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Designing for sustainability: ergonomics – *carpe diem*.

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Sustainability is a global issue that has worldwide attention but the role of ergonomics in designing for sustainability is poorly understood and seldom considered. An analysis of the literature on ergonomics, design and sustainability was conducted via a search of electronic databases: Scopus, Business Source Complete, Google Scholar, Emerald Publishing, Academic Search Premiere, Web of Science, Discover and Ergonomics Abstracts, for the years 1995–2012. A total of 1934 articles fulfilled the search criteria, but content analysis of the abstracts indicated that only 14 refereed articles addressed the main search criteria. Of those seven were in ergonomics journals and seven were in other journals (and were not written by ergonomists). It is concluded that the contribution of ergonomics to sustainability and sustainable design has been limited, even though the goals of sustainability and ergonomics are congruent. Ergonomists have not been at the forefront of research contributing to sustainability – and it is time for them to ‘seize the day’ – ‘*carpe diem*’.

Practitioner Summary: This literature review shows that ergonomics contribution to sustainability is limited but since there is congruence between the disciplines it calls for ergonomists to become more involved and to seize the day – *carpe diem*.

Keywords: human factors; green design; conservation; environment; review

1. Introduction

The literature related to sustainability, sustainable development and sustainable design is vast, and comes from many different perspectives. Definitions vary, depending on the author’s point of view. However overall, sustainability can be thought of in the sense that for something to be sustainable, it is able to be maintained, that it is ongoing. Many definitions of sustainability contain the idea of intra-generational equity, which is the present generation should not be undertaking activities that compromise the ability of future generations to meet their needs (WCED 1987). A major component of sustainable activity is the avoidance of ecological damage and the use of renewable resources (McLennan 2004). Also included may be social, economic and cultural concerns, reflecting that sustainability is generally viewed anthropocentrically. The Rio Declaration on Environment and Development’s first principle is that ‘human beings are at the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature’ (UNCED 1992).

Unfortunately, sustainable development has continued to be a challenge, post the Brundtland Report and the Rio Declaration, as reflected in another United Nations document which states ‘it is widely recognised that the rapid advance of globalisation since the first Earth Summit in 1992 has far exceeded the ability of the global system to respond to the sustainability challenges that this has caused’ (Schneeberger *et al.* n.d., p. 4). The World Wildlife Fund for Nature’s Living Planet Report (WWF 2010) states that natural resources are being consumed faster than the Earth is replenishing them. The earth’s population is currently consuming the equivalent of 1.5 planets to support human activities. If current trends continue, by 2030 we will need the resources of two planets to meet consumption needs and absorb CO₂ waste.

It is suggested that we need to redesign many of our systems to achieve sustainability and that ergonomics might be used to assist (Lueng 2003, Steimle 2006, Brown and Legg 2011). Sustainable building design, also called ‘green’ design, emphasises energy conservation, building in a resource efficient manner, using renewable resources, creating healthy indoor environments, and providing overall structural durability (Kopeck 2009, Forbes and Ahmed 2011). ‘Eco-efficiency’, which was encouraged by the World Business Council for Sustainable Development in 1992, is defined as greater resource productivity, using fewer resources to achieve the same goals and also producing less

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waste in the process (Fuad-Luke 2004). According to Anastas and Zimmerman (2003), sustainable design should also include designing for reuse and recycling. Products and systems should be designed for performance in a second 'afterlife'. They write about the '12 Principles of Green Engineering' which include using inherently non-hazardous materials, preventing waste and designing products that are efficient, durable, and that use renewable resources.

The role of ergonomics in sustainability, sustainable development and sustainable design is still seldom reported or considered, despite a call for research into ways to get people to modify their behaviour to be more ecologically conserving (Nickerson and Moray 1995). Vincente (1998) found that ergonomics textbooks scarcely addressed global problems. In a review of the literature on sustainable development and human factors, Thatcher (2012) reports that while definitions for sustainable development appear to be consistent, many articles fail to include any definition. There was also a bias towards economic and social capital and most articles were theoretical. Moray (1995) had also called for ergonomics to be involved in changing human behaviour. Drury (2008a,b) points out that ergonomists are increasingly accepted into design teams, but that the changing world of work has only slightly changed the emphasis of ergonomists work from physical towards decision making. He calls for changes needed to address the future world of globalisation. It seems surprising that these calls have been so little heeded. Although an International Ergonomics Association Technical Committee 'Human Factors and Sustainable Development' has recently been established and the 18th World Congress on Ergonomics held in 2012 had the theme of 'Designing for a Sustainable Future', and as an example the Human Factors and Ergonomics Society of New Zealand has sustainability as a central theme for its conference in 2012, the reality is that there is still very little sign of ergonomists tackling sustainability issues. This is reflected in the articles published in the IEA 2012 proceedings (IEA 2012): only one of 52 symposia, no workshops and only 17 of the 897 articles actually address the conference theme. It is also surprising in view of the well-recognised (amongst ergonomists) definition of ergonomics as: the 'scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and other methods to design in order to optimise human well-being and overall system performance' (IEA 2010).

Ergonomists can guide the process needed for successful design. For example, Moore (2007) describes a collective design process in sustainable residential construction that involves ergonomists. Frejus and Guibourdenche (2012) show how domestic activity can be adjusted to reduce household energy consumption and Marano *et al.* (2012) identify an early logical-interpretive model for ergonomic design for sustainability. Ergonomists can identify the important issues in the design and apply a methodical and scientific approach to evaluation and also to verify and contribute to the sustainability of a design (Sanders and McCormick 1992, Gennari 2000). Ergonomists can also work with designers to promote not only safety and productivity, but also the sustainability of a designed product or system (Hedge 1998, Kopec 2009). Development and design can, and should, be sustainable and involve ergonomics and ergonomists. Ensuring the goals of both ergonomics and sustainability are met should promote greater success for both. For example, a healthy indoor environment is one of the goals of ergonomics, as it will optimise the health and performance of the workforce (Hedge 1998).

Thus it seems logical that ergonomics must have a critical role to play in designing for sustainability. However, it is often the case that ergonomists have minimal input to *any* design processes – a situation that can range from mildly irritating (for example, a control knob that is 'illogically' placed or inaccessible (Sanders and McCormick 1992) to catastrophic (the incidents at Bhopal, Three Mile Island, Chernobyl and Ladbroke Grove (Wilson and Corlett 2005)). The ergonomics profession needs to 'seize the day' if it wishes to have more input into design for sustainability.

Additionally, it has been argued (Birkeland 2008) that there is a 'blame the consumer' approach for unsustainable behaviours, particularly in relation to the built environment. Birkeland (2008, p. 65) believes that societal systems are not well designed for achieving sustainable consumer behaviours: 'while consumption and design issues are inseparable, the focus on consumer behaviour implies that society has to change behaviour first . . . But consumers do not design the systems that result in waste, toxins and inequity . . . they cannot "choose" products that have not yet been designed . . . consumers demand services, not waste'. There is a parallel here with 'blame the worker' or 'blame the operator' approaches to accidents, and certainly the ergonomics profession has been instrumental in addressing latent (design) errors as well as active (operator) errors (e.g. Reason 1990, Chapanis 1999). An approach which addresses system design issues to encourage more sustainable consumer behaviours should be successful. Indeed, it appears that this approach is being espoused in the field of behavioural economics (Thaler and Sunstein 2008). Behaviour change around energy use would be much easier if we improved building design to not require so much heating and public transport to be efficient and convenient. Birkeland (2008, p. 65) believes this is a design issue and that design professions can 'reduce consumption and create meaningful consumer choices. We may not be able to control how people use buildings or products, but we can design them so that

conservation comes naturally and creates a higher quality of life'. The principles of design that would achieve these outcomes can be substantially informed by the accumulated knowledge base of the ergonomics profession (Moray 1995, Vicente 1998).

Recently, Scott (2009) and others, such as O'Neill (2005), have looked at ergonomics and sustainability in industrial developing countries (IDCs) from a wider perspective. Scott proposes that ergonomists assist developing nations to become more self-sustaining, so that they become more able to contribute on an equal basis to the global market. This then promotes 'universal sustainability' (Scott 2009, p. 437) or reducing the 'carbon footprint' and is an important development for ergonomics as a discipline that may have a worldwide impact.

The present article describes a literature review that explores what ergonomics has contributed to sustainability, and to sustainable design. It also considers ways in which ergonomics and ergonomists could do more and argues that it is time for them to 'seize the day' – '*carpe diem*'.

2. Methods

In carrying out the review, it was necessary to first define 'sustainability' and to be selective about what types of publications could be judged to be adopting a sustainable approach to design. In addition, the review aimed to cover research that could fall within the broad scope of ergonomics. The challenges involved in carrying out such a review largely relate to terminology and definition. As indicated already in the introduction, the term 'sustainability' for example, has many different definitions (e.g. in business it refers to ensuring that the business keeps operating; articles addressing this perspective were not included). Furthermore, 'design' is in itself broad in scope, covering work drawn from a wide variety of domains, including many bordering on mainstream ergonomics (e.g. organisation science, psychology, sociology), as well as different traditions and approaches within ergonomics (e.g. macroergonomics, socio-technical systems theory). In order to overcome these problems it was decided to keep the analysis of publications as broad as possible at the beginning and then to filter out articles judged to be outside the scope of 'designing for sustainability'.

