

Past, present, and future of E/HF for sustainability: A perspective from the HFSD Technical Committee

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Abstract.

BACKGROUND: Sustainability is a highly important theme worldwide and currently is being tackled by almost all disciplines. Indeed, the future of humanity is dependent on the actions taken now and in the immediate future. The Ergonomics and Human Factors (E/HF) community has not been indifferent to this issue, and one of the concrete actions adopted by the International Ergonomics Association (IEA) was the establishment of the “Human Factors for Sustainable Development” (HFSD) Technical Committee.

OBJECTIVE: To identify future paths of action, this paper recognizes the trajectory of the HFSD Technical Committee, summarizes the contributions presented at IEA2021, the International Congress on Ergonomics held virtually in Vancouver in 2021, and reflects on key aspects that should be boosted by the Technical Committee.

METHODS: This is a qualitative interpretative study that reflects on the contributions of members of the HFSD community working on E/HF for sustainability.

RESULTS: Central topics and opportunities in E/HF and sustainability include complexity of systems, behaviors, and work; energy use and consumption; co-design, interconnectivity, territories, and the relationships with stakeholders.

CONCLUSION: Although the contributions have been growing, there is still a lot of work needed, both theoretically and practically. Themes to be discussed include the concepts of sustainability and work. Considering the centrality of human beings (i.e., decision making for achieving the different dimensions of sustainability), the authors identify a set of values as core principles for leading the discussion.

Keywords: Ergonomics, human factors, values, sustainable development, IEA2021, beyond future of work, ergonomics and human factors towards sustainability, IEA technical committee

1. Introduction

Sustainability and sustainable development are subjects that have had increased interest in recent years, especially as a result of the great environmental challenges that humanity must face to ensure its survival [1]. A recent example is the danger of climate change, which has also been discussed in the interna-

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tional political context as one of the great challenges of the immediate and medium-term future. Although sustainable development has been mainly associated with improvements in environmental aspects, it is also inextricably linked to the need to jointly promote positive socio-economic development, recognizing that the limits of growth are determined by the limits of natural capital [2]. This discussion has also been adopted by organizations and has led to the inclusion of corporate sustainability and social responsibility policies. An example of the organizational approach is Elkington's [3] triple bottom line perspective of economic, environmental, and social outcomes. To do this, the stakeholder theory [4] points out that a company is more sustainable by creating value not only for its shareholders, but also for all stakeholders involved in its activities.

In this context, the argument for the involvement of ergonomics/human factors (E/HF) has been made. E/HF has arisen from the need to adapt artifacts/tools and processes to the psycho-physical characteristics of specific subjects involved in specific situations. For example, in the work context, E/HF points to the need to adapt processes, machinery, tools, environments, etc., to the specific characteristics of the workers. In another example within the context of product or facility design, E/HF promotes adaptation to the precise characteristics of its users. In other words, in the context of optimizing economic-financial performance, E/HF has always been concerned with creating social value for certain stakeholders, such as employees, employers, supplier organizations, or customers. E/HF is already focused on creating social and economic sustainability in organizations, and can therefore be a great ally in the introduction of other sustainability aspects, such as ecological sustainability.

Considering that workers (from strategic management levels to operational levels) and users (or the clients of an organization) may be sensitized to address environmental problems, could E/HF not also contribute to greater environmental sustainability? This is one of the possible contributions of E/HF to the theme of sustainability, corporate sustainability, and sustainable development. Sustainable development and sustainability are also concerned with ensuring equitable, long-term access to resources for everyone to lead meaningful, productive lives. This includes social sustainability issues such as sustainable work, participatory capacity building, empowerment, work-life balance, safety, and health/wellbeing. In this pillar of sustainability, the importance of work-

ers to achieve greater sustainability is recognized [5, 6]. From an economic sustainability perspective this includes aspects such as employability, macro-ergonomic change management for efficiency and effectiveness, and understanding the entire global value chain [7]. Finally, from an environmental sustainability perspective concepts such as green ergonomics [8], ergoecology [9], and the design of environmentally responsible products and systems [10–13] are relevant. There are many connections between E/HF and sustainability within organizations, from applications in operational areas to the support of organizational strategies, as proposed by macro-ergonomics.

This strong connection was recognized by the International Ergonomics Association (IEA) when it created the Human Factors for Sustainable Development (HFSD) Technical Committee in 2008 [14]. Since then, the HFSD Technical Committee has developed several projects in order to encourage and bring people together who are interested in the development and improvement of these topics. At the last international conference of the IEA, conducted online in June 2021, the HFSD Technical Committee was actively involved in organizing a number of sessions with contributions from its own network of researchers, and organizing another session in partnership with the Activity Theories for Work Analysis and Design (ATWAD) Technical Committee.

The role of the HFSD Technical Committee is essential for the development of knowledge that connects E/HF with sustainability, and it is currently the international meeting and aggregation point for research in this area. In addition to the technical support contribution, this Technical Committee can be considered as a group of people (professionals, researchers, students, etc.) interested in this area of knowledge. Considering this important role, our main objective is to describe the actions of this Technical Committee in the past and present, and to identify future paths of action. To achieve this goal, the paper has three sections. The first section describes the HFSD Technical Committee and identifies the main contributions since 2008 (i.e., the past). The second section organizes the current contributions, typified through the main research topics extracted from the IEA2021 Congress (i.e., the present). Finally, the third section presents our reflections on what was previously discussed, pointing out possible future actions of this Technical Committee in creating more knowledge in this specific area of E/HF (i.e., the future). A final section ends this discussion, present-

ing our main conclusions and vision of the future of this Technical Committee.

2. Past: HFSD Technical Committee and its contributions

The HFSD Technical Committee had its official launch during the IEA Congress in Beijing in August 2009 and currently has about 100 members worldwide. The first chairs of this TC were Professor Klaus J. Zink and Professor Colin G. Drury [15], who defined the following objectives: (i) To improve and increase the knowledge about the contribution of E/HF to corporate and societal sustainability concepts; (ii) to improve knowledge transfer from E/HF to the academic community dealing with sustainable development; (iii) to strengthen the relationship between E/HF specialists and other actors in this field; (iv) to promote E/HF as a stakeholder-oriented approach; and (v) to promote the role of E/HF in realizing sustainable development to the public at large.

