

Review

A Socio-Technical Perspective on the Application of Green Ergonomics to Open-Plan Offices: A Review of the Literature and Recommendations for Future Research

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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 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 well-being 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 it is true that OPOs can, indeed, exemplify how “going green” may be good for business.

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



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1. Introduction

Government targets around “Net Zero Emissions” [1] 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, emerging evidence demonstrating the success of businesses engaging with the green agenda lend weight to the claim being green makes good business sense [2]. Moreover, scholars have begun to recognize that sustainability is an essentially *human* activity [3]. 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 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., see [4]).

More recently still, the focus of business since 2020 has been 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 entered various forms of lockdown, organizations experienced a radical shift as office-based staff began working remotely to curb the spread of the virus. This represents a sudden acceleration in the trend towards remote (home) working [5]. The full implications of this mass “experiment” in working remotely will emerge over time, and might also 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 [6]. Bodin Danielsson and Bodin [7] define such offices as shared rooms or spaces with more than four workstations and minimal partitions between occupants, and which provide the capacity to accommodate large numbers of workers, including the flexibility to accommodate changing requirements. This contrasts with traditional (or cellular) offices that separate individual workspaces. The size and specification of OPOs can vary significantly (although, in this article, we do not distinguish between small, medium, or large OPOs).

An indirect effect of the COVID-19 pandemic, and in particular its effect on office-based work, could lie in addressing the issue of OPOs compromising workers' access to appropriate workstations for focused work. In a pre-pandemic survey, Leaman and Bordass [8] 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" [9], such as cafes and libraries, then a company's office may similarly transition from being "the place where work happens" to become "the place where *some types* of work happen".

In this review article, we propose that OPOs sit at the confluence of organizations. On the one hand, organizations need to take meaningful steps towards reducing their environmental impact. On the other hand, they need to adapt 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 employees' health, well-being, and productivity.

To conduct our exploratory review, we included research literature spanning human factors, workplace, organizational behavior, environmental psychology, and engineering fields that overlap to create the topic area of green ergonomics. We unpack this literature 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), cultural (e.g., the office as a projection of an organization's environmental values), and socio-technical (e.g., the benefit to occupants of working in a green OPO) aspects of OPOs as these pertain to sustainable development. Finally, we briefly outline an agenda for future research in this area.

2. Pros and Cons of OPOs

Outcomes of empirical studies into physical work environment such as OPOs presents a tension [10]. Specifically, OPOs can be profitable and yet detrimental for organizations [11]. For example, advocates of OPOs believe that they stimulate cooperation, social relations, communication, feedback, solidarity, teamwork, and knowledge-sharing between workers while helping to inculcate a commitment to organizational values [12,13]. Results from this stream of studies also suggest that OPOs facilitate work satisfaction, creativity [14] and reduce overhead costs [15].

In contrast, another stream of studies suggests that OPOs lead to distraction and lack of privacy [16,17]. In this regard, Lee and Brand [16] investigated employees' perceptions of physical work environment from employees in five different American organizations and show a negative relationship between perceived distraction levels in the workplace and satisfaction with the physical work environment. Similarly, these authors found that 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) relate positively to the physical environment and job satisfaction.

Additionally, Perrin Jegan and Chevret [17] found that employees' satisfaction depends on the general ambient sound, noise management, and the physical positioning of workstations. Furthermore, these authors found that employees are least satisfied in administrative open-plan spaces. Brennan, Chugh, and Kline [18] corroborate this, finding

that moving to an OPO increases employees' physical stress, decreases satisfaction with the physical environment, reduces team member relations, and lowers perceived job performance. Additionally, noise in OPOs can be detrimental to performance, fatigue, and motivation; the extent of which varies with the level of cognitive processes and hearing status a task requires [19].

In terms of interactions, we are aware that OPOs may also trigger conflict and similar difficulties [20,21], although there is some debate regarding this. For example, Ayoko and Härtel [20] found that co-locating employees with diverse work ethics and work orientations in an OPO escalates conflict behaviors in participating teams. Moreover, feelings of powerlessness stemming from a lack of space ownership can trigger territorial behaviors that provoke conflict among employees in OPOs. Thus, co-locating employees with diverse work ethics and work orientations in OPOs escalates conflict behaviors in participating teams due to issues around noise, lack of control over their workspaces, and lack of privacy, more so than in cell offices.