2.1. Identification and selection of publications

A database search was conducted on Scopus, Business Source Complete, Google Scholar, Emerald Publishing, Academic Search Premiere, Web of Science, Discover and Ergonomics Abstracts for the years 1995–2012 using the keywords 'sustainab*', 'design' and 'ergonom*' or 'human factors'. To ensure wider coverage it was repeated using the terms 'ergonom* AND sustainab*' OR 'human factor* AND sustainab*'. In this latter case, the term 'design' was not specifically included so as to also catch articles which involved or discussed design but which did not use the word 'design'. The databases were chosen for their coverage of literature relating to design, sustainability and ergonomics. The following relevance criteria were used to identify articles from those retrieved from the databases: ergonomics interventions that had a sustainability focus, calls for sustainable programmes, the advantages of the sustainability and design or its importance, and articles that 'championed' sustainability in design.

Article abstracts were selected if they addressed an issue that was likely to fall within the broad range of subject matter within ergonomics, whilst at the same time directly addressing 'designing for sustainability'. The selected articles were then read and included in this review if they met the above criteria.

3. Results

A total of 1934 publications were identified using the initial keyword search but only 14 peer-reviewed and refereed journal articles fulfilled the relevance criteria. Details of these are given in Table 1, together with additional key articles that were identified by the search repeated for wider coverage. Additionally, 15 books, three conference proceedings, a United Nations report, a World Wildlife Fund report and various documents from websites (such as the IEA and the Human Factors Society) met the search criteria. Details of these are given in Table 2. Additional articles were recalled from memory by the authors and these were also included in Table 2.

3.1. Themes identified from the review

For the initial general search, professional journals for designers, architects and/or builders were found to be a plentiful source of articles on sustainability, whereas professional ergonomics journals were not. This is an indicator of the lack of focus by ergonomists on sustainability. Of the articles that met the selection criteria, six articles were in

Table 1. Summary of journal findings and coverage of issues.

Author and year	Source journal	Title	Description/outcome measure/objectives	Key findings	Ergonomics interventions with a sustainability focus	Championing of sustainability in design
Anastas and Zimmerman (2003)	Environmental Science and Technology	Designing through the 12 principals of green engineering	To highlight that sustainability requires objectives at the molecular, product, process and system levels	<ul style="list-style-type: none"> Participative approaches encourage sustainability Ergonomics, and sustainability, still needs to be 'sold' to designers, managers and other stakeholders Sustainable design should include designing for reuse and recycling Products and systems should be designed for performance in a second 'afterlife'. Includes using inherently non-hazardous materials, preventing waste, and designing products that are efficient, durable, and that use renewable resources 	✓	✓
Attaianese and Duca (2010)	Theoretical Issues in Ergonomic Science	Human factors and ergonomic principles in building design for life and work activities: an applied methodology	A survey of ergonomics principles, analysing the role they play in the architectural design process. How a design methodology can support designers to create working and living spaces that fit the needs of inhabitants.	<ul style="list-style-type: none"> A comprehensive methodology for designing ergonomic buildings is still lacking Human-centred building design methodology is an iterative process and participative approaches work best Design methodology is described in operational steps supported by practical examples 	✓	✓
Drury (2008a,b)	Heidelberg: Physica Verlag,	The future of work in a sustainable society, in K.J.Zink (ed), Corporate sustainability as a challenge for comprehensive management.	Identifies the systems approach used in 'the limits of growth' report as being congruent with the systems approach used by HF/E	<ul style="list-style-type: none"> Level of usage of earth's resources is running beyond earth's capacity Limited capacity of HF/E professionals to influence resource use or limits but can influence the models that are used HF/E advocacy has been successful at level of national and international standards development 	✓	✓
Eswaramoorthi et al. (2010)	Work	Redesigning assembly stations using ergonomic methods as a lean tool	Assessment of posture and ergonomic stressors on a production line, and an attempt to create a 'Lean assembly line'	<ul style="list-style-type: none"> Lean manufacturing and the use of ergonomic methods can provide increased quality, lower cost and shorter lead times through the elimination of waste 	✓	✓

(continued)

Table 1. (Continued).

Author and year	Source journal	Title	Description/outcome measure/objectives	Key findings	Ergonomics interventions with a sustainability focus	Championing of sustainability in design
Fischer and Zink (2012)	Work	Defining elements of sustainable work systems – a systems-oriented approach.	Development of a system-oriented approach to analysing sustainable work systems	<ul style="list-style-type: none"> Sustainable development comprises the management of human, social, ecological and economic capital in a balanced manner 	✓	
Greenwald (2009)	Industrial Engineer	Sphere of safety	Describes how ergonomics can improve business outcomes with a proactive approach	<ul style="list-style-type: none"> Integrating lean manufacturing principles is good business practice 		✓
Guimaraes (2012)	Theoretical Issues in Ergonomics Science	Sociotechnical design for a sustainable world	Describes a sociotechnical design method for conceiving innovative sustainable products and/or systems.	<ul style="list-style-type: none"> A participatory approach to design that focuses on basic people needs using waste as raw material for developing products/systems with high added value Matrices for design opportunities, demands and environment, and evaluation in terms of sustainability, quality and cost. Aligned with a cradle to cradle approach consistent with Zero Emissions Research and an initiatives chain production system approach 	✓	✓
Guimaraes and dos Santos (2012)	Theoretical issues in ergonomics Science	Application of the sociotechnical design method for the development of eco-friendly shoes for Brazilian students of public schools.	Describes how a sociotechnical design method can be used to design eco-friendly shoes for school students	<ul style="list-style-type: none"> Shows how a traditional and dangerous method for shoe manufacture can be transformed into a more sustainable one 	✓	✓
Häkkinen and Belloni (2011)	Building Research and Information	Barriers and drivers for sustainable building	A literature review, interviews and case studies are presented to address the barriers to sustainable building	<ul style="list-style-type: none"> Participative approaches encourage sustainability 		✓

(continued)

Table 1. (Continued).

Author and year	Source journal	Title	Description/outcome measure/objectives	Key findings	Ergonomics interventions with a sustainability focus	Championing of sustainability in design
Hedge (2000)	Ergonomics	Where are we in understanding the effects of where we are?	Reviews research on the health effects of office lighting, indoor air quality in offices, and sick building syndrome	<ul style="list-style-type: none"> States the value of a systematic, ergonomics approach to designing the built environment Ergonomics, and sustainability, still needs to be 'sold' to designers, managers and other stakeholders 	✓	✓
Heerwagen (2000)	Building Research and Information	Green buildings, organizational success and occupant productivity	Considers the wider context of sustainable design to show how 'green' buildings provide organisational and economic benefits	<ul style="list-style-type: none"> Gives examples of the positive productivity outcomes achieved through green building practices 	✓	✓
Howarth and Hadfield (2006)	Materials and Design	A sustainable product design model	How using a structured design evaluation model can modify the design and improve the sustainable aspects	<ul style="list-style-type: none"> Ergonomic behavioural interventions can encourage sustainability Designers need to be encouraged to think how products can be more sustainable, and how use of a model can facilitate this process 	✓	✓
Imada (2008)	Heidelberg: Physica Verlag	Achieving sustainability through macroergonomics, In K.J. Zink (Ed), Corporate sustainability as a challenge for comprehensive management.	Proposes macroergonomics is able to make a large contribution to global sustainability, given the human centred and systems approach	<ul style="list-style-type: none"> Workable solutions must have three components: (a) it must examine the entire system (social, organisational, human interfaces), (b) it must have a plan to manage change by targeting challenges to change in a systematic and planned way, and (c) solutions need to have a longer time horizon beyond short-term metrics 	✓	✓
Macmillan (2006)	Building Research and Information	Added value of good design	Reviews current research on the benefits associated with a well-designed build environment	<ul style="list-style-type: none"> Design decisions need to be informed by the best available evidence about how the physical environment can support social and economic outcomes 	✓	✓
Monroe (2006)	Industrial Engineer	Ergonomics 101	What makes an ergonomics programme successful and sustainable	<ul style="list-style-type: none"> Many of the papers in this literature review show a lack of such evidence Ergonomics, and sustainability, still needs to be 'sold' to designers, managers and other stakeholders Identification of six core elements of successful ergonomics programmes (e.g. management commitment, participative approaches) 	✓	✓

(continued)

Table 1. (Continued).

