demirel & Duffy, 2013).

As major building systems, such as lighting and HVAC, develop into more energy efficient versions, the relative contribution of "small power" equipment increases. Equipment using power outlets such as computers, printers, refrigerators, coffee machines, and hand dryers, could account for as much as 50% of a green OPOs energy consumption (New Building Institute, 2012). Despite this, the contribution of small power equipment to overall office energy consumption is poorly understood (Menezes, Cripps, Buswell, & Bouchlaghem, 2013). For example, while the discrete energy consumption of computers and printers is often shown on energy labels, there is little information about the heat output of these devices. Menezes and colleagues argue further that, in an OPO (where the density of computers and people is likely to be high) the heat gain from computers can increase the cooling demands of HVAC systems. Minimizing energy consumption in an OPO, therefore, requires a systems-thinking approach that puts users and their behavior in the context of the technology, building infrastructure, culture, goals, and processes (Davis et al., 2011).

In the workplace, office occupants have considerably less autonomy over the choice of equipment they use than they might have at home over their choice of domestic appliances, since the workplace typically provides what they require to do their work. If office workers are unable to influence procurement decisions that determine what equipment they use, their contribution concentrates on how they use this equipment. A review of office computers demonstrates the importance of this. A comparison of personal computers manufactured before and after 2000 demonstrates that, while modern computers are more energy efficient in low power modes than earlier models, the sophistication they provide to meet user requirements means they use more energy in normal operation (Kawamoto et al., 2001). More recent reviews suggest the difference in energy consumption between these two different modes is widening (Menezes et al., 2013). Therefore, reducing the energy consumption of personal computers in an OPO appears to depend on user behavior, particularly the use of low-power mode.

From the technical systems perspective, green ergonomics can help realize the latent energy efficiency potential of green office equipment by focusing on how users interact with the equipment. For example, providing information to users about how reducing the delay time before a device switches to low-power mode can reduce energy consumption, and showing users how they can manage these settings. Reducing the delay increases the time an idle computer is in an energy efficient mode and can curb annual energy consumption by as much as 75% per device (Kawamoto, Shimoda, & Mizuno, 2004; NAEEEP, 2003). One way to transition from an OPO into a green OPO is tasking ergonomists to develop office user guides that increase occupant

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awareness of the green technology within the OPO, and how they can leverage this to optimise environmental performance.

In situations where discretionary user behavior drives energy efficiency, providing performance feedback is important. Green ergonomics applies usability heuristics (Nielsen, 1994) to evaluate the degree to which interface design supports EGB. In particular, the status of the system, which includes performance feedback. In a domestic setting, smart meters indicate energy consumption, which has a direct effect on household costs (Carroll, Lyons, & Denny, 2014). In an office setting, however, an occupant is unlikely to know how much they contribute to the overall energy demand or experience any feedback that might encourage them to minimize their energy consumption (Thatcher, Zink, & Fischer, 2019).

In the absence of behavioral feedback, energy saving behaviors may lack the reinforcement required to habituate them, however. Findings by Becker and Seligman (2008) suggest that signaling an opportunity to conserve energy might be more effective than simple informational feedback on consumption. In OPOs where users can moderate internal environmental controls, signaling when services such as heating, air conditioning, or lighting is providing negligible benefits and could be turned off without a noticeable difference could encourage energy conservation behavior. Such prompts also indicate to occupants their role in reducing the negative environmental impact of the office, which may encourage other EGB (Norton, Zacher, Parker, & Ashkanasy, 2017). Effectively deploying smart meters must consider the interaction with the user to ensure they are aware of the meter, that the information provided is useful, and they can interpret this information to make behavioral decisions (Payne & Griggs, 2017).

In this perspective, green ergonomics highlights the interaction between individuals and their environments, whereby workers shape—and are shaped by—their offices. The physical workplace environment can reinforce behavior, and consequently outcomes associated with those behaviors (Johns, 2018; Morgeson, Dierdorff, & Hmurovic, 2010). For example, Van Houten, Nau, and Merrigan (1981) reduced elevator use by as much as one third by slowing the speed at which it travelled between floors. By communicating the delay, the researchers changed occupants' perceptions about the convenience of using the elevator to make this a less appealing mode of transport, with the effect of encouraging stair use and reducing energy consumption.