In contrast, Bodin Danielsson and her team [21] found a significant influence of office type on workplace conflicts among women (not among men), which persisted after adjusting for noise disturbances. These authors also found that, especially in large OPOs, both genders report few conflicts, although they also found that women in flex- and combi-offices tend to report more conflict overall than men. Bodin Danielsson et al. conclude that other environmental factors inherent in this office layout account for the existence of conflicts.

One such explanation is that proximity between workstations escalates cognitive workload and decreases privacy [22]. This, however, contrasts with Davis, Leach, and Clegg [6], who found that open-plan layouts can facilitate serendipitous discussions and meetings that might otherwise not occur, and that personal autonomy tends to moderate whether an OPO environment is seen as distracting or enriching. In this regard, Monaghan and Ayoko [23] conclude that personal autonomy such as employees' personalization and territoriality is likely to be driven by the proximity of workstations to senior managers, hallways, and passers-by. Overall, these results indicate that OPOs are paradoxical insofar as they can impact employee behavior either positively or negatively.

Researchers also report finding that the air quality, noise, ergonomic conditions, and lack of privacy are significant predictors of psychological well-being [7,13,18,24–26]. Studying the impact of noise in open-plan working environments in China, Zhang and her colleagues [25] found that acoustic environment evaluations significantly correlate with fatigue, depression, and hypersensitivity to loud sounds. These authors also found significant correlations between job satisfaction and evaluation of various acoustics-related factors. This is consistent with Jahncke and Halin [19], who found in laboratory study that noise negatively impacts Swedish students' cognitive performance and motivation (as well as fatigue).

In other research, Herbig and her colleagues [26] 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 in this study 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 [7,27,28]). In addition to air quality and noise and privacy, Bae and colleagues [29] found that indoor air quality, furnishings, electric lighting, daylighting, and vibration/movement rank highest on influencing employees' health.

Ayoko and Ashkanasy [30] note 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 [31]. Similarly, covering surfaces and partitions with sound-absorptive materials can minimize speech sound levels [32], while higher dividing panels to separate workspace, or working in enclosed offices, can also serve as an

effective improvement measure [33]. Moreover, owing to prevalence of video conferencing, employees are more likely to use headphones as standard equipment, affording the capability to filter out ambient noises when the employee needs to concentrate.

Additionally, studies have shown that some categories of OPOs (e.g., Activity-Based Workspaces; ABWs; Combi offices) possess special characteristics. For instance, ABWs include offices where workers do not have assigned desks but are built with the purpose of switching between workspaces designed for specific set of activities [34]. In such spaces, there are usually intentionally designed supporting facilities (e.g., breakout rooms) to manage privacy issues (both in ABWs and in OPOs more generally). Such breakout rooms are usually not enough, however, and there is pressure on the few that are available [34]. Moreover, this may not be advantageous for employees who really do need to withdraw from an interaction, if only momentarily. We therefore suggest that additional side/private rooms (especially those that do not need strict pre-booking by users) should be facilitated. We argue that such supporting facilities (i.e., without the constraints of booking) would provide employees working on complex task (or needing to move away from stressful situations) the ability to withdraw (in the moment) and to complete tasks needing privacy or high concentration [24]. Additionally, flexible furniture should be considered as part of the solution for managing privacy issues (see [34]). Finally, Ayoko and Ashkanasy [30] also suggest that the challenge of privacy in OPOs is generally minimized by grouping employees working on similar tasks together. These authors argue that such grouping would engender informal communication that enable greater levels of privacy.

In the foregoing discussion, 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 potential for conflict. In the next 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 [35]. This manifests in evaluating and designing work environments, ways of working, and equipment to enable users 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 [36].