The HFSD Technical Committee and its sub-committees act as coordinators for the different objectives including: (i) to discuss issues related to the Technical Committee's focus and activity plan (e.g., via online platforms and meetings scheduled at conferences where several Technical Committee members participate); (ii) to coordinate research, practice and standards issues pertaining to the Technical Committee's domain through networking and collaboration with associated bodies such as International Organization for Standardization (ISO), International Labour Organization (ILO), World Health Organization (WHO), and the International Commission on Occupational Health (ICOH); and (iii) to organize scientific events endorsed or co-sponsored by the IEA (conferences, workshops, symposia, panels and demonstrations). Furthermore, the HFSD Technical Committee and its sub-committees are expected to support the IEA congresses by organizing one or several scientific paper sessions or panel discussions (including calls for and reviewing of papers, organizing workshops, etc.).

Going into detail, the HFSD Technical Committee has created an opportunity to disseminate research related to E/HF and sustainability through different means. Table 1 summarizes and provides the timeline of the most relevant contributions and activities, including journal and book publications, symposiums and sessions at congresses and conferences.

In these publications and events, the contributions of the HFSD Technical Committee participants were varied. Contributions ranged from promoting greater sustainable development for humanity or for specific stakeholders, to greater corporate sustainability for organizations. The studies ranged from the work context to product development or the improvement of the design of facilities for certain users. Theoretical research was developed discussing the contribution of E/HF in different systems where sustainability needs to be considered, but applications in different economic activities (e.g., mining, energy, etc.) were also studied. Different E/HF approaches were included, such as macro-ergonomics or activity ergonomics. Some concepts and applications were more focused on the contribution of E/HF to the environmental pillar of sustainability (e.g., green ergonomics or ergoecology), and others were more focused on the social pillar, focusing on the contribution of sustainability to different stakeholders.

3. Present: Studies related to the HFSD Technical Committee at the IEA 2021

The latest contributions of the Technical Committee took place at the IEA2021 Congress. Three sessions of IEA2021 were dedicated to the theme "Sustainable Development," in which 14 papers were presented, comprising both theoretical and practice-oriented research. Theoretical papers consisted of literature reviews and conceptual developments on ergoecology, sustainable work and, more generally, on the connection between E/HF and sustainability. In addition, three sessions, comprising 11 papers, were presented in a symposium jointly hosted with the Activity Theories for Work Analysis and Design (ATWAD) Technical Committee entitled "Developing ergonomic practices to address sustainability issues: from companies to territories." It is important to emphasize that these articles presented the most recent research in the area, adding (not summarizing) to the knowledge base that has already been built in by the Technical Committee.

3.1. Emerging issues from the IEA 2021 Sustainable Development sessions

Practical application papers focused on systems- and complexity-based approaches, such as complex system theory and the sustainable system-of-systems framework. Other papers presented studies on the

Table 1
Contributions and activities of the HFSD Technical Committee

Year	Type of dissemination	Description
2008	HFSD Technical Committee formed	HFSD Technical Committee formally recognized by the IEA
2009	Sessions (3) at congress	HFSD Technical Committee sessions at the IEA Congress on Ergonomics in Beijing, China
2010	Track (1) at conference	Track "Human Factors and Sustainable Development" at the German Human Factors and Ergonomics Society Conference
2011	Symposium at conference	Special symposium on EQUID (Ergonomics Quality in Design) and sustainable development at the ODAM (Organizational Design and Management) Conference in Grahamstown, South Africa
	Special Interest Group support	CIEHF, UK forms "Green Ergonomics" Special Interest Group with HFSD Technical Committee support
2012	Sessions (3) at congress	IEA Congress on Ergonomics in Recife, Brazil with many of the papers appearing in a Supplement of the journal "Work" [e.g. 16, 17]
2013	Symposium at congress	50th Anniversary Congress of the SELF (Société d'Ergonomie de Langue Française) in Paris, France
	Symposium at conference	International Annual Meeting of the Human Factors and Ergonomics Society (HFES) in San Diego, USA
	Journal articles (17)	Special issue "Ergonomics and sustainability" in Ergonomics [18]
2014	Symposium (2 sessions) at conference	ODAM-NES (Nordic Ergonomics and Human Factors Society) Conference in Copenhagen, Denmark
	Journal articles (9)	Special issue "Green ergonomics" [19]
2015	Symposium (3 sessions) at congress	IEA Congress in Melbourne, Australia
2016	Panel at conference	HFES Conference in Washington; USA
	Journal articles (10)	Special issue "Human factors for a sustainable future in Applied Ergonomics" [20]
2017	Symposium at conference	ODAM-ACE (Association of Canadian Ergonomists) Conference in Banff, Canada
	APERGE sub-committee support	French Association for Research in Psychology and Ergonomics (ARPERGE) officially launches "Concevoir pour le Développement Durable" sub-committee (Design for Sustainable Development in English) with support from HFSD Technical Committee
	Seminar support	"Concevoir pour le Développement Durable" sub-committee of APERGE hosts first seminar.
	Keynote address	CIEHF, HFSD TC Chair gives keynote address in support of Green Ergonomics Special Interest Group.
	Keynote address	HFSD TC Chair gives keynote address at HFESA conference, Woolongong, Australia
2018	Sessions (5) at congress	Four HFSD Technical Committee sessions and one joint session with the Activity Theory and Work Analysis and Design (ATWAD) and ODAM Technical Committees at the IEA Congress in Florence, Italy
	Book (15 chapters)	"Ergonomics and Human Factors for a Sustainable Future" by Springer Nature [21]
2019	Journal articles (5)	Special issue "Développement durable: nouvelles perspectives en psychologie ergonomique et ergonomie" in Psychologie Française [22]
	Online Symposium	First online symposium of the HFSD Technical Committee with 7 presentations
2020	Book (19 chapters)	"Human Factors for Sustainability: Theoretical Perspectives and Global Applications" by CRC Press [1]
	Keynote address	HFSD TC chair gives keynote address at ABERGO conference, Sao Paulo, Brazil
2021	Sessions (6) at IEA2021 Congress	Three HFSD Technical Committee sessions and three joint sessions with ATWAD Technical Committee at the IEA Congress in Vancouver, Canada
	Task Force support	HFSD Technical Committee providing ongoing support to HFES Task Force on Sustainability and Human Factors to develop a Technical Group.

