From systems ergonomics to global ergonomics: the world as a socio-ecological-technical system

Paul M. Salmon[1], Neville A. Stanton[2], Gemma J. M. Read[1], Guy H. Walker[3], Nicholas J. Stevens[1] & Peter A. Hancock[4]

[1]Centre for Human Factors and Sociotechnical Systems, University of the Sunshine Coast, Australia
[2]Transportation Research Group, University of Southampton, UK
[3]Institute for Infrastructure and Environment, Heriot Watt University, UK
[4]MIT2 Laboratory, University of Central Florida, USA

ABSTRACT

Our future existence on earth is under threat. Immediate and significant action is required, however, the issues that we face are complex, interrelated, and difficult to solve. The potential role of ergonomics in managing existential threats has been discussed; however, few studies have used ergonomics methods to analyse major global challenges. This article presents the findings from a study that explored the use of a systems ergonomics tool, the abstraction hierarchy from Cognitive Work Analysis, to develop a complex sociotechnical systems model of the world. The aim was to determine whether the method was able to cope with such a large and complex problem space, and to explore what insights the analysis would give on how society can respond to current and future global challenges. The findings demonstrate that the abstraction hierarchy is capable of modelling the world as one large-scale problem space. In particular, the model was able to encapsulate the major global challenges recently outlined by the World Economic Forum. A contribution of the analysis is to show the interrelatedness of the issues underlying these challenges, which in turn demonstrates the difficulties faced when attempting to respond to them. The implications of the model are discussed, along with further work that is required to embed ergonomics in wider multi-disciplinary efforts aiming to tackle current and future global challenges.

KEYWORDS

Systems thinking, systems ergonomics, global ergonomics, global challenges, work domain analysis, abstraction hierarchy

Introduction

Our world is at breaking point. Alarmingly, there are many issues that threaten either the earth itself, or our future existence on it. These include climate change and environmental degradation, extreme weather, overpopulation, food and water security, disease, misuse of the internet and social media, terrorism, cybercrime, nuclear warfare, inequality, human rights breaches, antimicrobial resistance, and instability in the world's economy, to name only a few. In addition to these issues, many of which are already wreaking havoc, by 2050 we will likely face an onslaught of new and emergent issues related to artificial intelligence and the singularity, automation replacing human work, the genetic modification of humans, an ageing population, and otherworld settling. As pointed out by many, if significant action is not taken immediately, a dystopian future awaits us.

Though questionable whether it is anywhere near enough, action is being taken. Many of the issues above are subject to multi-and trans-disciplinary programs aiming to either eradicate them completely or come up with strategies to manage and mitigate their impact. Experts from many disciplines are involved in this work; however, there is little evidence that ergonomists are involved, or that the science of ergonomics is being considered. Whilst the discipline's raison d'etre encompasses the optimisation of human health and wellbeing, and many of our methods allow us to understand and respond to highly complex issues, it seems that ergonomics is being overlooked when it comes to issues that threaten humanity.

This paper seeks to redress this by focussing on the role that ergonomics can potentially play in responding to global issues that have the potential to dramatically impact the human race and the world that we inhabit. The idea of a more significant role for ergonomics in addressing major societal and global issues is not new. Indeed, scholars have previously argued that ergonomics can make a significant contribution to the management of key global issues and challenges (Moray, 1995; Thatcher et al., 2017). Likewise, it is our view that the discipline of ergonomics has a key role to play in ensuring that our future world is a world we can, and want to, live in. In particular, we argue that systems ergonomics applications focussing on global issues provide an important line of inquiry both in terms of demonstrating the utility of 'global ergonomics' and in informing the development of interventions designed to eradicate or better manage the issues in question.

It goes without saying that global challenges and existential threats are large scale, complex and multifactorial, dynamic, and heavily interrelated. As a result, they are extremely difficult to describe, understand, and respond to. Arguably, systems ergonomics provides a suite of methods that are capable of describing and responding to such large scale and complex issues. Due the increasing popularity of systems thinking in ergonomics, since the turn of the century a range of systems ergonomics methods have either been developed or have experienced a resurgence in popularity (Salmon et al., 2017). These perhaps provide a useful toolkit of methods that could be used initially to explore and demonstrate the potential utility of global ergonomics.