As with many disciplines, ergonomics is adapting to the imperative of sustainable development [37]. Accordingly, contemporary research and practice contributes to a growing literature that considers how ergonomics can integrate sustainable development alongside existing priorities such as safety [38]. Within this literature, Thatcher [39] 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 disruptions to commuter transport networks, impacting the workload of signalers responsible for managing the network [39], who can work in open-plan control rooms. Similarly, engineers must now account for a broader range of extreme weather events in their designs [40,41]. These examples demonstrate how climate change affects what work people do, how they do it, and the conditions in which they do it, thus emphasizing the fact that human activity is nested within the wider ecosystem [42].

Green ergonomics applies ergonomic principles, perspectives, and methods to support sustainable development through the design of work systems comprising multiple elements, including workspaces. A key distinction between green ergonomics and other similar areas, such as green supply chain management and green production, is the focus on the individual as the fundamental unit of analysis. This approach rests on three fundamental assumptions: (1) the earth is a closed system, where disruption in one area will

have consequences elsewhere in the system; (2) humans are a component of nature and are vulnerable to variations in the health of their environment; and (3) human activity can positively or adversely impact the environment. According to Thatcher [39], green ergonomics has two functions with respect to this bi-directional relationship between humans and the natural environment (of which they are a part). First, by facilitating human activity that makes a positive contribution by conserving, preserving, restoring, and regenerating nature. Second, by leveraging this relationship between to support human well-being and effectiveness.

In the context of sustainable development, green ergonomics is rooted in the concept of the “triple bottom line” [27], which advocates the view that genuine sustainability meets environmental, social, and economic needs. Accordingly, the goal of green ergonomics facilitators is to design systems that are efficient and effective 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 [43] 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 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 [44]). In complex adaptive systems that feature dynamic interdependencies among independent components, such as organizations, stability is an emergent process [45]. 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 could enable individuals, groups, and teams to move around and to find a location that satisfies idiosyncratic needs (e.g., proximity to certain amenities, access to natural light, noise levels, etc.).

In *Principle 3*, Thatcher and his co-authors [43] 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 Principle 2, the nature of OPO design enables users to adapt their space to meet local requirements.

Finally, in *Principle 4*, green ergonomics practitioners acknowledge 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 [46].

At the other end of this spectrum, regenerative design strives for a net positive effect on the natural environment by restoring, renewing, and/or revitalizing the natural resources

it consumes [47]. This stance advocates against activity with the potential for widespread harm caused by systemic risks, such as those that exist in conditions of uncertainty [48]. For example, where the specific impact of high levels of carbon emissions on the ecosystem is unknown, a precautionary stance would be to avoid increasing such emissions (which may include 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 ergonomic principles might constitute effective working environments that support worker, organizational, and ecological requirements.

So far, our discussion has centered on the potential impact of green economics on OPOs. We argue however that green economics can also affect private cell and agile offices. On a positive note, we have previously argued that OPO layouts enable individuals and teams to move around and to find a location that satisfies their idiosyncratic needs (e.g., proximity to certain amenities, access to natural light, noise levels). We argue that this will be a similar experience for workers in agile offices. Moreover, this situation might differ in private cell offices (single occupancy) where individuals work alone without many interactions with others. In this respect, single cell offices are stable, so the opportunity to move around to interact with the environment and other colleagues may be minimized. This may also be true of spaces that are unassigned to anyone but are available for the needs of workers (e.g., breakout rooms).

The extent of the alignment between green ergonomics and their impacts on differing office types needs more empirical investigations. In their systematic literature review, Shafaghat, Keyvanfar, Ferwati, and Alizadeh [49] suggest that sustainable approaches to OPOs design show that flexible spaces have the highest positive OPO design sub-features, while auditory dictation has the highest negative impact. We also know that variables other than green ergonomic approaches (such as autonomy and personal control and task design) can also contribute [33,50].

In the next section, we develop this idea a step further, and explore how such green OPOs can be exemplars of sustainable development from three different perspectives: (1) technical, (2) cultural, and (3) socio-technical.