use of E/HF related to two main issues: energy (e.g., energy use management, eco-automation, carbon footprint) and waste (e.g., urban solid waste collection, recycling). The integrated analysis of the papers presented in the following subsections generates important ideas and reflections to consolidate E/HF and sustainability as a research field, to develop more systemic approaches within E/HF to frame sustainability issues, and to transform theory into practice.

3.1.1. Consolidating the field: Key concepts and opportunities in E/HF and sustainability

Papers from the Sustainable Development sessions discussed the relationship between E/HF and sustainability from different angles, paying attention to the emergence of key concepts and opportunities. A common point was the argument for the consolidation of E/HF and sustainability as a research area (from a theoretical and epistemological perspective) [23]. Although it is possible to identify a set of articles that

form the conceptual pillars from which the field has evolved, such as green ergonomics [8] and sustainable work systems [24], there was a concern that the work in E/HF and sustainability is disparate, where people have been operating in unconnected silos [25]. These papers shed light on possible paths towards greater integration.

Saravia-Pinilla, García-Acosta, and Daza-Beltrán [26] pointed to the lack of consensus on eco-concepts (i.e., eco-productivity, eco-efficiency and eco-effectiveness) and argued for greater conceptual consistency between the postulates of E/HF (productivity, efficiency, effectiveness, health, wellbeing, and quality of life of human beings) and the postulates of ergoecology [9]. Another example was the growing research on the concept of sustainable work [27]. Ribeiro and Bolis [28] pointed out that E/HF researchers have built on this concept to explore how to promote corporate sustainability [29] and to design sustainable work systems, more specifically in the context of remote work. This point deserves attention from the E/HF community in order to better understand the impacts on work and how to design post-pandemic work-from-home systems [30]. Lastly, researchers have identified the need for more empirical studies to develop and test practical solutions and concepts and from this perspective, it is worth mentioning Saravia-Pinilla and Ivorra-Peñafort's [31] proposal for a tool to improve the rationale of the decision-making process with regards to sustainable attributes of products/services.

3.1.2. *Interconnected world: Complex systems and complex behaviors*

The call for a greater emphasis on complex systems approaches in E/HF has been in place since the key early works [32, 33] and still remains relevant in more recent contributions, more specifically in the context of sustainability [1, 34]. Researchers have used systems- and complexity-based approaches to understand the interplay between work, the worker and the systems (of systems) that encompasses them [35]. There were also researchers interested in investigating sustainability issues so as to identify the relationships between different elements at different levels of the system, integrating micro- and macro-ergonomics perspectives [36]. The main theoretical approach that researchers have built on is the sustainable system-of-systems (SSoS) [37], and the problems studied range from general topics, such as corporate social responsibility [38] and user experience dynamics [39], to specific cases such as the

design of a greywater treatment system for urban informal settlements [40]. In general, it is worth mentioning the need for greater dialogue between E/HF approaches [41] and more empirical and practical applications to validate theoretical approaches such as SSoS.

3.1.3. *Application studies related to energy use and consumption: Social and personal changes and challenges about new behaviors*

Two papers presented at IEA 2021 sessions marked a clear orientation towards understanding the human situations of daily life in households. In this sense, they were E/HF evaluations that distanced themselves from the traditional evaluations that deal with working conditions. In these cases, E/HF could be understood in a broader way, such as understanding the dynamics of interaction of humans (in homes) with the systems that provide them with public comfort services for daily life (e.g., energy supply for their home). The studies were oriented in terms of analyzing, from a human perspective, what role both individual and collective human actions play, moving from their personal meanings to collective or social meanings. Fréjus [42] sought to understand the situations and mechanisms of energy consumption by envisioning the transformation of various situations, while maintaining both well-being and environmental protection. The work of Rivetta et al. [43] was very similar in the sense that it modeled human decisions. Rivetta et al.'s [43] study was about the use of a heating, ventilation, and air conditioning (HVAC) system. Rivetta et al. [43] aimed to improve energy sustainability without sacrificing the comfort of people in their homes. They sought to understand human decisions about the use of HVACs to promote energy saving behaviors. For both studies, the key was the relationship between energy management with greater knowledge and control by consumers, and the possibility of savings and a regulated supply consistent with future changes. This meant making the operation of the system more transparent and not leaving it as a black box to users or consumers. Both cases have found poor design of existing information systems and consumption control systems. It is necessary to promote smarter appliances and household management systems, sensitive to the context (e.g., geographical, population, architectural, etc.), which are useful and usable, and allow users to inform themselves, monitor and, consequently, be able to manage their consumption. The idea was to maintain a certain

range of comfort and ease of daily life without waste, but at the same time, establish specific mechanisms so that they can save energy.

Two other works were oriented towards the same global challenge of how to transform people's behaviors while reducing CO₂ emissions. Schrills et al. [44] addressed behavior and energy saving in general while Arend and Franke [45] looked at energy efficiency while driving hybrid vehicles. These two papers dealt with the challenges of people receiving more reliable information and efficient feedback so that they felt and recognized that their daily decisions were more in line with sustainability (e.g. reducing CO₂ emissions). For example, if feedback while driving hybrid vehicles was improved, the driving behavior could be made more efficient to save fuel. However, to support these changes in behaviors, it would be necessary to have the ability to obtain all the tracking information so that the support allowed making comparisons between measured CO₂ versus emission targets.