The aim of this article is to explore the use of systems ergonomics methods to understand major global issues by applying one such method to develop a model of the world as a socio-ecological-technical system. Specifically, the first phase of Cognitive Work Analysis (CWA; Vicente, 1999), Work Domain Analysis (WDA; Naikar, 2013), was used to develop a model of the world. The aim was, first, to determine whether the method was able to cope with such a large and complex problem space, and second, to explore what insights the analysis gave in terms of the development of strategies designed to respond to current and imminent major global challenges.

Method

Cognitive Work Analysis

CWA (Vicente, 1999) is a systems analysis and design framework that has become a popular method for understanding and optimising complex systems. The framework provides a series of modelling approaches that focus on identifying the constraints imposed on behaviour within the system under analysis (Vicente, 1999). The first phase, WDA, is used to construct an event- and actor-independent model of the system under analysis, known as an abstraction hierarchy (Naikar, 2013). This means it is not focussed specifically on any event (e.g. a global financial crash) and does not include actors who operate within the system (e.g. politicians, researchers). The aim is to describe the functional structure of the system as well as the purposes of the system and the functions, process and object-related constraints imposed on the actions of any actor performing activities within that system (Vicente, 1999).

The abstraction hierarchy method achieves this by describing systems across the following five conceptual levels:

1. Functional purpose – The overall purpose(s) of the system;
2. Values and priority measures – The values that are assessed and used to measure the system's progress towards its functional purposes;
3. Purpose-related functions – The general functions of the system that have to be undertaken within the system so that the functional purposes are achieved;
4. Object-related processes – The functional capabilities of the physical objects within the system that enable the purpose-related functions; and
5. Physical objects – The physical objects within the system that are used to undertake object-related processes.

Describing the relationships between components of a system is a key requirement when attempting to understand behaviour and complexity. Abstraction hierarchy models use means-ends links to show the relationships between nodes across the five levels of abstraction. To achieve this, the linked nodes at the level above a particular node in the hierarchy relate to 'why' that node is required, and the linked nodes at the level below the node relate to 'how' the node is achieved.

Abstraction hierarchy development

Naikar's (2013) nine-step WDA methodology was applied to develop the abstraction hierarchy. Initially the aims of the analysis were established and any relevant project constraints were identified and discussed. Next, the analysis boundary was defined as the world with an emphasis on human society and human health and wellbeing. A high level of granularity for the analysis was agreed upon to prevent the abstraction hierarchy from becoming too large and unwieldy.

An initial draft world abstraction hierarchy was then developed by the first two authors, both of which have extensive experience in applying WDA in a range of domains including defence, aviation, rail, disaster management, sport, and process control (see Stanton et al., 2017). Development of the abstraction hierarchy involved systematically working through each level using Naikar's (2013) prompts to identify relevant nodes. Publicly available information such as websites and the grey literature was also used where required. Discussion continued until both authors were in agreement regarding the nodes identified. Once the nodes were finalised the authors discussed the means-ends links, again agreeing on appropriate means-ends links to include in the model. The draft abstraction hierarchy was developed using the CWA software tool.

The draft abstraction hierarchy was then reviewed by the remaining authors and refined accordingly based on their feedback. The additional co-authors include researchers with extensive experience in complex system modelling and in the role of ergonomics in global issues and challenges.

Following Thatcher et al. (2017), a final feature of the analysis involved identifying the purpose-related functions that relate to the top ten major global challenges identified by the World Economic Forum (World Economic Forum, 2016, see Table 1 below). This involved the first two authors systematically working through each of the purpose-related functions and discussing whether they related to any of the ten major global challenges. Nodes deemed to be related to any of the ten major global challenges were subsequently shaded using the Microsoft Visio drawing package.

Table 1. World Economic Forum's ten global challenges

Challenge	
1. Food security	6. The internet
2. Wealth inequality	7. Gender equality
3. Unemployment	8. Global trade and investment
4. Climate change	9. Long term investment, infrastructure and development
5. Global financial systems	10. Healthcare

Results

The world abstraction hierarchy is presented in full in Figure 1 (shown right). In Figure 2 the purpose-related functions level is shaded to show which purpose-related functions relate to the ten global challenges presented in Table 1.

The functional purpose of the world, from a human perspective, is to sustain life. At the next level, eleven broad values and priority measures are included. These include values relating to human health and well-being, minimising damage to the environment (e.g. pollution and resource depletion), maximising discovery and economic growth, and managing issues such as conflict, diversity, sustainability, and equality. Twenty-three process-related functions are included. These cover functions relating to health and wellbeing (e.g. sustenance, health, social interaction, physical activity, recreation and play), mobility and access, employment, trade, sustainability (e.g. recycling, manage renewables, manage resources, sustainable development), crime prevention, land and sea use, peace and stability, education, cultural integration, and inclusivity.