Author and year	Source journal	Title	Description/outcome measure/objectives	Key findings	Ergonomics interventions with a sustainability focus	Championing of sustainability in design
O'Neill (2005)	Industrial Ergonomics	The promotion of ergonomics in industrially developing countries	To describe the difference between practicing ergonomics in IDCs and IACs	<ul style="list-style-type: none"> Ergonomics fits well with a sustainable livelihood approach Examples of interventions at a micro level 	✓	
Scott (2008)	Applied Ergonomics	Global inequality, and the challenge for ergonomics to take a more dynamic role to redress the situation	Proposes that it is relatively easy to promote a sustainable ergonomics ethos in IDCs	<ul style="list-style-type: none"> Both micro and macro problems need to be considered Sustainability, ergonomics and design need to be linked 		✓
Sutcliffe <i>et al.</i> (2008)	Sustainable Development	Can eco-footprinting analysis be used successfully to encourage more sustainable behaviour at the household level?	Research to find if individuals will make reductions to their environmental impact when given feedback about their 'ecological footprint'	<ul style="list-style-type: none"> Ergonomic behavioural interventions can encourage sustainability 	✓	
Thatcher (2012)	Work,	Early variability in the conceptualisation of 'sustainable development and human factors'.	To examine the diversity of definitions and approaches to sustainable development and human factors in early papers of the discipline	<ul style="list-style-type: none"> Consistent definitions for sustainable development but large proportion of papers gave no definition Bias towards economic and social capital Most papers were theoretical 	✓	
Thomas (2010)	Building Research & Information	Evaluating design strategies, performance and occupant satisfaction: a low carbon office refurbishment	To provide insights from evaluation of a large scale refurbishment project	<ul style="list-style-type: none"> Participative approaches encourage sustainability Green technologies and design strategies have benefits such as reduced use of resources, and are conducive to human health and productivity Sustainability, ergonomics and design need to be linked 	✓	✓

Table 2. Additional sources, findings and coverage of issues.

Author and year	Source	Description/title	Outcome measure/objectives	Key findings	Ergonomics interventions with a sustainability focus	Championing of sustainability in design
Birkeland (2008)	Book	Positive Development: From vicious circles to virtuous cycles through built environment design	A challenge to those working in or studying the areas of sustainable development, architecture or the built environment to rethink their current ideas and practices	<ul style="list-style-type: none"> • Presentation of an innovative new paradigm of 'Positive Development' in which the built environment provides greater life quality, health, amenity and safety for all without sacrificing resources or money. • With a different form of design, development itself can become a 'sustainability solution'. • A cornerstone of this new paradigm is the eco-retrofitting • The author presents a revolutionary new tool called SmartMode to achieve this end. • Businesses have good intentions towards corporate social responsibility and sustainability goals, but there is a gulf between 'good intentions' and 'good deeds' • Ergonomics can bridge the gulf between 'good intentions' and 'good deeds' resulting in 'good business' and improved outcomes across all three pillars of sustainable development (economic, environmental and social) • Key ergonomics facets which can be applied to sustainability goals are: sociotechnical systems approach, usability, designing for future users, multifactorial feedback, participation, change management and implementation of total quality management • Because of the systems approach in ergonomics, it lends itself to application to sustainable development where multiple dimensions need to be optimised jointly (rather than one dimension optimised at the expense of the others). Practical examples are given 	✓	✓
Brown and Legg (2011)	Book	Human factors and ergonomics for business sustainability	Promoting ergonomics as a means to sustainable development	<ul style="list-style-type: none"> • Ergonomics can bridge the gulf between 'good intentions' and 'good deeds' resulting in 'good business' and improved outcomes across all three pillars of sustainable development (economic, environmental and social) • Key ergonomics facets which can be applied to sustainability goals are: sociotechnical systems approach, usability, designing for future users, multifactorial feedback, participation, change management and implementation of total quality management • Because of the systems approach in ergonomics, it lends itself to application to sustainable development where multiple dimensions need to be optimised jointly (rather than one dimension optimised at the expense of the others). Practical examples are given 	✓	✓

(continued)

Table 2. (Continued).

Author and year	Source	Description/title	Outcome measure/objectives	Key findings	Ergonomics interventions with a sustainability focus	Championing of sustainability in design
Burns and Vicente (2000)	Applied Ergonomics	A participant-observer study of ergonomics in engineering design: how constraints drive design process	To find what barriers ergonomists face in making ergonomic contributions to design	<ul style="list-style-type: none"> Locally optimal ergonomic designs may not be globally optimal Ergonomists can improve their solutions by understanding the goals of other designers Future tools to aid ergonomists must be compatible with the constraint-rich environments in which they work 	<ul style="list-style-type: none"> Ergonomics interventions with a sustainability focus 	✓ (indirectly)
Chapanis (1995)	Ergonomics	Ergonomics in product development: a personal view	Description of ergonomic methods, and how they are used	<ul style="list-style-type: none"> A major goal of design and development is to specify precisely design requirements for a product that does not yet exist The development of any product goes through a number of steps, to which ergonomics can make substantial contributions 	<ul style="list-style-type: none"> Ergonomics interventions with a sustainability focus 	✓ (indirectly)
European Environment Agency 2011	European Environment Agency Website	Annual report 2010 and Environmental Statement 2010	Statement on environment and health	<ul style="list-style-type: none"> The interactions between the environment and human health are multifaceted and complex to assess The most proven health impacts are related to ambient air pollution, poor water quality and insufficient sanitation 	<ul style="list-style-type: none"> Ergonomics interventions with a sustainability focus 	✓
Flemming <i>et al.</i> (2008)	Human Factors and Ergonomics Society 52nd Annual Meeting	The need for human factors in the sustainability domain.	Review of literature on how energy consumption can be achieved through behavioural interventions	<ul style="list-style-type: none"> Ergonomic behavioural interventions can encourage sustainability Well designed feedback tools can increase the likelihood of individuals conserving energy Call for an interdisciplinary approach to conservation and sustainability Sustainability, ergonomics and design need to be linked 	<ul style="list-style-type: none"> Ergonomics interventions with a sustainability focus 	✓
Forbes and Ahmed (2011)	Book	Modern construction: Lean project delivery and integrated practices	Description of a systems approach building. Managing the building process from proposal to completion using lean practices	<ul style="list-style-type: none"> Encourages the adoption of lean methodologies, and demonstrates how these methods can improve projects Sustainability, ergonomics and design need to be linked 	<ul style="list-style-type: none"> Ergonomics interventions with a sustainability focus 	✓

(continued)

Table 2. (Continued).

Author and year	Source	Description/title	Outcome measure/objectives	Key findings	Ergonomics interventions with a sustainability focus	Championing of sustainability in design
Fuad-Luke (2004)	Book	The eco-design handbook	Presents 'best-designed' objects for the home and office, using the most environmentally sound materials and building products. Good summary of history of 'green design'.	<ul style="list-style-type: none"> Many of the examples do not meet ergonomics principles – thus highlighting the gulf between designers and ergonomists Sustainability is a growing business concern 		✓
Hedge (2008)	HIFES Bulletin	The sprouting of 'green' ergonomics	To encourage ergonomists to have a proactive approach in sustainable design	<ul style="list-style-type: none"> Sustainability, ergonomics and design need to be linked Sustainable building practices need also be incorporated at all stages. A good building from an environmental perspective should also be healthy and comfortable for its inhabitants 		✓
Hedge (1998)	Book	What can we learn about indoor environmental quality concerns from studies	Offers legal, medical, behavioural, industrial hygiene, and engineering expertise on prevention and planning for professionals concerned with building-related illness	<ul style="list-style-type: none"> A review of common indoor environmental quality problems, such as HVAC systems, noise, lighting, and water 		✓
Heilala <i>et al.</i> (2008)	2008 Winter Simulation Conference	Simulation-based sustainable manufacturing system design.	Description of integrated simulation tool which maximises production efficiency	<ul style="list-style-type: none"> Engineers and designers need decision support to optimise sustainability Sustainability is becoming a growing business concern 		✓
Human Factors and Ergonomics Society (2004)	2004–2005 Directory and Yearbook.		The Society's mission is to promote the discovery and exchange of knowledge concerning the characteristics of human beings that are applicable to the design of systems and devices of all kinds	<ul style="list-style-type: none"> Engineers and designers need decision support to optimise sustainability Sustainability is becoming a growing business concern Ergonomics has a far reaching remit – 'to better the quality of human life through the discipline of human factors/ergonomics' 		✓

(continued)

Table 2. (Continued).