4.3 Summary of the technical systems approach to green ergonomics

The purpose of an office environment from the technological perspective is primarily to provide a space that facilitates task performance. Accordingly, the application of green technology needs to be in such a way that supports office workers to complete their tasks. The technical systems approach recognizes ergonomics as a discipline and human-centered design as a methodology to achieve this by understanding user requirements, and thus help to identify not just the right technology, but how to provide this in a way that interacts with occupants and their behavior to minimizes consumption (e.g., of energy) and waste.

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5. The Social-Cultural Approach to Green Ergonomics

From the socio-cultural perspective, OPOs act as a canvas for an organization to project its sustainability ambitions, and to create an environment that supports sustainability-related activity. We therefore now consider the social aspect of an OPO through the concept of organizational culture. Specifically, how green ergonomics can facilitate a workplace culture that complements the technical aspect we described above, with the intent of encouraging emergent system-level outcomes that make a meaningful contribution to sustainable development. The social contexts of workplaces in general and especially OPOs (given their inherently social layout), might be a stronger influence on occupant behavior than personal attitudes towards sustainable development (Christina, Dainty, Daniels, & Waterson, 2014).

Schein (2010) defines culture in terms of a pattern of shared basic assumptions (learned by a group as it solves problems of external adaptation and internal integration) that has worked well enough to be considered valid; and therefore to be taught to new members as the correct way to perceive, to think, and to feel in relation to those problems. Contributors to this field consider culture an important driver of individual, group, and organizational behavior (Ashkanasy, Wilderom, & Peterson, 2011), including behavior aligning with environmental sustainability (Norton, Zacher, & Ashkanasy, 2015). Schein's (1990) prominent structural model begins with fundamental assumptions, which inform beliefs and values, and manifest into tangible artifacts, such as language, procedures, and symbols. The office is a both a cultural artifact, as well as gallery for other artifacts (Vilnai-Yavetz, Rafaeli, & Yaacov, 2005). In this section, we present the office as a cultural showcase, and that a OPO featuring green ergonomics could reinforce, and potentially help develop in the first place, a workplace culture that aligns with and supports sustainable development.

Like brand names, logos, and uniforms, an office has symbolic value for an organization, although the office is more likely to reflect its utilitarian function rather than aesthetic form (Vilnai-Yavetz et al., 2005). Nevertheless, the physical design of an office communicates corporate cultural values, which in turn influences the social context and influences occupants' normative behavior (Lindenberg, 2018). For example, a cellular office with name plates on closed doors could indicate workplace values for formality, privacy, and independent work. Alternatively, an OPO showcasing elements of the natural environment (e.g., plants, organic shapes, natural light and ventilation) and green technology (e.g., a screen showing real-time energy use data) could reflect workplace values towards responsible consumption, balancing organizational and environmental performance, and encouraging collaboration among colleagues. When individuals interpret the artifacts and symbols within their workplace, they are also interpreting and evaluating the underlying assumptions, beliefs and values (Hatch, 1993). Upon entering either of these examples, a person is likely to use the information available to them to make sense of their environment, and determine how to adapt their behavior to fit in.

Green technology can take on symbolic value. For example, staff at a Scottish distribution company nicknamed the company's wind turbine "Windy Boy", making it a symbol of the organization's commitment to sustainable development (Cox et al.,

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2012). By the same token, such symbols can represent a liability if they fail to deliver on their potential to improve environmental performance. Using green ergonomics can support the selection, use, and maintenance of green technology to mitigate the risk of it failing in this regard. Introducing and promoting green technology in a way facilitates such symbolism can also lead to members evaluating whether existing cultural norms are compatible, and updating these (Hatch, 1993).

All offices have the potential to display cues that indicate a corporate value towards sustainable development, however we argue the inherent communal nature of an OPO makes it an ideal layout to prime normative (i.e., social) pro-environmental goals. In this section, we describe how an OPO can support the emergence of both injunctive and descriptive norms regarding sustainable development, which are an antecedent of EGB (Norton, Zacher, & Ashkanasy, 2014). As such, occupants may be more likely to interpret design features within an OPO as cues for pro-social normative behavior, such as reducing energy consumption and waste.

To begin with, OPOs provide opportunities for an organization to demonstrate that it approves of sustainable development. For example, BT provides a digital message board featuring information that underlines the organization's value towards sustainable development, such as partnerships with local charities, upcoming tree planting days, office energy consumption, tips for occupants to reduce their personal environmental impact at work (Cox et al., 2012). This constitutes an injunctive social norm, of which other examples include corporate statements regarding sustainable development (Cialdini, Reno & Kallgren, 1990), publishing an environmental strategy (Ramus & Steger, 2000), and announcing science-based targets (e.g., see Network Rail, 2020). Research suggests that employee perceptions of injunctive norms contribute to task-related EGB (Norton et al., 2014).