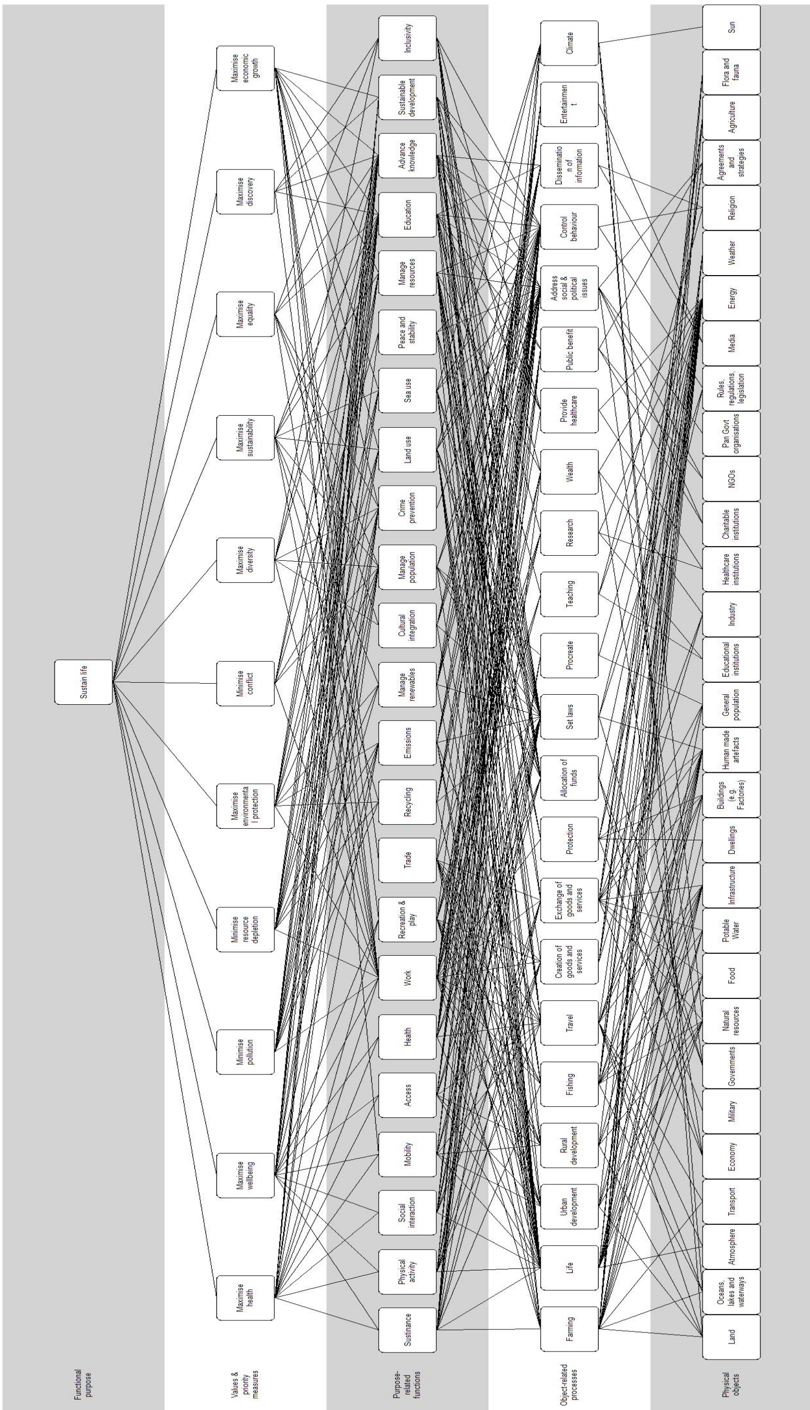

Figure 1. World abstraction hierarchy

The physical objects level includes 30 objects ranging from ecological objects such as land, oceans, lakes and waterways, energy, natural resources, the sun, flora and fauna, and weather to man-made artefacts and systems such as transport, healthcare, the economy, agriculture, the military, governments, and infrastructure. The object-related processes level includes the processes that the physical objects afford. For example, the physical object 'land' affords the object-related processes of 'farming', 'urban development', 'rural development', and 'travel'.