This group of work showed how the relationship between understanding the activities and work/action situations and their immediate and future transformations could lead to changes in behavior so that sustainability materializes through individual and collective actions from a socio-technical perspective. The role of changes in energy efficient behaviors and the management and control of energy use by consumers requires: (i) feedback and reliable information on the consequences of their actions and their daily behaviours on energy consumption and its impact; and (ii) improvements in energy consumption information devices (home and transport) as well as household appliances and vehicles, to offer reliable information on how to regulate and manage energy. This knowledge, recognition, and sociotechnical transformation allows people (in the present and in the future) to become aware and to re-evaluate their need to form new habits. However, changes in habits must be driven by individual and collective sustainability values [46, 47], so that society specifically orients their actions towards all dimensions of sustainability.

3.1.4. *Studies of working conditions in relation to waste and recycling*

This group of papers was made up of two studies aimed at the systemic recognition and evaluation of the working conditions in both solid waste collection activities in a city [48] and in the mattress recycling processes [49]. Both works focused on the evalua-

tion and identification of risks due to the physical demands, with methodologies focused on activities as well as tools to evaluate the conditions of physical and cognitive demand, using methodological assemblies for understanding and diagnosis. Both papers were framed in the E/HF evaluation of work, so that it was possible to understand the critical activity that could lead to severe physical risks (musculoskeletal injuries) and mental risks, derived from activities with greater physical and repetitive demand. From this perspective, it was clear that jobs under such conditions could affect social sustainability (i.e., the maintenance of these types of jobs, since they are not attractive jobs to take on and there is a threat that they will become automated). It was assumed due to the focus on collecting waste and recycling that these tasks were automatically oriented towards environmental sustainability. However, this is not necessarily the case. Recycling mattresses is both environmentally responsible and socially responsible by creating jobs. In conclusion, it should be noted though that these papers did not reflect on the value of this work beyond the immediate environmental sustainability benefits. The dominant vision of evaluating the specific conditions of the activity (i.e., recycling) under consideration was maintained, without also considering the consequences for other dimensions of sustainability.

3.2. *Joint symposium on "Developing ergonomics practices to address sustainability issues: From companies to territories"*

The impetus for the joint symposium stemmed largely from the identified need for E/HF approaches to adopt a much broader scale of analysis when considering sustainability issues. For example, both Thatcher, Nayak and Waterson [50] and Salmon et al. [51] have emphasized the need for taking a broader systems approach when addressing global problems, such as sustainability, from an E/HF perspective. The papers presented in this symposium were therefore closely aligned to Thatcher, Guibourdenche, and Cahour's [41] call for the activity theories used in E/HF to adopt a more macro-systems approach in order to address sustainability issues. One of the critiques of previous ATWAD research on sustainability issues was that the research and application tended to focus on the micro- (i.e., detailed work analysis of a single person or a dyadic work situation) or meso- (i.e., a narrowly defined work systems such as a team

or a small organization) rather than macro-work systems situations that encapsulate large organizations or even the broader geographical region. This joint symposium showcased this emergent way of thinking.

Apart from three papers which were predominantly methodological or theoretical in nature, the other papers in the symposium were each empirical examples of activity theory and work analysis applied to interpret and understand macro-systems. Already this is a significant advancement from previous studies in HFSD that have discussed larger systemic issues. Previous research has almost exclusively been theoretical in nature [34] or has only re-analysed existing data [46, 47]. The studies in this symposium covered an interesting range of application areas including optimizing the design of an organic farm without pesticides [52], the revival of ancestral agriculture methods [53], the design of an efficient packaging distribution system, the design of a public transport system [54], the design of organic waste management systems [55, 56], the design of informal trading systems in a slum [57], the design of an eco-tourism site [58], and Guimaraes' presentation of a co-creation website for the design of a sustainable city. Four common issues emerged from the symposium which have a bearing on directions for future work in HFSD: co-design, "boundary objects," defining a territory, and competing sustainability goals.

3.2.1. Co-design

One of the common features of these papers was the emphasis on co-design/co-creation. Lange-Morales et al. [59] have also emphasized co-design and participatory approaches as a vitally important value (i.e. respect for diversity) in designing sustainable systems. Two of the papers [58] specifically focused on the co-design elements in their respective papers, but other papers in the symposium also included co-design as important components of their design processes [52, 55, 60]. In reviewing the ATWAD approach to addressing sustainability issues, Thatcher et al. [41] noted participatory and co-creation methods were already central to activity theory. These empirical studies clearly demonstrated the critical value that co-design plays in facilitating the design of sustainable work systems.

3.2.2. "Boundary objects"

Papers in the symposium also identified the need to develop new methods of understanding the territorial work domain: called "boundary objects." Parallel

discussions have taken place in the HFSD literature about developing or adapting existing tools to help E/HF understand the complexity inherent in designing for sustainability [1, 37, 51]. Cunha and Lacomblez [54] noted the relevance of incorporating geographical information systems as a design tool, whereas Gomes de Lima et al. [58] emphasized the need for interviews *in situ*, where the "sense of place" might be captured (i.e. *genius loci*). Pereira et al. [57] used a technique called the "effectuation approach," which adopts alternative reality scenarios to both characterize existing work designs and to imagine new work designs. These are all techniques that are new to the HFSD literature and emphasise the need for greater synergy between the Francophone and Anglophone traditions of E/HF.

3.2.3. What is a "territory"

From a theoretical perspective, the papers in this joint symposium spent considerable effort trying to conceptualise a "territory." In many respects a "territory" can be operationalized as existing within specified, bounded geographical space. However, it was also evident that a territory might also be conceptualized as consisting of ecological objects and processes (i.e., an "ecological territory") that have their origins beyond the boundaries of the specified geographical space (e.g., weather, biodiversity, economic flows, political arrangements, cultural and social norms, technology-transfers, etc.). In one instance a territory was also conceptualised as encompassing socio-historical elements [53]. This (historical) time aspect is a critical component for understanding sustainability. Both Zink [24] and Thatcher and Yeow [37] have recognised the centrality of the time aspect in their models/frameworks of how to conceptualise sustainability within E/HF. Other authors [59, 61] have also highlighted the importance of time in E/HF, calling for "unfreezing" E/HF when understanding and intervening in processes, recognizing their history and projection.