Author and year	Source	Description/title	Outcome measure/objectives	Key findings	Ergonomics interventions with a sustainability focus	Championing of sustainability in design
Human Factors and Sustainable Development (2010)	International Ergonomics Association website		The Technical Committee is intended to build a powerful global network of experts in the fields of ergonomics and sustainability	<ul style="list-style-type: none"> The stated objectives are to increase knowledge about the contribution of ergonomics to other academics and strengthen the relationship between ergonomists and others working in the area of sustainability Sustainability, ergonomics and design need to be linked Ergonomics, and sustainability, still needs to be 'sold' to designers, managers and other stakeholders 		✓
Kopec (2009)	Book	Health, sustainability and the build environment	Examines the concept of sustainability as it pertains to sustaining human health	<ul style="list-style-type: none"> Identifies the positive and negative effects designs can have on the health of occupants 	✓	✓
McLennan (2004)	Book	The philosophy of sustainable design	This book is intended as a starting point for anyone involved in the building industry to learn how to build more sustainably	<ul style="list-style-type: none"> A philosophical and historical description of what responsible and sustainable design is Sustainability, ergonomics and design need to be linked 		✓
Moray (1995)	Ergonomics	Ergonomics and the global problems of the twenty-first century	Questions what is the role of ergonomics in addressing major social and ecological problems in the coming century	<ul style="list-style-type: none"> Discussion on what is the future of ergonomics Review of the role of ergonomics in agriculture and related technologies for reducing consumption and increasing productivity of food Discussion on whether ergonomics can help to design systems that cannot pollute Discussion on what ergonomics can contribute to the design of megalopolis 		✓
D. Moore (13 July 2011)	Personal communication	Designing for sustainability		<ul style="list-style-type: none"> Sustainability, ergonomics and design need to be linked Ergonomics, and sustainability, still needs to be 'sold' to designers, managers and other stakeholders 		✓

(continued)

Table 2. (Continued).

Author and year	Source	Description/title	Outcome measure/objectives	Key findings	Ergonomics interventions with a sustainability focus	Championing of sustainability in design
Moore (2009)	Book	Vulnerable populations in industrially advanced countries	Presenting a global view of the state of ergonomics in IDCs	<ul style="list-style-type: none"> Industrially developing countries have the largest populations, the highest levels of poverty, poor health, and illiteracy, and the greatest need for improvement in working conditions Defines the steps that can be taken to close the gap between working conditions in affluent and deprived nations. Promotes the idea that good ergonomics is good economics. Examples of low-cost interventions at the work place in IDCs and how sustainable progress is achievable in the developing world Demonstrates the need for a more inclusive macro approach, citing managerial input essential for sustainable progress. 	✓	✓
Moore <i>et al.</i> (2011)	IHFE Annual Conference	HF/E in sustainable development.	Introduces ideas on new roles and opportunities for ergonomists related to Sustainable Development	<ul style="list-style-type: none"> Ergonomists need to be involved in the design of systems related to the transition to low carbon economies, decision support, distributed working, and transportation Ergonomists the skills to contribute to sustainable design Sustainability, ergonomics and design need to be linked Ergonomics, and sustainability, still needs to be 'sold' to designers, managers and other stakeholders 		✓
Nickerson and Moray (1995)	Book	Emerging needs and opportunities in human factors research	Identifies areas that represent new needs and opportunities for human factors research	<ul style="list-style-type: none"> Need for a focus on national or global problems, including productivity in organizations, education and training, employment and disabilities, health care, and environmental change; technology issues, including communications technology and telenetworking, information access 		✓

(continued)

Table 2. (Continued).

Author and year	Source	Description/title	Outcome measure/objectives	Key findings	Ergonomics interventions with a sustainability focus	Championing of sustainability in design
Nightingale (1860)	Book	Notes on nursing: what it is, and what it is not	To help in the practice of treating others	<ul style="list-style-type: none"> and usability, emerging technologies, automation, and flexible manufacturing, and advanced transportation systems; and human performance, including cognitive performance under stress and aiding intellectual work 	✓ (indirectly)	
Reason (1990)	Book	Human Error	A theoretical integration of the mechanisms of error	<ul style="list-style-type: none"> Related to design – the importance of the physical environment in maintaining and restoring health Identification of cognitive processes common to a wide variety of error types Discussion on how improved safety can be achieved only on the basis of a better understanding of human error mechanisms 	✓ (indirectly)	✓ (indirectly)
Sanders and McCormack (1992)	Book	Human factors in engineering and design	Book written for upper-level undergraduate and graduate students, as well as for practicing professionals	<ul style="list-style-type: none"> Topics covered include information input, human output and control, workplace design, environmental conditions and human factor applications 		✓ (indirectly)
Schneeberger <i>et al.</i> (n.d.)	Rio+20 United Nations Conference on Sustainable Development: website	A Pocket Guide to Sustainable Development Governance	Conceptualisation of sustainable development	<ul style="list-style-type: none"> Highlights the need for sustainability Sustainable development integrates three pillars: economic development; social development; and environmental protection. Outlines and comments on current global initiatives 	✓	✓
SCION (2009)	Website	Scion is a Crown Research Institute dedicated to building the international competitiveness of the New Zealand forest industry and building a stronger biobased economy		<ul style="list-style-type: none"> Sustainability, ergonomics and design need to be linked 	✓	✓

(continued)

Table 2. (Continued).

Author and year	Source	Description/title	Outcome measure/objectives	Key findings	Ergonomics interventions with a sustainability focus	Championing of sustainability in design
Scott (2009)	Book	Sustainability: an ergonomics watchword for the twenty-first century	Presenting a global view of the state of ergonomics in IDCs	<ul style="list-style-type: none"> Sustainability, ergonomics and design need to be linked, in developing nations in particular, so that they become more self-sustaining Participative approaches encourage sustainability Participative approaches encourage sustainability Participative approaches increases the safety, environmental, production and quality standards of a design 	✓	✓
Shaw (2008)	Human Factors and Ergonomics Society of Australia Conference, Adelaide.	Participative workplace design: essential to creating sustainable workplaces	Describes how participative approaches can be used by building designers to give them an understanding of how a building is used as a workspace	<ul style="list-style-type: none"> Aims to develop New Zealand's capability and capacity to research, develop and deliver sustainable products and services Sustainability, ergonomics and design need to be linked Undertakes research into issues related to the sustainable development of New Zealand for example, genetic modification. Sustainability, ergonomics and design need to be linked Participative approaches encourage sustainability 	✓	✓
Sustainable Design NZ (n.d.)	Sustainable Design Group New Zealand website		A forum of New Zealand design professionals dedicated to promoting the growth of sustainable design	<ul style="list-style-type: none"> Collective of people with sustainability as a goal, to assist the realisation of a sustainable New Zealand 		✓
Terry (2011, April 19)	Sustainability NZ website	NZ's Climate Response - Officially Inadequate - UN	Collective of people with sustainability as a goal, to assist the realisation of a sustainable New Zealand	<ul style="list-style-type: none"> The authors show that by knowing how people think, they can design choice environments that make it easier for people to choose what is best for themselves, their families, and their society 		✓
Thaler and Sunstein (2008)	Book	Improving Decisions about Health, Wealth, and Happiness		<ul style="list-style-type: none"> Human are all are susceptible to various biases that can lead them to blunder. 		✓

(continued)

Table 2. (Continued).

Author and year	Source	Description/title	Outcome measure/objectives	Key findings	Ergonomics interventions with a sustainability focus	Championing of sustainability in design
WCED (1987)	Report	Our Common Future: The Report of the World Commission on Environment and Development.	The commission was created to address growing concern about the accelerating deterioration of the human environment and natural resources and the consequences of that deterioration for economic and social development	<ul style="list-style-type: none"> Mistakes make us poorer and less healthy; often people make bad decisions involving education, personal finance, health care, mortgages and credit cards, the family, and even the planet itself. In establishing the commission, the UN General Assembly recognized that environmental problems were global in nature and determined that it was in the common interest of all nations to establish policies for sustainable development 	✓	✓
International Ergonomics Association (2010)	Website	What is ergonomics?	The mission of the IEA is to elaborate and advance ergonomics science and practice, worldwide	<ul style="list-style-type: none"> To develop more effective communication and collaboration with federated societies To advance the science and practice of ergonomics at an international level To enhance the contribution of the ergonomics discipline to global society 	<ul style="list-style-type: none"> Many of these problems can only be solved by technological innovation, but also by changing human behaviour 	✓
Vicente (1998)	<i>Systems Engineering</i>	Human Factors and Global Problems: A systems approach	This article describes how the discipline of human factors (or ergonomics) can play a unique role in helping to solve global problems	<ul style="list-style-type: none"> Two illustrative design principles—behaviour-shaping constraints and salient, immediate feedback—are discussed. 	<ul style="list-style-type: none"> Focus needs to be on changing the design of the whole system 	✓ (indirectly)
Vicente (2008)	Theoretical issues in Ergonomics Science	Human factors engineering that makes a difference: leveraging a science of societal change	Identifies challenges to making ergonomic changes			

(continued)

Table 2. (Continued).