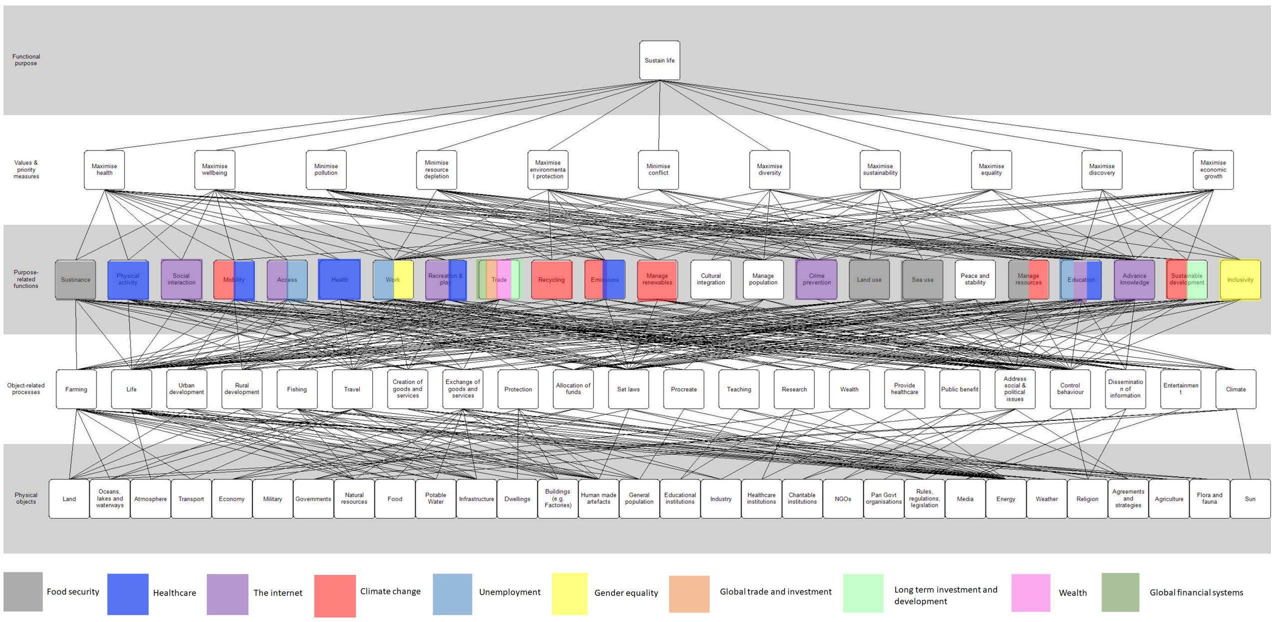

Figure 2. World abstraction hierarchy with shading to highlight purpose-related functions relating to the World Economic Forum's top ten major global challenges

Discussion

This proof of concept study involved using the abstraction hierarchy method from WDA to develop a complex socio-ecological-technical systems model of the world. The aim was to determine whether WDA was able to cope with such a large and complex problem space, and to explore what insights the analysis would give in terms of responding to major global challenges. The work relates to the notion that ergonomics can play a key role in understanding and responding to major global issues, and attempts to build on a growing interest in its capacity to do so (Thatcher et al., 2017).

First and foremost, the analysis suggests that, at least at a high level of granularity, WDA is capable of dealing with the large scale and complex problem space that is the world. Whilst further work is required to validate the model and its contents, as an initial proof of concept application the study was able to achieve its primary aim of constructing a coherent and useful model of the world. Parenthetically, the analysis represents the first time that an ergonomics approach has been used to model the entire world as one socio-ecological-technical system (van der Leer et al., 2018). Further applications of other systems ergonomics methods in this context are encouraged.

An important initial test of the model was whether it could incorporate the range of issues that are known to represent a significant existential threat. As shown in Figure 2, the World Economic Forum's current top ten global challenges were encapsulated within the model. An important contribution is to present these and other issues within the one model and to show their interrelations via the means-ends links and shading of the nodes. This serves to demonstrate the complexity of global issues as well as the difficulties faced in developing suitable strategies and interventions that can respond to all of the issues that we face.