The papers in this symposium demonstrated the wide array of complex interrelated systems that impact on the functioning of the system under investigation and were strongly reminiscent of Thatcher and Yeow's [37] SSoS framework for E/HF. In short, the work provided good empirical support for Thatcher and Yeow's [37] SSoS framework. In comparing waste-recycling work systems in France and Brazil, Boudra et al. [55] found that the type and quantity of recyclable materials and the methods of recycling were significantly different according to geographical

territory and the “ecological territory” provided different constraints for what was possible in the design processes. Boudra et al. [55] therefore demonstrated how the territory (both the physical territory and the process territory) led to different design issues that needed to be tackled with the local territory perspective in mind. This aspect might also be found in the values for sustainability in E/HF by Lange-Morales et al. [59] when emphasizing the respect for diversity value. Respect for diversity often means letting local solutions dominate over holistic, global solutions.

3.2.4. *Competing sustainability goals*

Le Bail and Cerf [60] reminded E/HF designers that there are often competitive forces within (and between) territories that mean that sustainability goals may be pitted against other goals of participants in the locality or territory. For example, job creation (or job maintenance) in a specific territory needed to be balanced against the need to centralize jobs (and living arrangements) to reduce the need for carbon emissions from excessive travel. Additionally, job creation in one sector (e.g., organic farming) might create job losses in another sector (e.g., non-organic farming). These competing demands need to be borne in mind. Thatcher and Yeow’s [37] SSoS framework also emphasised the need to incorporate multiple, sometimes competing, goals when considering sustainability and these studies provided empirical support for this contention. In addition, E/HF “flows” between territories were also relevant for understanding how to design the focal system. For example, Pereira et al. [54] noted the importance of inter-territory monetary exchanges in the sustainability of entrepreneurship businesses. These also needed to be taken into account when supporting the design of their entrepreneurship activities. Perreira et al. [57] therefore demonstrated empirical support for another of Thatcher and Yeow’s [37] theoretical contentions about the strong interplay between different hierarchical levels in the SSoS.

4. Future: What could be the future of the HFSD Technical Committee in expanding knowledge that connects E/HF to sustainability?

In this section we have attempted to synthesize these lessons into an agenda for the Technical Committee.

4.1. Ideas for moving from the present to the future based on studies at the IEA 2021

Many of the research and applications that address the concept of “sustainable development”, even in the context of E/HF, are based on the notion of eco-efficiency, but this leads to the Jevons paradox [62]; increases in efficiency leads to decreases in costs and therefore greater use of the product or service with the net effect being that total consumption levels stay the same or even increase with an population growth. A debate on the paradigm of “sustainable development” is therefore required by theorists in the E/HF community to move to a broader notion of “sustainability” beyond eco-efficiency to concepts such as eco-effectiveness and eco-productivity in the dynamics between human systems and other systems. Epistemological consolidation is required to explicitly establish the paradigmatic aspects of E/HF oriented towards sustainability. This should be supported by a review of the theoretical bases and conceptual principles that have been raised within E/HF such as corporate social responsibility, green ergonomics, and ergoecology.

Based on the above, it is necessary to promote the development of methods and tools in each of these approaches. In particular, empirical studies, field studies and practical applications are needed to validate key concepts and theoretical approaches (e.g., ergoecology, sustainable work, and SSoS). Systems- and complexity-based approaches have been used to frame sustainability problems [35, 37, 40] and future efforts need to be directed towards the operationalization of knowledge (i.e., transforming theoretical approaches into concrete strategies and tools and empirical field studies). Researchers and practitioners need to focus on the complexity of the systems and behaviors that are involved in sustainability and should apply these new principles and approaches to discover, adapt and develop new methodologies and tools aimed at sustainability. Some of this work has already started [41, 54, 57, 58], but needs to be tackled more consistently and systematically if E/HF is to play a more significant role.

In the short term, the goal of E/HF beyond its role of problem identification, must be emphasized. The work of the HFSD Technical Committee has been excellent in diagnosing problems and issues that require addressing but has not been as successful in the implementation and evaluation of design solutions. Of course, there were exceptions presented at the IEA2021 Congress [40, 45, 52]. It is necessary

to be more design-driven, so that physical and social transformations within sustainability parameters are promoted and effectively carried out for work design, technology design, and innovative processes, tools, and products.

It is important to establish the same theoretical basis as the sociotechnical and systemic approach (i.e., inputs, transformation, and outputs of sustainable energy and information) as an epistemological framework that allows for the development of more studies on the performance of users or consumers in various activities and roles that are negatively impacting social and environmental sustainability (as well as other dimensions of sustainability that are not usually recognized such as political and cultural sustainability). E/HF and sustainability should be seen as a frontier field, where it is possible (or rather necessary) to work from a multidisciplinary perspective, with solid epistemological bases in theories from multiple disciplines that enable designers to incorporate systemic aspects, to create transdisciplinary knowledge. A new way of approaching E/HF evaluations is required, addressing problems with a more strategic focus.

4.2. The future of E/HF and the future of work

The future of the HFSD Technical Committee is also closely related to the future of E/HF and the future of work. It is therefore important to tackle some of the related topics discussed at the IEA 2021 Congress, especially those covered during the sessions “The future of ergonomics: three triennials later” organized by Jan Dul, “HFE values, principles, and approaches for contributing to mold the future of work we want” chaired by Juan Carlos Hiba, and “HFE global strategies and activities for molding the future of work we want” chaired by Klaus Zink.

Regarding the future of E/HF, two main topics were discussed. The first tackled the complexity of work (i.e., sociotechnical systems with a focus on the systems approach, the changing nature of work, and the need for specific E/HF approaches). In this discussion, Industry 5.0 [63] was seen as an excellent opportunity to expand the impact of E/HF, as the concepts involved in this proposal are human-centric and seek a transition to a circular economy to have resource-efficient and sustainable industries. The second theme dealt with approaches to the managerial context. Here the emphasis was put on speaking in the language of powerful stakeholders, by first delivering the benefits of E/HF in performance terms.