Author and year	Source	Description/title	Outcome measure/objectives	Key findings	Ergonomics interventions with a sustainability focus	Championing of sustainability in design
Wilson and Corlett (2005)	Book	Evaluation of Human Work	World-renowned experts present ergonomics techniques and methods	<ul style="list-style-type: none"> Ergonomics and design need to be linked Participative approaches work best 		✓ (indirectly)
WWF (2010)	Website	Living Planet Report	WWF's mission is to stop the degradation of the planet's natural environment and to build a future where people live in harmony with nature	<ul style="list-style-type: none"> Aims to conserve the world's biological diversity Aims to ensure that the use of renewable natural resources is sustainable Promotes the reduction of pollution and wasteful consumption 		✓
Zink (2008)	Book	Corporate sustainability as a challenge for comprehensive management.	A comprehensive and up to date coverage of key concepts and ideas relevant to HF/E and sustainability	<ul style="list-style-type: none"> Future of work in a sustainable society Achieving sustainability through macroergonomics Building sustainable human centred systems Human factors business excellence and corporate sustainability – differing perspective joint objectives 	✓	

building and design journals, one in the Journal of Sustainable Development and seven articles from ergonomics journals. This reversal of numbers simply reflects the use of ‘ergonom*’ or ‘human factor*’ as a search term.

This article aims to bring the concepts/disciplines of ergonomics and sustainability together to bear on the main problem facing our age: sustainability itself. Such issues of helping two disparate disciplines to work together have been addressed before. An obvious one is the interface between ergonomics and quality e.g. Drury (2008a,b) and Imada (2008). Another obvious one is the extensive current literature about links/disparities between lean manufacturing and ergonomics, with findings not always as optimistic as indicated in the quote included in the present article (e.g. Holman *et al.* 2002, Stuart *et al.* 2003, Wells *et al.* 2007). However these issues, whilst very relevant, are somewhat beyond the scope of the present article, but should be recognised.

The majority of studies focused on either the need for sustainability, or on a project that had sustainability as a goal. They paint a picture of the development of sustainable design that provides a brief history, outlines the need for it and how it is becoming a growing business concern. It also shows how sustainability and ergonomics can optimise human well-being and overall system performance, and that behavioural interventions and participative ergonomics can encourage sustainability. Finally, they show that there is synergy between sustainable practices, ergonomics and design. Seven themes were identified during the content analysis and they are discussed below.

3.2. A brief history of sustainable design

‘Green design’ was the norm in previous centuries. Goods were made locally, from readily available local resources, up until the Industrial Revolution. During that time almost half the rural population (in Britain) moved to the cities to work in factories. More and more resources were necessary to feed, clothe, transport and house this population. The first energy crisis in 1971 saw technologists begin designing products that consumed less energy (Fuad-Luke 2004). The words ‘environmental friendly’ began to be used extensively on advertising, though this was often not substantiated. Green design gathered momentum with the publication of the Bundtland Report in 1987.

‘Lean manufacturing’ arose in the 1950s at the Toyota production plants, with the aim to provide the best quality, lowest cost and shortest lead time through the elimination of waste (Eswaramoorthi *et al.* 2010). This promotes both sustainable and ergonomics ideals. Lean practices can be defined as using the minimal amount of equipment, space and workers time, goals that will also lead to best ergonomics practices. An example taken from Greenwald (2009) is when wasted motion is addressed and the resulting change reduces an operator’s reach distance and brings the work closer to them, both lean standards and ergonomics principles are met.

3.3. The need for sustainability

There is no doubt that without sustainable practices, the global population (estimated to surpass nine billion by 2050) will not have sufficient resources (WCED 1987, WWF 2010). The WWF propose that the solutions to this lie partly with companies, and the role they can play in sourcing, producing and purchasing raw materials that are sustainably harvested. Ergonomics knowledge will be necessary to guide production, to ensure efficient and effective outcomes. Ergonomics practitioners are needed to input at a macro level, as well as at a micro level with innovative interventions.

The European Union has regulations relating to pollution, and many other directives relevant to designers and manufacturers, including on vehicles, electronic equipment, toxic and dangerous waste and packaging and packaging waste (Fuad-Luke 2004). Once again, ergonomists are well placed to take a systems view and apply their knowledge and skills to sustainable practices at all stages of design. However, as found in this literature review, ergonomists have been slow to add their voice to the sustainability issue.

3.4. Sustainability is a growing business concern

It can be seen from this that sustainability is becoming a growing business concern (Fuad-Luke 2004, Heilala *et al.* 2008) and that an increasing number of international companies are including sustainability as an essential part of their corporate vision. Indeed Ellison and Nou (2011) point out that more companies now place an emphasis on a balance between people, planet and profit as well as equity, environment and economy, and that ergonomists are increasingly involved. Fuad-luke and Heilal *et al.* claim that designers should aim to reduce the environmental impact of products, buildings and material by designing in a ‘sustainable way’. The ultimate design challenge is to avoid the negative impacts of all products on the environment. However, many of the examples in Fuad-Luke’s

book do not meet ergonomics principles e.g. chairs that may be ‘beautiful’ and are made from renewable or recycled or recyclable material but not supportive or comfortable. This would not optimise human performance.

Another example is given by Guimaraes and dos Santos (2012), in which they describe the application of the sociotechnical design method for the development of eco-friendly shoes for students in Brazilian schools. They show how a traditional and dangerous method for shoe manufacture can be transformed into a more sustainable one by identifying users’ basic needs, the residue materials in the local region, identifying the product needs in terms of all users and the environment, evaluating the cost and benefits of potential solutions by considering sustainability, quality and recycling.

Sustainability can also be considered from a health perspective, with an emphasis on the use of human- and environmentally friendly products (Kopec 2009). Using ergonomics principles to design a build environment that promotes health will also increase productivity. ‘Sick building syndrome’ and building related illnesses such as Legionnaires disease came to prominence in the 1980s, and Kopec (2009, p 14) writes that ‘when designers consider sustainability, we must consider ways to sustain good health’. In 1860, Florence Nightingale wrote of the beneficial effect of sunlight, views from windows and fresh air. She stated that the very first canon of nursing was ‘to keep the air he breathes as pure as the external air, without chilling him’ (Nightingale 1860, p. 8). The European Environment Agency (EEA 2011) notes that the interactions between the environment and human health are multifaceted and complex to assess. The most proven health impacts are related to ambient air pollution, poor water quality and insufficient sanitation, and many ergonomists have contributed information and research in these areas, notably, Alan Hedge (Hedge 1998).

Additionally, as Macmillan (2006) highlights in his review on building design, decisions need to be informed by the best available evidence about how the physical environment can support social and economic outcomes. He states that many of the articles he cites in his literature review show a lack of such evidence.

3.5. Sustainability – and ergonomics –optimises human well-being and overall system performance

Chapanis (1995, p. 26), an ergonomist with over 50 years of experience, writes that ergonomists apply their knowledge to ‘the design of tools, machines, systems, tasks, jobs, and environments for productive, safe, comfortable, and effective human use’. The overall design process involves the analysis, design and evaluation of any or all of these components, and is an iterative process. A design undergoes many iterations before it is complete. Therefore, an ergonomists role is to guide this process, and part of this is incorporating sustainable ideas and practices. Fischer and Zink (2012) extend this to argue that sustainable development comprises the management of human, social, ecological and economic capital in a balanced manner.

Patricia Scott in her article ‘Global inequality, and the challenge for ergonomics to take a more dynamic role to redress the situation’ takes a more far-reaching view. She asserts that ergonomics, in industrially developing countries, must assist companies ‘to strive for sustainable development through an ethos of productivity devoid of exploitation’ (Scott 2008, p. 498) to satisfy humankind’s material needs. She states that appropriate ergonomics guidance is required to improve productivity, which also addresses the poor working conditions of the workers in these countries. Scott says participative programmes work best, and are also sustainable.

3.6. Ergonomic behavioural interventions can encourage sustainability

Reductions in energy consumption can be encouraged using behavioural interventions (Vincente 1998, Flemming *et al.* 2008). These authors found that well designed feedback tools can increase the likelihood of individuals conserving energy. One study (Wood and Newborough 2003, cited in Flemming *et al.* 2008) found that participants used 12% less electricity to cook meals at home with the help of an electronic feedback display. Fleming *et al.* (2008, p. 752) call for an interdisciplinary approach to conservation and sustainability and note that ‘human factors engineers can contribute their knowledge of decision making, mental models, and displays and controls, as well as their skills in experimental design and usability assessment’ to the domain of sustainability.

Sutcliffe *et al.* (2008) report a similar finding. They reported that individuals made reductions to their environmental impact when given feedback about their ‘ecological footprint’. D. Moore, C. Drury, and K. Zink (personal communication, 12 July 2011) also conclude that those working in ergonomics have opportunities and responsibilities for some new applications of existing skills, and can make contributions towards sustainable outcomes. Young designers also need to be encouraged to think how products can be more sustainable – by the selection of the product material, a reduction in energy usage or waste generated, or by changing the behaviour of the person using the product (Howarth and Hadfield 2006).

Guimaraes (2012) outlines a participative approach to sociotechnical design for a sustainable world that aims to meet the basic needs of people at the base of the social pyramid using waste as raw material for developing products/systems with high added values. He describes a multiple matrix approach that identifies design opportunities by brainstorming the cross match between basic needs and the available forms of waste in a locality, considers the ergonomic demands of primary, intermediate and end users, and evaluates the design alternatives in terms of sustainability, quality and cost. His method is aligned with cradle-to-cradle and initiative chain production system approaches, and is consistent with zero emissions research.