Providing normative messaging can encourage an occupant to develop and reinforce a perception that the organization is committed to sustainable development. With an ergonomic understanding of how occupants interact with their office environment, organizations can more effectively install features that promote injunctive norms for sustainable development. For example, green ergonomics could optimize the location of communication material to maximize reach and readability, such as in toilet cubicles and not in locations where the signal-to-noise ratio is poor—such as message boards in kitchenettes. Unlike other office layouts, OPOs can position communications material in open locations visible to large numbers of people, which may facilitate the development of shared perceptions that indicate a pro-environmental workplace climate (Norton, Zacher, & Ashkanasy, 2012).

Second, an OPO affords greater potential for occupants to observe others engaging in EGB. In OPOs with green champions (i.e., employees who are passionate or active in pro-environmental activities), the visibility of these role models augments the impact they can have on occupants with less motivation. Green ergonomics can, through the design of facilities, procedures, and including features that encourage EGB, support the emergence of descriptive norms that demonstrate sustainable development is not just something members of the organization say (injunctive norms), it is also something that people in the organization do (descriptive norms). Research suggests

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descriptive norms are particularly important for encouraging non-task related behavior (Norton, Zacher, & Ashkanasy, 2015), which might include participating in environmental groups, volunteering, and supporting others' EGB.

For example, many organizations provide green "binfrastructure" to support effective waste management, such as receptacles for separate waste streams.[2] Green ergonomics can support the usability of these facilities by considering where they are located, making them enjoyable to use, and providing additional information to support effective use (Cox et al., 2012). For example, researchers found that the proximity of messages encouraging users to recycle to receptacles has a substantial impact on behavior; recycling rates were 25% higher when signs were directly over the bin than when signs were merely in proximal (Austin, Hatfield, Grindle, & Bailey, 1993). An ergonomic study of kitchenette waste behavior could investigate waste-stream contamination to determine the role of user behavior. Green ergonomics could then inform the design of an intervention from a systems perspective to improve waste separation behavior.

Another target for green ergonomics is encouraging energy related EGB. Providing behavioral cues at the point of use is an example of understanding the dynamics between users and technology (Abrahamse, Steg, Vlek, & Rothengatter 2005). Energy audits show that placing stickers near light switches, monitors, and computers is an effective way to prompt office occupants to interact with these devices to conserve energy (Russell, Evans, Fielding, & Hill, 2016). Providing an environment that encourages normative goals is particularly important for pro-environmental behavior, which is less stable when driven by hedonic or gain goals (Lindenberg & Steg, 2007). Therefore, applying green ergonomic principles in the design on OPOs in such a way that they support the emergence of norms towards sustainable development, and then promote these to occupants, is an important contribution to aligning green OPOs to sustainable development.

So far in the present section, we have outlined how OPOs can support the emergence of social norms, which can facilitate behaviors occupants associate with these norms. We now present an argument for why OPOs might be particularly effective in promoting social norms for sustainable development. A workplace characterized by an inherently communal layout, as opposed to other office layouts, might encourage a more social orientation among OPO occupants, and pro-social behavior such as EGB (Cameron, Brown, & Chapman, 1998; McCalley & Midden, 2002). This seems to align with the assumptions that underlie sustainable development, such as preserving the ability of others in the future to meet their own needs (WCED, 1987).

Research pointing to the social benefits of OPOs, including promoting collaboration (Chigot, 2003) and relationships between co-workers (Khazanchi, Sprinkle, Masterson, & Tong 2018), suggests that this layout might facilitate a shared social identity (Heerwagen, 2006). An active social identity can encourage members to engage in

[2] See https://www.zerowastescotland.org.uk/litter-flytipping/binfrastructure

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pro-social behaviors that contribute to group goals, even if these are at the expense of personal gain (Reicher, Spears, & Postmes, 1995). EGB is an example of such a pro-social behavior, whereby there is an asymmetry between an actor's input (i.e., behavioral effort) and the extent to which they personally benefit relative to other group members.