4. The Technical Approach to Green Ergonomics

The focus on this perspective is on how ergonomic design and evaluation might be used to conserve, to preserve, and to restore nature. The UN estimates 28% of global CO₂ emissions derive from building operations; and 6.6% from commercial buildings (See <https://www.climatewatchdata.org/>, accessed on 12 July 2021). With approximately half of service sector organizations' environmental impact coming from building operations [51], the carbon intensity of an office is a prime target for companies seeking to align themselves with sustainable development. Lighting and heating/cooling are 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 practitioners use a variety of methods such as task analyses, people flow, usability testing and human error analyses [52] to design and evaluate work systems through prototyping, and post occupancy reviews for continuous improvement [53]. 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, these focus 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 an 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, so that 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 [54]. Notably, however, deploying green office technology without a clear understanding of ergonomics will still likely fail to promote efficiency, effective, and satisfying use on behalf of office workers [55].

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 [56]. 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 [57]. 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 also subsequently identify opportunities to reduce energy consumption. Using such understanding, de Bakker, Aarts, Kort, and Rosemann [58] 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 [33], namely, how and where people work, can rationalize energy use without compromising the conditions that facilitate task performance and, at the same time, help meet comfort needs for ambient lighting [59]. 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 [8]), and using light-reflecting finishes on surfaces [60].

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 [61]. 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 [62]). 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% [63].

Automated building services (such as lighting and environmental control) may also offer another technically sufficient way to reduce the energy consumption of an office (e.g., see [64]). If this is done in a way that is insensitive to user requirements and preferences, such as by failing to provide adequate thermal comfort, there could be unintended consequences, however. For example, users can manipulate the sensors that input into automated building services, which may move the energy efficiency of the office away from the technical ideal [64].

Accordingly, Leaman and Bordass [8] note that the environmental performance of green buildings can be fragile, owing to the complexity of their design. In our view, 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 office designers to develop OPOs that require less energy overall [55], while still preserving the autonomy of individuals to adjust [65]; for example, by designing a layout that enables occupants to optimize their exposure to natural light, ventilation, and solar radiation (and thus minimize the need for artificial light and HVAC systems).

The foregoing examples demonstrate some ways through which green ergonomics practitioners can apply a thorough understanding of user requirements, and how users can 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 help to address the human factor in an OPOs environmental impact.

4.2. Helping Employees to Limit Their Environmental Impact

The American Physical Society found that building energy consumption often exceeds projections made during the design process [66]. 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 [67,68]. Leaman and Bordass [8] suggest projections might fail to consider the dynamics of user behavior accurately; 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 researchers considers user variability as a design parameter [36] that could identify and proactively address such issues (i.e., 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 [69] 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 potential depends on occupant/user behavior.

This also relates to the concept of employee green behavior (EGB), which Ones & Dilchert [70] define as “scalable actions and behaviors that employees engage in or bring about that are linked with, and contribute to, environmental sustainability” (p. 87). Unsworth, Davis, Russell and Bretter [71] argue further that researchers and practitioners should consider EGB from a systems perspective. Tools such as the Leadership in Energy and Environmental Design (LEED) rating system support this view; and consider the ergonomic features of office equipment [36]. 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 [72]. 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 [73].

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 [74]. Despite this, the contribution of small power equipment to overall office energy consumption is poorly understood [75]. 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 [75] 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 [6].

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; this is because the workplace typically provides what employees 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 by Kawamoto and his associates [76] demonstrates the importance of this. These researchers compared personal computers manufactured before and after 2000 and found 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 in fact use *more* energy in normal operation. More recent reviews suggest the difference in energy consumption between these two different modes is widening [75]. Therefore, reducing the energy consumption of personal computers in OPOs appears to depend on user behavior, particularly the use of low-power mode. Results from interventions where users receive prompts to turn off office equipment (e.g., see [77]) suggest this is an effective green ergonomics solution.

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. Indeed, research shows that 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 [78,79]. One way to transition from an ordinary OPO into a green OPO is therefore to task ergonomists to develop office user guides that increase occupant awareness of the green technology within the OPO; and show how they can leverage this to optimize environmental performance.

In situations where discretionary user behavior drives energy efficiency, providing performance feedback is important. Green ergonomics applies usability heuristics [80] 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 [81]. In an office setting, however, occupants are unlikely to know how much they contribute to the overall energy demand or to experience any feedback that might encourage them to minimize their energy consumption [38].