3.7. Participative approaches can encourage sustainability

Many studies found that it is important to engage all stakeholders in the design process. In particular, users of building or other designs gain a better understanding of the intent of the designers, and how the features of the design can best be utilised (Anastas and Zimmerman 2003, Thomas 2010, Häkkinen and Belloni 2011). Additionally, Shaw (2008) states that building designers tend to focus on the environmental aspects of the structure itself, rather than the environmental impacts of its use as a workplace. Designers may also have little understanding of how the building will be used as a workplace. A participative approach can address this by using industry and workplace knowledge, along with design skill, to meet all objectives, including the goal of sustainability. The most effective design is one that achieves all standards, ergonomic, environmental, production, quality and occupational health, as well as meeting the needs of all the stakeholders.

3.8. Sustainability, ergonomics and design

The possible synergistic effect of sustainable practices, ergonomics and design can be illustrated with a simple example. Research suggests that the greatest benefits for comfort, health and productivity occur with an office lighting system in which indirect ambient light is coupled with direct, user adjustable task light to create a two-component lighting solution with daylight (Hedge 2000). 'Deep' buildings were once the norm but now designers are seeing the advantages of designs that allow for natural light, therefore promoting health, ergonomics benefits and sustainable practices.

In July 2008, members of the International Ergonomics Association founded a Technical Committee, 'Human Factors and Sustainable Development', with the intention of building an authoritative global network of experts in the fields of ergonomics and sustainability. The stated objectives are to increase knowledge about the contribution of ergonomics to other academics and strengthen the relationship between ergonomists and others working in the area of sustainability. The group states that:

a more efficient design of work processes, participatory capacity building concepts or the use of macroergonomic change management instruments ... (will allow) ... those technical, organizational and social innovations that are necessary for a more sustainable development in regard to environmental, social and economic aspects (Human Factors and Sustainable Development 2010).

However, as one committee member has noted 'designing for sustainability is not straightforward' (D. Moore, personal communication, 13 July 2011). Moreover, ergonomists appear to be dawdling in making their contribution in this area.

4. Discussion

A number of themes can be identified from the present review. These are: (1) changing to sustainable practices is essential to avoid significant negative impacts in the (near) future; (2) ergonomics needs to be 'sold' to designers and (3) sustainability, and ergonomics, and 'green' design need to be linked.

4.1. Sustainability is needed – and is, to a degree, legislated

Governments are encouraging or even legislating to reduce waste sent to landfill by increased reuse and recycling (Howarth and Hadfield 2006). The European Union has specific regulations relating to pollution, and dangerous waste. However, in New Zealand, a UN review team has stated that the government's response to climate change is inadequate. The UN could find no plan for how the nation could meet their emissions reduction target for 2020. The review voices its 'great concern' about whether New Zealand will put measures in place in time to do so (Terry 2011).

Taking the New Zealand example further, there are some positives. In New Zealand (as in other countries) the Sustainable Business Network runs a Sustainable Design and Innovation award annually to seek out and profile excellent new design. Another group, Sustainable Design NZ, has a vision to ‘develop New Zealand’s capability and capacity to research, develop and deliver sustainable products and services’ (Sustainable Design NZ n.d.). However, while their stated aim is to foster collaboration between key stakeholders in sustainable design, there is no evidence of input by ergonomists evident on their website or documents. Likewise, the New Zealand Ergonomics Society website has makes no reference to, or has any links to ‘sustainability’.

However, a government entity, Scion (involved in the New Zealand forest industry and in building a stronger bio-based economy) list sustainable design as one of their three major research areas – ‘providing new knowledge and technologies needed to achieve positive economic outcomes, resulting in the lowest environmental footprint and maximising social and cultural outcomes’ (SCION 2009). New Zealand is not alone in having lack of focus and inconsistencies in its approach. Designers, and ergonomists, that can incorporate principles of lean, or green, manufacturing into their designs will also have a competitive business edge.

4.2. Sustainability – and ergonomics – still needs to be ‘sold’ to designers

There is a plethora of information available by, and for, engineers, designers and architects on sustainability. Very little has been written by ergonomists about designing for sustainability. Ergonomists are in fact still struggling to be incorporated and recognised as an integral part of the design process. Monroe (2006, p. 42) points out that ‘engineers new to ergonomics are often surprised by how much of their time they have to spend selling ergonomics to managers and others in their organisation’. Just as ergonomics benefits are often difficult to quantify, so too is ‘selling’ the benefits of sustainability. The goal is for both ergonomics, and sustainability, to become a central part of design. To do this it will be necessary to show that by incorporating these practices both quality and productivity can be enhanced.

As recently as 2010, Attaianesi and Duca have found that a comprehensive methodology for designing ergonomic buildings is still lacking. They outline an iterative process for architectural design activities that includes ergonomics. Sustainable building practices need also be incorporated at all stages. A good building from an environmental perspective should also be healthy and comfortable for its inhabitants (Hedge 2008).

One way to promote sustainable design is to communicate to all stake-holders about the economic benefits to be gained. Sustainable buildings are energy efficient and can offer major cost savings during operation. They save by reducing waste, are able to anticipate forthcoming legislation in regard to building practices, and have improved brand and reputation which translates in higher occupancy rentals (Häkkinen and Belloni 2011). However, if a green building is designed with little thought to ergonomic principles it will not promote efficient and effective use and worker satisfaction.

Design, without an ergonomist’s input, is less likely to lead to productive and successful outcomes. Wilson and Corlett (2005) provide many examples; one which led to loss of life and great financial cost was the failed implementation of a new control system for the London Ambulance Service. These authors state that the potential benefits of human centred design include improved safety, performance and satisfaction. Unfortunately, it is not always seen this way, and ergonomists are often underutilised (Wilson and Corlett 2005). There are many reasons for this, and Burns and Vicente (2000, p. 73) argue that ergonomists ‘need to understand the constraints that govern engineering design projects and how those constraints impact the consideration of ergonomic design features’. They conclude that the one of the greatest barriers to successful design is the inability of different disciplines (designers, engineers and ergonomists) to understand and appreciate each other’s different views. This requires ongoing negotiation, and education on the benefits of ergonomics. Ergonomists have an essential role in the design process, and as stated in the IEA definition, it is their responsibility is to ensure ergonomic theories and principles are applied to design.

4.3. Sustainability, and ergonomics, and ‘green’ design need to be linked

Green technologies and design strategies include such things as selection of building materials that have low toxicity, increased use of daylight, and inclusion of high quality, energy efficient lighting (Heerwagen 2000). Not only will such practices have benefits such as reduced use of resources, but they will also be conducive to human health and productivity (Thomas 2010). Moreover, the cost of sustainable construction is often no greater than the cost of a conventional building (Forbes and Ahmed 2011). Heerwagen’s article provides several examples of the positive productivity outcomes achieved through green building practices. For example, she states that numerous studies have found that office workers favour daylight and prefer being by windows. People who sit by windows experience less stress and lower levels of Sick Building Syndrome (even when the windows don’t open).

In the USA, the Green Building Council endorses the Green Building Rating System, through the Leadership in Energy and Environmental Design (LEED) process. In the past decade, more than 14,000 LEED-certified projects have been completed in the USA and in 30 other countries (Hedge 2008). The rating system measures factors such as the sustainability of the site, water efficiency, energy and atmosphere, materials and resources and indoor environmental quality. Ergonomists with a system approach can make contributions to all these factors, and in particular to the final category – with innovation in the design process. This includes the creation and maintenance of a flexible, ergonomic environment that accommodates building users, and promotes healthy, comfortable and productive work.

5. Limitations

The initial search conducted only used terms which included either ‘ergonom*’ or ‘human factors’ and ‘sustainab*’. At least two journal articles (Moray 1995, Vicente 1998) which covered the topic of ergonomics design for sustainability were not found by this search, because they did not use the term ‘sustainab*’. This begged the question as to whether there were further articles which might be found if a wider range of search terms were employed; for instance both of these articles, which were simply recalled from memory by one of the authors, used the phrase ‘global problems’, yet this is not a standard ergonomics term seen as equivalent to ‘sustainability’ (indeed it has many other meanings, including in information processing and computation). It also begs the question of how familiar ergonomists are with the term ‘sustainability’ and whether this might have changed over the last decade.