The findings suggest that many of the functions, objects and processes included in the model have a role to play in multiple issues. Purpose-related functions such as ‘manage resources’, ‘manage population’ ‘land use’, ‘education’, and ‘advance knowledge’ each link to multiple values and priority measures, suggesting that they represent key leverage points when attempting to respond to global challenges. For example, the land use function and its means-ends links indicate that optimising land use can support health and wellbeing and environmental protection whilst at the same time minimising pollution and resource depletion. A simple example relates to the way in which land use can be used to initiate positive modal shifts within transport systems. Initiating model shift to active forms of transport such as cycling and walking will have positive effects on health, wellbeing, and the environment (McClure et al., 2015; Woodcock et al., 2007; 2009). Active transport enables people to increase their participation in physical activity (Woodcock et al, 2007), which in turn reduces the risk of cardiovascular diseases, diabetes, cancers, and depression (WHO, 2006). Removing energy intensive transport modes such as the motor car will reduce many adverse impacts, including crashes leading to trauma, congestion and pollution, and various harmful environmental impacts (Heinrich et al, 2005; Woodcock et al., 2007).

Optimising land use to initiate a shift to active modes of transport will therefore have many benefits that tackle multiple global challenges. Such modal shifts can be facilitated through land use approaches such as increasing the quality of cycling and walking trails, improving street lighting, ensuring sidewalk continuity, using a mix of residential, commercial and community land uses, and introducing a high quality of public realm and amenity (e.g. Aytur et al, 2008; Banister, 2005; Stevens et al. 2016). Development density is a key consideration, as motor vehicle use becomes essential in low density developments where travel distances from communities to places of work and shopping precincts become too large for alternative active and public transport modes to be competitive (Buehler, 2011). Motor vehicle use also becomes slower and less appealing in denser areas due to factors such as congestion and limited availability of parking (Buehler, 2011). A key use of the model is to identify ways of responding to multiple issues, as opposed to attempting to develop interventions which respond to issues in isolation.

A final notable finding was the fact that the abstraction hierarchy included purpose-related functions that do not relate to the World Economic Forum’s top ten global challenges. These included ‘peace and stability’, ‘manage population’, and ‘cultural integration’. Whilst these are acknowledged to be significant global challenges, their inclusion as specific purpose-related functions in the model suggests that issues related to these functions (i.e. conflict, overpopulation and discrimination) could be added to the World Economic Forum’s set of challenges.

Saving the world with a system of systems ergonomics approach

The analysis demonstrates how systems ergonomics can be used to describe and understand complex global issues. Whilst this systems level view is useful, one criticism is that the analysis is too high level to support identification of specific interventions. Moving forward then it is likely that taking a ‘system of systems’ approach will be useful when attempting to understand and respond to complex existential threats. System of systems refers to ‘super systems’ that comprise components that represent large-scale systems in their own right and are managed independently (Harvey & Stanton, 2014; Maier, 1998). As shown in the abstraction hierarchy, the world is one such system of systems comprising many interrelated large-scale and complex sociotechnical systems such as transport, healthcare, education, crime prevention, the economy, and also socio-ecological systems such as the environment. Whilst the focus of the present study was on the world as one socio-ecological-technical system, additional analyses could now take components of this model and undertake further, more detailed systems analyses. This will be useful for identifying strategies designed to optimise component systems and how they interact with one another. WDA could therefore be used to develop detailed models for each of the purpose-related functions in the present model that represent systems in their own right, such as education and crime prevention.

Study limitations and areas for further research

As a proof of concept study there are some limitations worth noting. The model was not subject to validation by subject matter experts. This represents an important area for future research, and could be achieved through the conduct of a Delphi study or similar. The granularity of the model is also a limitation. This was deliberately set at a high level so that the analysis did not become too complex and unwieldy; however, it prevents some of the specific details underlying certain issues from being included in the model. This could be resolved by developing separate abstraction hierarchy models for each of the purpose-related functions (as discussed above).

The present analysis opens up many areas of further research. Applying the other phases of CWA is one that could be beneficial, both to further understand some of the issues included in the model and for developing interventions to remove or manage them. The strategies analysis phase could be used to explore ways of optimising certain purpose-related functions in the model, such as manage resources, land use, and recycling. In addition, there is scope to apply other systems ergonomics methods in this context. For example, the Systems Theoretic Model and Processes (STAMP) model and associated methods (Leveson, 2004) could be used to describe the controls that are currently used to manage certain issues (e.g. climate change) and to identify new control and feedback mechanisms. Accimap and Actormap (Rasmussen, 1997) could also be used to identify the network of factors and actors that contribute to specific issues. No doubt there are other potential applications of other methods, and further exploration is encouraged.