In the absence of behavioral feedback, energy saving behaviors may lack the reinforcement required to habituate them, however. Findings by Becker and Seligman [82] 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 EGBs [83]. Effectively deploying smart meters must also consider the interaction with users to ensure they are aware of the meter, that the information provided is useful, and users can interpret this information to make behavioral decisions [84].

Under 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 [85]. For example, Van Houten, Nau, and Merrigan [86] reduced elevator usage by as much as one third by slowing the speed of elevators travelling 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; this in turn had the effect of encouraging stair use while simultaneously 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 support 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). As such, this approach helps to identify not just the right technology, but how to provide this in a way that interacts with occupants and their behavior to minimize consumption (e.g., of energy) and waste.

5. The Cultural Approach to Green Ergonomics

From a cultural perspective, organizations can use the open layout of an OPO as a kind of gallery within which to display artifacts and symbols of sustainable development, and project a positive value to supporting sustainability related activity. We therefore now consider the social aspect of an OPO through the concept of organizational culture. Specifically, we look at 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 [87].

5.1. Defining Culture

Schein [88] defined 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, can 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 [89], including behavior aligning with environmental sustainability [90]. Schein's [91] most recent 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 thus both a cultural artifact and a gallery for other artifacts [92]. In this section, we therefore present the office as a cultural showcase that an OPO featuring green ergonomics could reinforce, and potentially help to develop in the first place, that is, a workplace culture that aligns with and supports sustainable development.

5.2. Cultural Symbols

Like brand names, logos, and uniforms, an office has symbolic value for an organization, although the office is usually considered more likely to reflect its utilitarian function rather than aesthetic form [92]. Nevertheless, the physical design of an office communicates corporate cultural values, which in turn influences the social context and influences occupants' normative behavior [92]. For example, a cellular office with name plates on closed doors could indicate workplace values of formality, privacy, and independent work. Alternatively, an OPO showcasing elements of the natural environment (e.g., plants, organic shapes, natural light, ventilation, etc.) and green technology (e.g., a screen showing real-time energy use data) could reflect workplace values of 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 [93]. 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 also 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 [54]. 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 then updating these [94].

5.3. Social Norms

While all offices have the potential to display cues that indicate a corporate value towards sustainable development, 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 antecedents of EGB [95]. 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 (British Telecom, London, UK) 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 [54]. This constitutes an injunctive social norm, of which other examples include corporate statements regarding sustainable development [96], publishing an environmental strategy [97], and announcing science-based targets (e.g., see [98]). This is all consistent with research demonstrating that employee perceptions of injunctive norms contribute to task related EGB [99].

Providing normative messaging can also further encourage employees to develop and to reinforce a perception that their organization is committed to sustainable development. With an ergonomic understanding of how occupants interact with their office environment, organizational managers should be able more effectively to install features that promote injunctive norms for sustainable development. For example, using the principles of green ergonomics, they 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, OPO managers 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 [99].

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 descriptive norms are particularly important for encouraging non-task related behavior [99], which might include participating in environmental groups, volunteering, and supporting other employees' EGB.

For example, many organizations provide a green "binrastructure" to support effective waste management, such as receptacles for separate waste streams (See <https://www.zerowastescotland.org.uk/litter-flytipping/binrastructure>, accessed on 12 July 2021). 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 [54]. Researchers have also 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 [100]. 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 [101]. 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 [78]. Providing an environment that encourages normative goals is therefore particularly important for pro-environmental behavior, which is less stable when driven by hedonic or gain goals [102]. Moreover, 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 promoting these to the occupants) could be an important contribution to aligning green OPOs to sustainable development.

So far in this section, we have outlined how OPOs can support the emergence of social norms, which can then 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 alternative office layouts) might encourage a more social orientation among OPO occupants, and pro-social behavior such as EGBs [103,104]. This would also align with the assumptions that underlie sustainable development, such as preserving the ability of others in the future to meet their own needs [105].