Ergonomists often use the term ‘sustainability’ with reference to, say manufacturing, in the sense of less waste or fewer injuries, or in particular to refer to efficiency, somewhat akin to ‘lean’ manufacturing and TQM. There is also a narrow sense of the word relating to economic performance of businesses – a business is sustainable if it can continue to operate (e.g. retain staff and turn a profit). Another reasonably narrow use often applies in ergonomics to ‘social sustainability’, in the sense of avoiding injuries and providing a healthy work environment, somewhat akin to corporate social responsibility. In effect, ergonomists appear to refer to the economic and social dimensions of the ‘triple bottom line’ of sustainable development, less often referring to the (global) environmental dimension. This presumably follows from the traditional concept in ergonomics of ‘joint optimisation’ of technical and personnel subsystems. Unfortunately, this would seem to be skewing the meaning of ‘sustainability’ and ‘sustainable development’ away from the more complete meaning it is supposed to have. This would be forgivable if a simple sustainable development model applied whereby social, environmental and economic factors were perceived as three equally intersecting Venn diagrams. It would be less forgivable if, as many insist, a stronger sustainability model is more accurate [in which the economy (the ‘econosphere’) is a subset of society (the ‘sociosphere’) which is a subset of the environment (the ‘biosphere’) SANZ 2009, p. 8].

It is suggested that ergonomists wishing to refer to a more limited concept – i.e. one that does not seek to integrate social, environmental and economic aspects of sustainability, should perhaps choose to describe their concept without using the word ‘sustainable’. Even phrases like ‘sustainable production systems’ (used by Westgaard and Winkel 2011, to mean ‘the joint consideration of competitive performance and working conditions in a long term perspective’) are somewhat misleading when one is accustomed to ‘sustainable development’ referring to three, rather than two, dimensions and ‘sustainability’ as being an overarching systems discipline.

Thatcher (2012) discusses the skewed coverage of economic and social elements of sustainability, at the expense of environmental elements. In a way, many ergonomists seem to refer to a narrow aspect of ‘sustainability’ in the way that many non-ergonomists seem to think ergonomics is physical anthropometry and design of objects. In fact both are disciplines dealing with complex sociotechnical systems.

In choosing which articles to include, we selected those which appeared to have a complete concept of sustainability, rather than a narrow concept which used the term but could have been referring to ‘efficiency’ or ‘CSR’. Clearly this is a subjective assessment and others might make different selections. The search start date of 1995 was chosen as a pragmatic start point but the end date of 2012 means that the review is current. It should be noted that ‘environmental change’ had not received a lot of attention from the ergonomics research community prior to this (Nickerson and Moray 1995).

6. Conclusions

The results of this literature review provide a mixed picture of the role of ergonomics in sustainability and sustainable design. The research so far appears to provide only limited ergonomics commentary on the issue, and little in the way of methods on how to achieve the goals. The review shows that ergonomists have not been at the

forefront of research contributing to sustainability. With a few exceptions, sustainability appears to be a relatively new concept to ergonomics, and some ambiguity surrounds the constructs and concepts. Many approaches are being developed across disciplines, industries and sectors, but it is clear that these approaches are currently neither systematic nor comprehensive. In their review article about the barriers and drivers for sustainable building, Häkkinen and Belloni (2011, p. 239) state that the most important actions to promote it are ‘the development of the awareness of clients about the benefits of sustainable building’ and ‘the development of designers’ competence and team working’. Therefore, there is much scope for the involvement of ergonomics and ergonomists. This presents them with an opportunity to ‘seize the day’.

The benefits of sustainable design are those also sought by ergonomists – improved well-being and productivity of occupants and users of the design, due to improved design performance. D. Moore, C. Drury, and K. Zink (personal communication, 13 July 2011) however point out that ‘we are considering Sustainable Development whilst within our discipline we still have problems, consciously or otherwise, with consistently demonstrating what good practice in old-fashioned (possibly unsustainable) development looks like; particularly in large scale, top down endeavours’. They go on to say that the ergonomics community is well placed to have a strong role in sustainable development. Practitioners have the skills and techniques needed for a system approach and for user-centredness.

The likelihood that change will be initiated is also dependent on having a significant group of organised advocates (Vicente 2008). Vicente’s article reviews how ergonomics can affect societal change. He points out that the focus needs to be on changing the design of the whole system, that making changes at a micro level will not bring about widespread behavioural change. Ergonomics has a far reaching remit – ‘to better the quality of human life through the discipline of human factors/ergonomics’ (Statement of Purpose, Human Factors and Ergonomics Society 2004, p. 361). Moore (2009, p. 197) also advocates that ergonomics ‘underlying philosophy needs to be not only fitting the tasks to mankind, but also, fitting mankind to the planet’. In conclusion, sustainability needs a holistic approach, with participative input, from all sectors and disciplines to achieve the goal of the planet not living beyond its means. In view of these findings, there is considerable scope for ergonomist to contribute to sustainable design by ‘seizing the day’ – ‘*carpe diem*’.

References

- Anastas, P.L. and Zimmerman, J.B., 2003. Designing through the 12 principles of green engineering. *Environmental Science and Technology*, 37 (5), 94–101.
- Annual report 2010 and Environmental Statement, 2010. *Annual report 2010 and Environmental Statement* [online]. Available from: <http://www.eea.europa.eu/publications/annual-report-2010> [Accessed 27 June 2011]. From European Environment Agency.
- Attaianese, E. and Duca, G., 2010. Human factors and ergonomic principles in building design for life and work activities: an applied methodology. *Theoretical Issues in Ergonomic Science*, iFirst, 13 (2), 1–16.
- Birkeland, J., 2008. *Positive development: from vicious circles to virtuous cycles through built environment design*. London: Earthscan.
- Brown, C. and Legg, S., 2011. Human factors and ergonomics for business sustainability. In: G. Eweje and M. Perry, eds. *Business and sustainability: concepts, strategies and changes, critical studies on corporate responsibility, governance and sustainability*. Vol. 3. Bingley, UK: Emerald Group Publishing Limited, 61–81.
- Burns, C.M. and Vicente, K.J., 2000. A participant-observer study of ergonomics in engineering design: how constraints drive design process. *Applied Ergonomics*, 31, 73–82.
- Chapanis, A., 1995. Ergonomics in product development: a personal view. *Ergonomics*, 38 (8), 1625–1638.
- Chapanis, A., 1999. *The Chapanis chronicles: 50 years of human factors research, education, and design*. Santa Barbara, CA: Aegean Publishing Company.
- Drury, C.G., 2008a. The future of ergonomics/the future of work: 45 years after Bartlett (1962). *Ergonomics*, 51 (1), 14–20.
- Drury, C.G., 2008b. The future of work in a sustainable society. In: K.J. Zink, ed. *Corporate sustainability as a challenge for comprehensive management*. Heidelberg: Physica Verlag, 199–214.
- Ellison, J. and Nou, D., 2011. Ergonomics hitches a ride. *Industrial Engineer*, 43 (9), 40–44.
- Eswaramoorthi, M., John, M., Rajagopal, C.A., and Prasad, P.S., 2010. Redesigning assembly stations using ergonomic methods as a lean tool. *Work*, 35, 231–240.
- European Environment Agency, 2011. *Environment and health* [online]. Available from: <http://www.eea.europa.eu/themes/human>: <http://www.eea.europa.eu/themes/human> [Accessed 28 June 2011].
- Fischer, K. and Zink, K.J., 2012. Defining elements of sustainable work systems – a systems-oriented approach. *Work*, 41, 3900–3905.
- Flemming, S.A., Hilliard, A., and Jamieson, G., 2008. The need for human factors in the sustainability domain. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 52 (11), 748–752, doi: 10.1177/154193120805201111.
- Forbes, L. and Ahmed, S., 2011. *Modern construction: lean project delivery and integrated practices*. Baco Raton, FL: CRC Press.
- Frejus, M. and Guibourdenche, J., 2012. Analysing domestic activity to reduce household energy consumption. *Work*, 41, 539–548.