Observers might perceive behaviors in an OPO differently than in a less social environment. The inherent social context of an OPO may emphasize the impact of an individual's behavior on others in the office. For example, turning off lights or encouraging others to put their computers into low-power mode might be evidence of being a 'team player', which can promote an actor's social capital. Appreciating the sensemaking process wherein occupants interpret the various features within the office to determine what is appropriate behavior, an open-plan layout might encourage occupants to interpret features such as green technology and communications as evidence of a workplace culture that supports sustainable development. Green ergonomics should communicate and emphasize the design intent of a green OPO to manage the interaction between occupants and the OPO environment. Where users understand the design intent, they tend to be more tolerant of things that might not meet their requirements (Leaman & Bordass, 2007). Thus, occupants may perceive features like low-flow faucets and slow elevators not as inconveniences, but as symbols of a workplace culture that support sustainable development, and their place within that culture.

6. Combining the Technical and Socio-Cultural Perspectives: A Socio-Technical approach to Green Ergonomics

According to Lindenberg (2018), the most salient cues for normative behavior are the presence of other people in the environment, indicators of others' normative behavior, objects associated with the normative goal, and visceral cues. An OPO that demonstrates green ergonomics could provide such cues to encourage the efficient and effective use of green technology, not to mention other EGB. A green ergonomic OPO approach can create an OPO environment that aligns to and supports values towards the natural environment and deeper assumptions about our place in the ecosystem. By supporting both injunctive and descriptive norms, OPOs can facilitate specific EGBs that match the context (e.g., reducing printing, meeting virtually instead of traveling), as well as behaviors that might sit beyond an occupant's role (e.g., partnering with local charities to donate surplus catering; see Bissing-Olson, Iyer, Fielding, & Zacher, 2013). Furthermore, by co-locating group members in a shared space, OPOs can facilitate the exchange of information (Heinzen, Cacciatori, Zoller, & Boutellier, 2018) including normative information.

6.1 How ecosystem services might be harnessed to facilitate the improved wellbeing and effectiveness of human system (Input)

A person-environment fit perspective (Edwards, Caplan, & Harrison 1998) emphasizes the need for a workspace to align with worker's needs. As with green ergonomics, person-environment fit espouses a reciprocal relationship between a worker and their work environment (Su, Murdock, & Rounds, 2015). A green OPO would not

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only minimize its environmental impact, but also provide a healthy and restorative environment for occupants.

Good buildings should support the wellbeing and comfort of occupants (Hedge, 2008). Organizations that prioritize occupational and environmental health, as recognized by professional associations, tend to perform well on other measures of corporate performance, such as stock market value (Fabius et al., 2013). This suggests that the health of an organization according to traditional metrics might rest on the health of its human capital. Thatcher (2014) argues that complex systems, such as organizations, have a duty to maintain their fundamental components, including their people. Green ergonomics, which prioritizes the contribution of the office environment to the health and wellbeing of occupants (Gou, 2019) has a critical role in the interaction between workers and their workspaces.

Biophilic design, which we describe next, provides cognitive, psychological, and physical health benefits (Ryan, Browning, Clancy, Andrews, & Kallianpurkar, 2014) and is a fundamental component of a green OPO. As evidence of how biophilia benefits occupants, Ulrich (1984) compared gallbladder surgery patients with and without views of nature from their hospital rooms. Patients with views of nature had shorter post-operative stays, had fewer negative comments from nurses, and requested lower doses of painkillers than others without views of nature. In the context of green ergonomics, biophilic design represents the dynamic interaction between people and their environment and how green OPOs can support the wellbeing and performance of office workers.

Biophilia refers to a fundamental need for humans to connect with nature (Ryan et al.,2014). Biophilic design aims to generate positive emotional experiences through design, which are fundamental to development place attachment (Kellert, Heerwagen & Mador, 2008). Designers can demonstrate biophilic design in three ways: by introducing nature into the space, such as plants but also light and thermal variability; providing natural analogues, such as shapes and colors found in nature; and by considering the nature of the space, for example places to interact and places to rest (Cramer & Browning, 2008). By applying green ergonomics methods and principles, designers can leverage biophilia to create workspaces that not only support occupants' performance at work, but also their wellbeing and capacity to perform sustainably.

Natural visual stimuli can improve typical cognitive resources office workers use throughout the day, such as concentration and memory (Alvarsson et al. 2010). One example of biophilic visual stimulation are complex pattens from fractal geometry, such as those found in wood grain, which contrast to the typically neutral office aesthetic. While these patterns can reduce stress, perhaps by providing fascination per Attention restoration theory (Kaplan & Kaplan, 1989), high dimensions of pattern intensity can induce stress and nausea (Salingaros, 2012). Green ergonomics should consider how different stimuli, such as patterns in carpets, wallpapers, and seat cushions, coalesce and form a single visual scene. The existing evidence suggests that, while visual stimuli can support employee performance and wellbeing, there is a tipping point, beyond which these elements compromise the user experience.