Research pointing to the social benefits of OPOs, including promoting collaboration [106,107] and relationships between co-workers [108], suggests further that the OPO layout might facilitate a shared social identity [109]. An active social identity can encourage members to engage in pro-social behaviors that contribute to group goals, even if these are at the expense of personal gain [110]. 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 s/he would benefit personally (relative to other group members).

Observers might perceive behaviors in an OPO differently than in a less social environment, however. The inherent social context of an OPO might 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.

Moreover, by adopting a green ergonomics perspective, office designers should communicate and emphasize the design intent of a green OPO to manage the interaction between occupants and the OPO environment. This is because, where users understand the design intent, they tend to be more tolerant of things that might not meet their requirements [8]. Thus, occupants may learn to perceive features such as 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). Organizational leaders also have an important role to play in this respect. Ayoko and Härtel [111] propose in this regard that a leader's conflict, space management, and social-oriented skills are critical in creating a climate conducive to effective management of conflict in diverse teams and, by extension, in creating a culture that will be beneficial for the development of sustainable OPO environments.

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

According to Lindenberg [93], the most salient cues for normative behavior comprise 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 be seen to provide such cues to encourage the efficient and effective use of green technology, not to mention other EGBs. A green ergonomic 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 [112]). Furthermore, by co-locating group members in a shared space, OPOs can facilitate the exchange of information [113], including normative information.

6.1. Well-Being and Performance Benefits for Occupants

A person-environment fit perspective [114] emphasizes the need for a workspace to align with worker's needs. As with green ergonomics, the person-environment fit perspective espouses a reciprocal relationship between a worker and their work environment [115]. A green OPO would not only minimize its environmental impact, but also provide a healthy and restorative environment for occupants.

Good buildings should support the well-being and comfort of occupants [116]. In this context, well-being refers to a positive state of being that emerges from the interaction of physical, social, and mental components [117]. 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 [118]. This suggests that the health of an organization according to traditional metrics might rest on the health of its human capital. Thatcher [119] 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 well-being of occupants [120], has a critical role in the interaction between workers and their workspaces.

Biophilic design provides cognitive, psychological, and physical health benefits [121] and is a fundamental component of a green OPO. Biophilia refers to a fundamental need for humans to connect with nature [122]. Biophilic design aims to generate positive emotional experiences through design, which are fundamental to development place attachment [122]. Designers can demonstrate biophilic design in three ways: (1) by introducing nature into the space, such as plants and living walls [123], but also light and thermal variability; (2) by providing natural analogues, such as shapes and colors found in nature; and (3) by considering the nature of the space, for example places to interact and places to rest [122]. In the context of green ergonomics, biophilic design thus represents the dynamic interaction between people and their environment; and explains how green OPOs can support the well-being and performance of office workers. 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 well-being and capacity to perform sustainably.

Natural visual stimuli can also improve typical cognitive resources office workers use throughout the day, such as concentration and memory [124]. One example of biophilic visual stimulation involves complex patterns 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 [125]), high dimensions of pattern intensity can induce stress and nausea [126]. Green ergonomics designers should consider how different stimuli, such as patterns in carpets, wallpapers, and seat cushions, coalesce and form a single visual scene. The available evidence suggests

that, while visual stimuli can support employee performance and well-being, there is a tipping point beyond which these elements compromise the user experience.

In his stress restoration theory, Ulrich [127] 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 [128] or after [129] 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 [130], though this is not as strong an effect as viewing actual nature (e.g., through a window [131]). Interestingly, urban environments featuring water elements appear to have similar health benefits to natural scenes without water [121]. Nevertheless, following this general line of reasoning suggests that the optimal condition is one that integrates real examples of nature, such as plants and clean running water [122].

Regulators such as the British Council for Offices require OPOs to provide a minimum amount of ambient noise for conversation privacy [132]. 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 [133].

Meta-analytic findings also point to benefits from listening to natural sounds for stress and annoyance, physical and mental health, and cognitive performance [134]. 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 [125]). In addition to having a restorative effect to support workers capacity to respond to new stressors, nature sounds can also stimulate creative performance [135].