- Fuad-Luke, A., 2004. *The eco-design handbook*. London: Thames & Hudson Ltd.
- Gennari, C., 2000. Architectural ergonomics and sustainable design: a model proposition. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 44, 36–39, doi:10.1177/154193120004400809
- Greenwald, J., 2009. Sphere of safety. *Industrial Engineer*, 41 (3), 26–30.
- Guimaraes, L.B.de M., 2012. Sociotechnical design for a sustainable world. *Theoretical Issues in Ergonomics Science*, 13 (2), 240–269.
- Guimaraes, L.B.deM and dos Santos, R.F., 2012. Application of the sociotechnical design method for the development of eco-friendly shoes for students of Brazilian public schools. *Theoretical issues in ergonomics Science*, 13 (1), 43–74.
- Häkkinen, T. and Belloni, K., 2011. Barriers and drivers for sustainable building. *Building Research and Information*, 39 (3), 239–255.
- Hedge, A., 1998. What can we learn about indoor environmental quality concerns from studies. In: J.T. O'Reilly, P. Hagan, R. Gots, and A. Hedge, eds. *Keeping buildings healthy*. New York: John Wiley, 119–136.
- Hedge, A., 2000. Where are we in understanding the effects of where we are? *Ergonomics*, 43 (7), 1019–1029.
- Hedge, A., 2008. The sprouting of “green” ergonomics. *HFES Bulletin*, 51 (12), 1–3.
- Heerwagen, J., 2000. Green buildings, organizational success and occupant productivity. *Building Research and Information*, 28 (5/6), 353–367.
- Heilala, J., Vatanen, S., Tonteri, H., Montonen, J., Lind, S., Johansson, B., and Stahre, J. (2008). Simulation-based sustainable manufacturing system design. In: S.J. Mason, R.R. Hill, L. Mönch, O. Rose, T. Jefferson, J.W. Fowler, eds. *2008 Winter simulation conference*. Miami, FL. Piscataway, NJ: IEEE, 1922–1930.
- Holman, D., Wall, T.D., Clegg, C.W., Sparrow, P., and Howard, A. 2002. *The new workplace: a guide to the human impact of modern working practices*. Chichester, UK: John Wiley.
- Howarth, G. and Hadfield, M., 2006. A sustainable product design model. *Materials and Design*, 27, 1128–1133.
- Human Factors and Ergonomics Society, 2004. *2004–2005 Directory and yearbook*. Santa Monica, CA: HFES.
- Human Factors and Sustainable Development, 2010, July 16. Available from: http://www.iea.cc/browse.php?contID=hf_and_sustainable_dev [Accessed 13 July 2011]. From International Ergonomics Association.
- International Ergonomics Association [IEA], 2010. *What is ergonomics?* [online]. Available from: http://www.iea.cc/browse.php?contID=what_is_ergonomics [Accessed 21 June 2010].
- International Ergonomics Association [IEA], 2012. n.d. Available from: <http://www.iea2012.org/submission.htm> [Accessed 28 September 2011].
- International Ergonomics Association [IEA], 2012. *Proceedings of the 18th World Congress on Ergonomics*, 12–16 Feb 2012. Recife, Brazil, In Work, 41, doi:10.3233/WOR-2012-0053-3869.
- Imada, A., 2008. Achieving sustainability through macroergonomics. In: K.J. Zink, ed. *Corporate sustainability as a challenge for comprehensive management*. Heidelberg: Physica Verlag, 129–138.
- Kopec, D., 2009. *Health, sustainability and the built environment*. New York: Fairchild Books, Inc.
- Lueng, M.H., 2003. Ergonomics and sustainable development. In: *Ergonomics in the Digital Age. Proceedings of the XVth Triennial Congress of the International Ergonomics Association & the 7th Joint Conference of the Ergonomics Society of Korea & the Japan Ergonomics Society*, 24–29 August, Seoul, Korea. Seoul, Korea: Ergonomics Society of Korea, 7.
- Macmillan, S., 2006. Added value of good design. *Building Research and Information*, 34 (3), 257–271.
- Marano, A., Bucchioanico, G.D., and Rossi, E., 2012. Strategies and arguments of ergonomic design for sustainability. *Work*, 41, 3869–3873.
- McLennan, J.F., 2004. *The philosophy of sustainable design*. Kansas City: Ecotone LLC.
- Moore, D., 2007. The ergonomist and the eco house: the use of an experimental collective design process in sustainable residential construction. *Proceedings of the New Zealand Ergonomics Society Conference 2007, 'Ergonomic(s) Perspectives'*. Available On CD-Rom, 1 January 2007. Palmerston North, New Zealand: New Zealand Ergonomics Society, 124–127.
- Moore, D., 2009. Vulnerable populations in industrially advanced countries. In: P. Scott, ed. *Ergonomics in developing regions: needs and applications*. Boca Raton, FL: CRC Press, 185–200.
- Monroe, K., 2006. Ergonomics 101. *Industrial Engineer*, 38 (3), 41–45.
- Moray, N., 1995. Ergonomics and the global problems of the twenty-first century. *Ergonomics*, 38 (8), 1691–1707.
- Nickerson, R. and Moray, N., 1995. Environmental change. In: R. Nickerson, ed. *Emerging needs and opportunities for human factors research*. Washington, D.C: National Academy Press, 158–176.
- Nightingale, F., 1860. *Notes on nursing: what it is, and what it is not*. London: Harrison.
- O'Neill, D., 2005. The promotion of ergonomics in industrially developing countries. *Industrial Ergonomics*, 35, 163–168.
- Reason, J., 1990. *Human error*. Cambridge: Cambridge University Press.
- Sanders, M.S. and McCormack, E.J., 1992. *Human factors in engineering and design*. New York: McGraw-Hill.
- Schneeberger, K., Dodds, F., Shaw, A., Bottero, M., Cornforth, J., and White, R. n.d. *A pocket guide to sustainable development governance* [online]. Stakeholder Forum, Commonwealth Secretariat. Available from: <http://www.uncsd2012.org/rio20/index.php?page=view&nr=27&type=400&menu=45> [Accessed 2 July 2010]. From Rio+20 United Nations Conference on Sustainable Development.
- SCION, 2009. *About us: energy & materials, sustainable design, forestry science* [online]. Available from: <http://www.scionresearch.com/general/about-us> [Accessed 2 August 2011]. From SCION.
- Scott, P.A., 2008. Global inequality, and the challenge for ergonomics to take a more dynamic role to redress the situation. *Applied Ergonomics*, 39, 495–499.
- Scott, P., 2009. Sustainability: an ergonomics watchword for the twenty-first century. In: P. Scott, ed. *Ergonomics in developing regions: needs and applications*. Boca Raton, FL: CRC Press, 437–444.

- Shaw, A., 2008. Participative workplace design: essential to creating sustainable workplaces. Human Factors and Ergonomics Society of Australia Conference. Adelaide: Ergonomics Society of Australia, 46–50.
- Sustainable Aotearoa New Zealand Inc. (SANZ), 2009. Strong sustainability for New Zealand: principles and scenarios. Wellington: Nakedise Ltd., 8.
- Sustainable Design NZ, n.d. Available from: <http://www.sustainabledesign.org.nz/> [Accessed 2 August 2011]. From Sustainable Design Group New Zealand.
- Sutcliffe, M., Hooper, P., and Howell, R., 2008. Can eco-footprinting analysis be used successfully to encourage more sustainable behaviour at the household level? *Sustainable Development*, 16, 1–16.
- Steimle, U., 2006. Sustainable development and human factors. *International Encyclopedia of Ergonomics & Human Factors*, 2nd Edition, 2, 2355–2360.
- Stuart, M. Tooley, S., and Holtman, K., 2003. The Effects of Ergonomics, Lean Manufacturing, and Reductions in Work Force on Musculoskeletal Health. *Proceedings of the XVth Triennial Congress of the International Ergonomics Association*, August 24–29, Seoul, Korea. Seoul, Korea: Ergonomics Society of Korea, 8–14.
- Terry, S. (2011, April 19). *NZ's climate response officially inadequate – UN* [online]. Available from: <http://www.sustainabilitynz.org/docs/NZsClimateResponseOfficiallyInadequate.pdf> [Accessed 2 August 2011]. From Sustainability Council of New Zealand.
- Thaler, R., and Sunstein, C., 2008. *Nudge: improving decisions about health, wealth, and happiness*. New Haven, CT: Yale University Press.
- Thatcher, A., 2012. Early variability in the conceptualisation of “sustainable development and human factors”. *Work*, 41, 3892–3899.
- Thomas, L., 2010. Evaluating design strategies, performance and occupant satisfaction: a low carbon office refurbishment. *Building Research & Information*, 38 (6), 610–624.
- UNCED, 1992. *United nations conference on environment and development. Rio declaration on environment and development* [online]. Available from: <http://www.un.org/documents/ga/conf151/aconf15126-1annex1.htm> [Accessed 21 October 2009]. From UNCED.
- Vicente, K., 1998. Human factors and global problems: a systems approach. *Systems Engineering*, 1 (1), 57–69.
- Vicente, K., 2008. Human factors engineering that makes a difference: leveraging a science of societal change. *Theoretical issues in Ergonomics Science*, 9 (1), 1–24.
- Wells, R., Mathiassen, S.E., Medbo, L., and Winkel, J., 2007. Time – a key issue for Musculoskeletal health and manufacturing. *Applied Ergonomics*, 38, 733–744.
- Westgaard, R.H. and Winkel, J., 2011. Occupational musculoskeletal and mental health: significance of rationalisation and opportunities to create sustainable production systems – a systematic review. *Applied Ergonomics*, 42, 261–296.
- Wilson, J., and Corlett, N., Eds., 2005. *Evaluation of human work*. 3rd ed. Boca Raton, FL: CRC Press.
- World Commission on Environment and Development, 1987. *Our Common Future, Report of the World Commission on Environment and Development (aka Brundtland Report)*. Published as Annex to General Assembly Document A/42/427, Development and International Co-operation: Environment. 2 August 1987. Oxford: Oxford University Press.
- WWF, 2010. *Living planet report* [online]. Available from: <http://www.worldwildlife.org/sites/living-planet-report/> [Accessed 5 July 2011]. From World Wildlife Federation.
- Zink, K.J., ed., 2008. *Corporate sustainability as a challenge for comprehensive management*. Heidelberg: Physica Verlag.