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In his stress restoration theory, Ulrich (1984) argues that affective responses to natural features in the physical environment can trigger a stress restoration process following surgery. Research shows that viewing nature either before (Brown, Barton, & Gladwell, 2013) or after (Tsunetsugu & Miyazaki, 2005) experiencing a stressor has beneficial effects in terms of blood flow and brain activity. Importantly for offices in urban environments, viewing images of nature (e.g., on a screen) can provide benefits regarding stress (Grahn & Stigsdotter, 2010), though this is not as strong an effect as viewing actual nature (e.g., through a window; Kahn et al., 2008). Interestingly, urban environments featuring water elements appear to have similar health benefits to natural scenes without water (Ryan et al., 2014). Nevertheless, following this general line of reasoning suggests that the optimal condition is one that integrates actual examples of nature, such as plants and clean running water (Alvarsson et al., 2010).

Regulators such as the British Council for Offices require OPOs to provide a minimum amount of ambient noise for conversation privacy (BCO Guide, 2019). In instances where the mechanical services and building façade mean this minimum is not met, designers recommend white noise generators. Green ergonomics extends beyond visual examples of nature to include auditory, haptic, olfactory, or gustatory stimuli (Hunter et al., 2010). Meta-analytic findings point to benefits from listening to natural sounds for stress and annoyance, physical and mental health, and cognitive performance (Buxton, Pearon, Allou, Fristrup, & Wittemeyer, 2021). For example, providing sounds from nature, such as running water, bird songs, or rustling trees can facilitate psychological restoration at a rate 37% faster than urban noise (e.g., traffic, construction sounds; Alvarsson et al., 2010). In addition to having a restorative effect to support workers capacity to respond to new stressors, nature sounds can also stimulate creative performance (Mehta, Zhu, & Cheema, 2012).

Perhaps the most common example of biophilic design is the ubiquitous "office plant." Office plants are a common sight in OPOs and are an example of the multidimensional nature of biophilia and biophilic design. First, plants provide occupants with access to recognizable example of the natural world, which can reduce stress and improve mood (Burchett, Torpy, Brennan, & Craig, 2010). Second, plants reduce air pollutants, such as the compounds synthetic materials, computer equipment, and humans emit, which supports occupants' cardiovascular health and mental acuity (EPA, 2000). Park (2006) found that post-operative patients randomly assigned to rooms featuring plants had better short-term health outcomes than others in rooms without plants. Overall, office plants make a positive contribution to the workplace and improve employee wellbeing and productivity (Burchett et al., 2010; Lohr, Pearson-Mims, & Goodwin, 1996).

6.2. Inherent biophilic nature of OPOs.

Biophilic design is also apparent in the most ancient of human structures, and in this context is a setting to which humans are more familiar and suited to than an artificial office environment (Ryan et al., 2014). As an analogy, Heerwagen (2006) considers the difference between outdated versus modern zoos, and the apparent effects animal welfare. She argues that, while animals can survive in zoos (in the same way

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office workers can fulfil their role responsibilities in offices), it is difficult if not impossible for them to thrive in an environment that bears little resemblance to that which a species has adapted to. To address this, zoos worked with biologists to transform animal enclosures to recreate as closely as they could different species' natural environments. Considering the office environment, green ergonomics is an ideal discipline to similarly transform workspaces into simulating and nurturing environments that enable occupants to thrive in three particular ways.

First, an OPO provides the opportunity to apply green ergonomics and to create an occupant experience that includes moderate levels of environmental variability (e.g., light, sound, temperature), such as those found in nature. Artificial environments where such factors fall within a narrow, supposedly optimal range, can lead to boredom (Schooler, 1984), which could explain why people prefer moderate variability (Heerwagen, 2006). Providing such variability is one way to move away from the erroneous notion of a one-size-fits-all office that fails to appreciate the homogeneity among occupant preferences (Davis, 2019).

Second, OPOs also afford occupants the opportunity to see from one space to another, a spatial condition known as "prospect" (Ryan et al., 2014). From an evolutionary perspective, this gives humans the ability to have an awareness of their surroundings (including, in necessary, the presence of potential threats). Heerwagen and Orians' (1993) research shows the preference for prospect is strongest in savannah-like ecosystems, within which, like OPOs, an individual can conduct visual search with few obstructions.