The sessions devoted to the future of work dealt with values, principles, approaches, contexts, and strategies oriented to clarify the role and possible contributions of E/HF to dignifying human work. This relates to the issues of values and the need to develop a new ethical instance for E/HF. The ethics and values of E/HF and sustainability has previously received attention from the HFSD community [7, 18, 27, 40, 61] and will have particular relevance for those people in E/HF who are working on understanding the future of work. The question here could be: What is meant by dignified human work? Lange-Morales et al. [59] proposed six values (respect for human rights, respect for the Earth, respect for ethical decision-making, appreciation of complexity, respect for transparency and openness, and respect for diversity) that can be summarized in two main focuses: social and environmental responsibility, emphasizing the need for tackling both in parallel. Dignity is related essentially with respect, and human work is related essentially to using or transforming the environment for human survival and need satisfaction. Since human survival depends directly on the planet as a whole, dignified human work can be understood as working towards all dimensions of sustainability (i.e., cultural, social, economic, technological, and political) and environmental sustainability, as proposed in the ergoecological approach [9, 26, 31, 59].

One of the aspects highlighted in these sessions was the diversity of contexts, recognizing that this diversity did not occur only in different geographical regions but also within the same country/region. On the other hand, all regions share common challenges, and most work, globally speaking, does not happen within the formal structure of an organizational context, but in informal work contexts (i.e., informal marketplaces, subsistence work, recreation, and the home). According to the International Labor Organization (ILO), “more than 60 per cent of the world’s employed population are in the informal economy” [65]. Therefore, by concentrating on the human workers hired in organizations, we are only concentrating on the smallest part of the universe of work. Consequently, E/HF’s impact is limited. This leads to the conclusion that the concept of work typically used in E/HF should be re-considered based on the pressing challenges of sustainable development and the complexity this adds [41, 45, 50, 59, 66]. Another aspect to consider is that there are megatrends relevant for all parts of the world (i.e., the rise of robotic and artificially intelligent systems, the casualization of work, etc.) [20, 21, 34, 37, 64], and within these

trends, climate change is especially relevant to the issues tackled by members of HFSD community such as ergoecology [9] and green ergonomics [8].

It should also be noted that the concept of sustainability is ambiguous within the E/HF field [20, 37, 67] and even within the HFSD community. Sustainability is often seen as a synonym for work under good conditions throughout the work life (i.e., related to workability, employability, and work longevity). Another, broader, understanding views sustainability as the concurrent development of economic, environmental, human, and social resources engaged in work processes. However, even this second view is limited, especially when it is expressed as sustainable development, which links tacitly to the dominant economic model [27, 29].

In short, these themes can be categorized as representing the complexity of work and relationships with stakeholders. Not only do the concepts of work and sustainability need a deeper discussion within the E/HF community, but also the relationships with stakeholders must be strengthened. While emphasizing the benefits of E/HF for performance has already been recognized as a strategic way to convince powerful stakeholders [47, 68], this is insufficient when thinking about all the dimensions of sustainability. This suggests that there is a need to redefine E/HF and work. Some authors [e.g. 59] have even proposed redefining the whole concept of E/HF. This may also be an opportunity to rename this committee from the HFSD Technical Committee to the “Ergonomics and Human Factors towards Sustainability” Technical Committee.

4.3. Practical agenda: Consolidating the work of the HFSD Technical Committee through its sub-committees

Considering how much has been written so far, there is still a lot of work to be done by the HFSD Technical Committee to extend the knowledge that connects E/HF to sustainability. From a practical point of view, the HFSD Technical Committee involves its network of participants through sub-committees. We therefore make some suggestions to guide future actions of the sub-committees although the final decisions rest with the relevant sub-committee leadership and membership. The six sub-committees are: “Theoretical Perspectives on Human Factors and Sustainable Development”; “Human Factors and Sustainable Development in Global Value Creation”; “E/HF and Design for Sus-

tainability”; “Energy and Mobility”; “Sustainability in the Built Environment”; and “Smart/Intelligent Systems.”

The work of the “Theoretical Perspectives on HFSD” sub-committee is now fairly mature. There is a much clearer (and shared) understanding about sustainability and sustainable development within the HFSD community and this is clear in the work at the IEA2021 Congress and beyond. However, misunderstandings and misuse of these terms still prevail beyond the HFSD community and therefore the work of this sub-committee could be to look at how to make these definitions more widely known. Further, despite the theoretical development being relatively mature there are still many avenues for elaboration, clarification, and expansion. In this paper we have mentioned the work on ergoecology [26], the SSoS framework [40], and the design of sustainable work [27], demonstrating fertile ground for further growth. Given that the ATWAD symposium papers were tackling similar theoretical issues such as defining relevant systems, the interplay between relevant systems, and how to deal with multiple competing goals, it is possible that theoretical advancements could come from outside this sub-committee. Theoretical advancements of this nature will still need to be integrated with existing thinking in the HFSD community. While the theoretical construction of the relationship between E/HF and sustainability is relatively mature, the application of these concepts is not. Practical application of these theoretical concepts needs to be included in this sub-committee. This could mean changing the name of this sub-committee to “Practical Perspectives on HFSD.”

No work of the “Human Factors and Sustainable Development in Global Value Creation” sub-committee was presented at the IEA2021 Congress. However, equitable and sustainable treatment across the entire value chain is still relevant. Both in our review of the IEA2021 Technical Committee program and in the ATWAD joint symposium, it was evident that the need to understand and model complex systems to resolve sustainability issues was required. Given that global value chains are an example of a complex, global system, it is possible that this work might be combined to form a sub-committee with a broader scope, looking at how E/HF might tackle larger, systemic issues [34].