Conclusions

Humanity has arrived at perhaps the most critical juncture in its relatively brief existence. If we continue to live as we currently do, a dystopian future awaits us. Systems ergonomics can and should play an active role in efforts to respond to the various global challenges that we face. Despite other scholars arguing the same, ‘global ergonomics’ does not appear to have received attention from those who operate outside of our discipline. This article aimed to test a popular systems ergonomics approach, the abstraction hierarchy, for its ability to model the world as one complex sociotechnical system. The analysis demonstrates that the abstraction hierarchy can be used to construct a coherent and useful model of the world. The model was able to incorporate all of the recognised major global challenges and their interrelations, and emphasised three additional issues. Contributing to the management of existential threats represents perhaps the most important line of work for our discipline. Further applications of systems ergonomics in the global ergonomics context are therefore encouraged. Indeed, such applications will demonstrate what we have to offer in this context, and will help establish human factors and ergonomics as an important consideration when attempting to respond to key global challenges.

References

Aytur, S. A., Rodriguez, D. A., Evenson, K. R., Catellier, D. J., Rosamond, W. D. (2008). The sociodemographics of land use planning: Relationships to physical activity, accessibility, and equity. *Health & Place*, 14:3, 367-385

Banister, D. (2005). Unsustainable transport – City transport in the new century. Taylor and Francis: London.

Buehler, R. (2011). Determinants of transport mode choice: a comparison of Germany and the USA. *Journal of Transport Geography*, 19, pp. 644-657.

Harvey, C. and Stanton, N. A. (2014) Safety in System-of-Systems: ten key challenges. *Safety Science*, 70, 358-366.

Heinrich, J., et al. (2005). Studies on health effects of transport-related air pollution, In M. Krzyzanowski, B. Kuna-Dibbert and J. Schneider (Eds.), Health effects of transport-related air pollution, (pp. 125-165), World Health Organisation Europe Report, ISBN 92 890 1373 7

Leveson, N. G. (2004). A new accident model for engineering safer systems. *Safety Science*, 42:4, pp. 237—270.

Maier, M.W. (1998). Architecting principles for systems-of-systems. *Syst. Eng*. 1, 267–284.

McClure, R. J., Adriazola-Steil, C., Mulvihill, C., Fitzharris, M., Bonnington, P., Salmon, P. M., Stevenson, M. (2015). Simulating the dynamic effect of land use and transport policies on the development and health of populations. *AJPH.* 105, S2, 223-229.

Naikar, N. (2013). WDA: Concepts, Guidelines, and Cases. CRC Press, Boca Raton, FL, USA.

Moray, N. (1995). Ergonomics and the Global Problems of the Twenty-first Century. *Ergonomics* 38:8, 1691–1707.

Salmon, P. M., Walker, G. H., Read, G. J. M., Goode, N. & Stanton, N. A. (2017). Fitting methods to paradigms: are ergonomics methods fit for systems thinking? *Ergonomics*, 60:2, 194-205.

Stanton, N.A., Salmon, P.M., Walker, G.H. & Jenkins, D.P. (2017). Cognitive Work Analysis: Applications, extensions and future. CRC Press, Boca Raton, FL.

Stevens, N. J., Salmon, P. M., & Taylor, N. (2016). Work domain analysis applications in urban planning. Active transport infrastructure and urban corridors. Cognitive Work Analysis: Applications, Extensions and the Future. CRC Press, Boca Raton.

Thatcher, T., Waterson, P., Todd, A. & Moray, N. (2018). State of Science: ergonomics and global issues, *Ergonomics*, 61:2, 197-213

Janneke van der Leer, J., Timmeren, A. v., & Wandl, A. (2018). Social-Ecological-Technical systems in urban planning for a circular economy: an opportunity for horizontal integration, *Architectural Science Review*, 61:5, 298-304

Vicente, K. J. (1999). Cognitive Work Analysis: Toward Safe, Productive, and Healthy Computer-Based Work. Mahwah, NJ: Lawrence Erlbaum Associates.

WHO Europe (2006). Physical activity and health in Europe: evidence for action. http://www.euro.who.int/__data/assets/pdf_file/0011/87545/E89490.pdf

World Economic Forum. (2016). What are the ten biggest global challenges. https://www.weforum.org/agenda/2016/01/what-are-the-10-biggest-global-challenges/, accessed 16th October 2018.

Woodcock, J., Banister, D., Edwards, P., Prentice, A.M., Roberts I. (2007). Energy and transport. *The Lancet*, 370:9592, 1078 – 1088.

Woodcock, J. Edwards, P., Tonne, C., Armstrong, B. G., Ashiru, O., Banister, D. (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. *The Lancet*, 374:9705, 1930-1943.