Third, and perhaps most importantly, the inherent social dimension of an open-plan layout affords the opportunity for social cohesion through shared place attachment (Kellert et al., 2008). Social interaction is one aspect of OPOs that users are more satisfied with compared with private office layouts (Bodin Danielsson & Bodin, 2008). Based in the results of a longitudinal qualitative study, Gray and Birrell (2014) describe the reactions of occupants to a biophilic redesign of a construction site office, which indicated positive effects on psychological, physical, and social wellbeing. A shared space creates opportunities for shared experiences to create and reinforce bonds between group members, which nurtures a fundamental human need for relatedness (Deci & Ryan, 1985). OPOs are therefore seem to constitute an appropriate layout to enable occupants to develop the interpersonal connections critical for informal collaboration—which is an increasingly common way of working for employees working in complex contexts (Davis et al., 2011). Moreover, OPO features such as breakout spaces that enable such interaction to have positive associations with communication, job satisfaction, and wellbeing, particularly for occupants with higher levels of autonomy (Davis, et al., 2020). This interaction underlines the need to thoroughly consider the ergonomic interaction between the user and the space to enable the design of workspaces that provide the necessary physical and organizational environment for employees to thrive.

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6.3. Conclusion:

Integrating green ergonomics in a socio-technical approach to the design of OPOs could create enabling environments that facilitate workers' positive contributions to an organization's economic and environmental performance. Within this perspective, green OPOs could establish the balance between economic, social, and natural capital required as part of sustainable development (Thatcher et al., 2019). If there is truth in the views that (1) happy people are productive people (e.g. Bellet, De Neve, & Ward, 2019), (2) healthy people are happy people (e.g. Steptoe, 2019), and (3) healthy environments make for healthy people (e.g. van den Berg, Joye, & de Vries, 2013), then using green ergonomics to design OPOs that support occupants' physical, psychological, and social wellbeing should in turn enable organizations occupying such offices to improve their environmental, social, and financial performance.

7. Future research agenda

Ergonomic integration has the capability to identify and mitigate user issues and optimize the design of systems and system components, including how these align to sustainable development. Nenetheless, and particularly in multidisciplinary design processes, ergonomists often have to fight for their right to influence, and it is to this challenge that green ergonomics needs to rise (Martin, Legg, & Brown, 2013). In Table 1, we propose a future research agenda as a starting point for this.

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Table 1. Proposed future research agenda.

Research domain	Illustrative research questions
Return on investment	• What factors determine if and how rapidly investment in a green OPO might pay dividends? • To what extent does a green OPO influence the productive output at individual-, team-, and office-levels? • What factors mediate the relationship between green OPO and performance (e.g. psychological stress and restoration, collaboration, innovation)? • What are the reciprocal effects of a green OPO? • Do green OPOs having a positive mediating effect on the general relationship between job satisfaction and performance (e.g., Veitch, 2015)?
Occupant-technology interaction	• How much environmental variability (e.g., heating, lighting, breeze) is beneficial in an office environment? • How can ergonomists facilitate behavior change to maximize the benefit of green office technology? • What are the different requirements among typical office users (e.g., FM staff, occupants)? What implications does this have for providing performance feedback (e.g., interface design)?
Organizational Culture	• Do green organizations create green offices, or can a green office catalyze the emergence of a green organizational culture? • How might a green OPO reinforce other cultural values?
Biophilic design	• On what dimensions and to what extent do different examples of biophilic design (e.g., fractal patterns, olfactory stimuli, auditory stimuli) differ? • To what extent does the impact of biophilic design persist over time? • How do the effects of biophilic design scale beyond the individual (i.e., to the team level and beyond)? • Can standard performance metrics capture the impact of biophilia on knowledge work, which is often collaborative and focused on novel problem-solving? • Can providing nature sounds instead of white noise help moderate the experience of work stress?
Future of work	• How might organizations adapt their office space in the event of a sustained step-change to more virtual ways of working? • What opportunities does this create for organizations to leverage office-space in new ways to align to sustainable development? • How might organizations adapt their office space to flex with variable occupancy levels whilst minimizing environmental impact? • What mediates or moderates the impact of a more sustainable office environment on employee perceptions of organizational culture, including virtual workers. • What influence has an increase in remote working had on place attachment to a company's office?

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