Regarding the “E/HF and Design for Sustainability” sub-committee, there is a huge opportunity for contributing to sustainability inside and outside the formal work arena, especially considering the design-

driven orientation of E/HF. As shown in some of the papers presented at IEA2021, it is necessary to make consumption patterns transparent for the users, so that they have information for making better decisions in daily life to support sustainability. However, based on previous contributions, this sub-committee needs to expand its role for a broader view of design for sustainability. Considering stakeholder theory [4], this sub-committee needs to explore stakeholder impacts on the three pillars of sustainability when designing artifacts, tasks, and built environments. These stakeholders could be consumers of an artifact, as we see in the IEA2021 contributions, but also users of a constructed environment, workers within work processes, etc.

In this broader view, the other three sub-committees can be considered as specific applications within the context of “Design for Sustainability.” “Sustainability in the built environment” specifically focuses on designing for sustainability in the homes, offices, neighborhoods, cities, and other infrastructure. “Energy and Mobility” is currently focused on changing user behavior towards the use of mobility products, but it is evident that there are a multitude of other contexts where design for sustainability with energy products and services are relevant including home and office energy systems, entire energy grids, public transport systems, and energy storage systems. For “Smart / Intelligent Systems” there are numerous relevant applications including systems that improve the tracking of consumption (e.g., energy, water, waste, etc.) to make consumption trends transparent for users, and supporting behavior change towards sustainability. Work on understanding sustainability in the context of smart grids, smart homes, and smart cities will be important.

In reviewing the ATWAD joint symposium it is also evident that sustainability and sustainable development are not issues that should only be tackled by a single Technical Committee. The HFSD and ATWAD Technical Committees have held joint symposia at both the IEA2018 and IEA2021 Congresses, demonstrating the value of working cooperatively. We believe that there are opportunities for collaboration with other Technical Committees. For example, the Sustainability and the Built Environment sub-committee could have cooperative arrangements with the Building and Construction Technical Committee (e.g., on advancements in E/HF in green buildings, green cities, and green infrastructure). Other IEA Technical Committees such as “Affective Design,” “Ergonomics in Design for All,” “Ergonomics in

Manufacturing,” “Organizational Design & Management,” and “Transport Ergonomics and Human Factors,” each have natural affinities with the HFSD Technical Committee and cooperative relationships should be established.

4.4. *Conceptual agenda: The importance of having a common orientation regarding the relation between E/HF and sustainability*

The previous sections show the variety and complexity that the E/HF must tackle to contribute to sustainability. A deep reflection must be built from the studies and practices promoted so far by the HFSD Technical Committee and the emerging discussion about the future of E/HF and the future of work. From a conceptual point of view, it is possible to observe that the relationship between E/HF and sustainability is approached from multiple perspectives, sometimes from contradictory points of view. We believe this plurality of views currently present in the HFSD community is important, allowing the creation of an inclusive space that allows for many inputs for the advancement of this knowledge. On the other hand, the presence of multiple views can lead to confusion. Considering the importance of having a common orientation that allows a joint and more robust construction of knowledge, we think it is necessary for the HFSD Technical Committee to promote a conceptual discussion in order to propose a broad and inclusive definition of the relationship between E/HF and sustainability.

Without intending to avoid the broader discussion or to unify concepts, we point out some elements that can be included in this conceptual discussion. First, we can point out that people and their decisions are central to sustainability. This could be a worker (at all organizational levels), a consumer (user of a product or a service), a politician or a leader, etc. All people make decisions that end with actions, and depending on these decisions, it is possible to promote greater or lesser sustainability (in all its aspects). In this context, E/HF when discussing work (even in a broader sense, as discussed in the “future of work”), places people centrally in the systems in which they operate, further optimizing human well-being and overall system performance, by including sustainability concerns [25, 47]. To do this, we think it is important that E/HF promotes decisions based on substantive rationality, guided by ethical values related to sustainability. Using different approaches, two separate groups of researchers [59, 69, 70] came to almost the

same conclusions with regards to underpinning values towards sustainability: respect for human rights, respect for ethical decision-making, appreciation of complexity, respect for transparency and openness, respect for diversity, respect for the Earth and the natural environment (including all living beings), economic values as a mean and not as an end, quality of life (including cultural preservation) and altruism and sense of community (including ethics, justice, morality, equity, equality, democracy and citizenship). These values should be pursued by the E/HF community and promoted in their actions, taking into account time (especially the long term) and space. In this second dimension, there is another element to be included in this conceptual discussion, namely the consideration of the presence of several systems where E/HF can act, needing to consider their inter-correlation and complexity.

5. Conclusions

The work presented at the IEA2021 Congress only represents a small proportion of the work amongst researchers and practitioners working in this area. We have therefore not limited ourselves only to the learnings that have emerged from the IEA2021 Congress but have integrated these contributions into the broader work of members of the Technical Committee. Also, we have tried to phrase the proposals as questions as we do not pretend that we have all the answers or indeed, all the questions. We think it is important to emphasize the need for increased connectivity between the work of the sub-committees within the HFSD Technical Committee as well as greater collaboration in the work between the different Technical Committees. In fact, one might argue that sustainability and sustainable development is something that is important to all Technical Committees. Greater potential for networking between components of a system supports more resilient systems [21]; a characteristic of a sustainable system.

The HFSD Technical Committee has been growing and generating numerous contributions. This can be understood as an increasing interest and awareness of the E/HF community in the related themes. However, although practical applications have increased, in theoretical terms there is still too much work to do. Concepts such as sustainability and work, intimately related with co-design, time and territory, must be

thoroughly debated, to identify points of consensus and disagreement that can orient future developments at different scales, while understanding the limits and possibilities of E/HF in probably the most important reality humanity is facing: current economic and living practices are leading to the extinction of life as we know it.