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. We argue the office plants have two major benefits. First, plants provide occupants with access to recognizable example of the natural world, which can reduce stress and improve mood [136]. Second, plants can reduce air pollutants, such as the compounds synthetic materials, computer equipment, and humans emit, which supports occupants’ cardiovascular health and mental acuity [137]. In addition, Park [138] found that post-operative patients randomly assigned to rooms featuring plants tend to have better short-term health outcomes than others in rooms without plants. At the same time, it is worth noting that the benefits of office plants have recently become less clear (see [139]). Nonetheless, while there is some debate about the benefits of indoor plants, Han and Ruan [140] concluded from a comprehensive meta-analysis that, “Indoor plants have great potential to not only improve the air quality and comfort of indoor environments but also enhance people’s health and well-being as well as save energy” (p. 16051).

Finally, biophilic design can alter the extent to which occupants are physically active in the office. This also extends to features that permit and promote physical activity. In this regard, Wallmann-Sperlich, Hoffmann, Salditt, Bipp, and Froboese [141] ran a pilot study during an office refurbishment that incorporated examples of biophilic design and features to permit and encourage occupants to enjoy a wider range of physical activity in the office. The authors found a 40-min increase in typical time spent standing after seven months, which could mitigate musculoskeletal issues that can arise from sedentary work (see also [142]).

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 [121]. As an analogy, Heerwagen [109] considered 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 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, modern zookeepers have adopted a philosophy of “environmental enrichment,” where they work with biologists to transform animal enclosures to recreate (as closely as possible) different species’ natural environments [143]. Considering the office environment, green ergonomics is an ideal discipline to transform workspaces similarly into simulating, enriched and nurturing environments that enable occupants to thrive in three ways.

First, OPOs provide 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 [144], which could explain why people prefer moderate variability [109]. 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 [145].

Second, OPOs afford occupants the opportunity to see from one space to another, a spatial condition known as “prospect” [121]. 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’ [146] 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 [126]. Social interaction is one aspect of OPOs that users are more satisfied with compared with private office layouts [8], and that workers might increasingly demand from an office to offset the social isolation that can occur when working flexibly or remotely [34]. Based in the results of a longitudinal qualitative study, Gray and Birrell [147] describe the reactions of occupants to a biophilic redesign of a construction site office, which indicates positive effects on psychological, physical, and social well-being. A shared space also creates opportunities for shared experiences to create and reinforce bonds between group members, which nurtures a fundamental human need for relatedness [148]. OPOs are therefore seen 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 [6]. Moreover, OPO features such as breakout spaces enable such interaction to have positive associations with communication, job satisfaction, and well-being, especially for occupants with higher levels of autonomy [149]. This interaction underlines the need to consider the ergonomic interaction between the user and the space thoroughly. This, in turn, should enable the design of workspaces that provide the necessary physical and organizational environment for employees to thrive.

6.3. Conclusions

Integrating green ergonomics in a socio-technical approach to the design of OPOs has the potential 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 [38]. If there is truth in the views that (1) happy people are productive people [150], (2) healthy people are happy people [151], and (3) healthy environments make for healthy people [152], then using green ergonomics to design OPOs that support occupants’ physical, psychological, and social well-being 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 to mitigate user issues; and also to optimize the design of systems and system components, including how these align to sustainable development. Nonetheless, and particularly in multidisciplinary design processes, ergonomists must often fight for their right to influence, and it is to this challenge that green ergonomics needs to rise [53]. In Table 1, we propose a future research agenda that we feel should serve as a starting point for this end.

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., see [153])?
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 optimize green office technology? • What are the different requirements among typical office users (e.g., Facilities and maintenance 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 (e.g., justice, social value)?
Biophilic design	• On what dimensions and to what extent do different examples of biophilic design (e.g., fractal patterns, olfactory stimuli, auditory stimuli) impact occupants (e.g., stress, focus, performance)? • How can organizations monitor, measure, and evaluate the impact of biophilic design on mental, physical, and social well-being? • To what extent do benefits from biophilic design persist over time? • Do biophilic design benefits scale beyond individuals (i.e., to the team and organization levels)? • 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 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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