This article has several limitations that should be stressed. The scope of work is clearly limited to the perspectives of HFSD Technical Committee leaders. Although the paper recognizes its historical roots (section 2), the focus is specifically on the contributions presented at the IEA 2021 Congress (section 3). Therefore, this paper is not an exhaustive study of the E/HF literature that relates E/HF to sustainability but rather a consideration of the emerging trends as presented at the IEA 2021 Congress. Including other measures of impact is considered important, but broader and deeper studies, using other methods (e.g., surveys, systematic literature reviews, interviews), would be necessary. Furthermore, it should be noted that bringing an HFSD Technical Committee perspective does not mean that it represents the view of all members, but only the position and independent reflections of the authors.

Future studies can benefit from the reflections present in the section 4, dedicated to the possible future of the HFSD Technical Committee in expanding knowledge that connects E/HF to sustainability. A central issue would be turning the theoretical approaches into concrete E/HF strategies, tools, and interventions to achieve greater sustainability for the planet and its inhabitants. The sub-committees of the HFSD Technical Committee offer promising avenues to stimulate this discussion. In addition, it is important to increase the connection between researchers in the field, increasing the diversity of approaches and disciplines, and consolidating the common orientation regarding the relation between E/HF and sustainability.

Ethical approval

Not applicable.

Informed consent

Not applicable.

Conflict of interest

None declared.

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References

- [1] Thatcher A, Zink KJ, Fischer K. *Human factors for sustainability: Theoretical Perspectives and Global Applications*. CRC Press, Taylor & Francis, 2020.
- [2] Mauerhofer V. 3-D Sustainability: An approach for priority setting in situations of conflicting interests towards a Sustainable Development. *Ecol Econ*. 2008;64:496-506.
- [3] Elkington J. *Cannibals With Forks: The Triple Bottom Line of 21st Century Business*. London: John Wiley and Sons, 1997.
- [4] Freeman RE. The stakeholder approach revisited. *Zeitschrift Für Wirtschafts Und Unternehmensethik*. 2004;5:28-41.
- [5] Bolis I, Brunoro CM, Szelwar LI. The workers role in knowledge management and sustainability policies. *Work*. 2012;41(SUPPL.):2713-20.
- [6] Bolis I, Brunoro CM, Szelwar LI. Work in corporate sustainability policies: The contribution of ergonomics. *Work*. 2014;49:417-31.
- [7] Zink KJ. *Corporate Sustainability as a Challenge for Comprehensive Management*. Heidelberg: Springer, 2008.
- [8] Thatcher A. Green ergonomics: Definition and scope. *Ergonomics*. 2013;56:389-98.
- [9] García-Acosta G, Saravia Pinilla MH, Romero Larrahondo PA, et al. Ergoecology: Fundamentals of a new multidisciplinary field. *Theor Issues Ergon Sci*. 2014;15:111-33.
- [10] Braungart M, McDonough W, Kälén A, et al. Cradle-to-Cradle Design: Creating Healthy Emissions - A Strategy for Eco-Effective Product and System Design. In: Shamiyeh M (ed) *Creating Desired Futures*. Boston: Birkhäuser, 2012, pp. 247-71.
- [11] García-Acosta G, Lange-Morales K. Beyond Product Life Cycles: An Introduction to Product Sociotechnical Cycles (PstC) as an Alternative for HFE toward Sustainability in Product Design and Development. In: Thatcher A, Zink K, Fischer K (eds), *Human Factors for Sustainability: Theoretical Perspectives and Global Applications*. CRC Press Taylor & Francis Group, 2020, pp. 123-42.
- [12] Attaianesi E. A broader consideration of human factors to enhance sustainable building design. *Work*. 2012;41(S1):2155-9.
- [13] Marano A, Bucchianico G Di, Rossi E. Strategies and arguments of ergonomic design for sustainability. *Work*. 2012;41(S1):3869-73.
- [14] Zink KJ. New IEA human factors and sustainable development technical committee. *HFES Bull*. 2008;51:3-4.
- [15] Radjijev A, Qiu H, Xiong S, et al. Ergonomics and sustainable development in the past two decades (1992-2011): Research trends and how ergonomics can contribute to sustainable development. *Appl Ergon*. 2015;46:67-75.
- [16] Attaianesi E, Duca G. The human component of sustainability: A study for assessing "human performances" of energy efficient construction blocks. *Work*. 2012;41(S1):2141-6.
- [17] Di Bucchianico G, Marano A, Rossi E. Toward a transdisciplinary approach of ergonomic design for sustainability. *Work*. 2012;41(S1):3874-7.
- [18] Haslam R, Waterson P. Ergonomics and sustainability. *Ergonomics*. 2013;56:343-7.
- [19] Dorsey J, Miller L. Green ergonomics. *Work*. 2014;49:345-6.
- [20] Thatcher A, Yeow PHP. Human factors for a sustainable future. *Appl Ergon*. 2016;57:1-7.
- [21] Thatcher A, Yeow PHP. *Ergonomics and human factors for a sustainable future: Current research and future possibilities*. Palgrave Macmillan, 2018.
- [22] Guibourdenche J, Cahour B. Développement durable: Nouvelles perspectives en psychologie ergonomique et ergonomie. *Psychol Fr*. 2019;64:115-8.
- [23] Bolis I, Ribeiro JDC, Sigahi TFAC, et al. Ergonomics/Human Factors and Sustainability: Evolution and Opportunities. In: Black L, Neumann WP, Noy I (eds), *21st Congress of the International Ergonomics Association. Book of extended abstracts – Part 2*. Springer, 2021, pp. 865-7.
- [24] Zink KJ. Designing sustainable work systems: The need for a systems approach. *Appl Ergon*. 2014;45:126-32.
- [25] Bolis I, Morioka SN, Leite WKS, et al. Sustainability is all about values: The challenges of considering moral and benefit values in business model decisions. *Sustain*. 2021;13:664.
- [26] Saravia-Pinilla MH, García-Acosta G, Daza-Beltrán C. A Comprehensive Overview on 'Eco-concepts' Use from Ergoecology Vision. In: Black NL, Neumann WP, Noy I (eds.), *Proceedings of the 21st Congress of the International Ergonomics Association. Vol. II: Inclusive Design*. Springer, 2021, pp. 566-72.
- [27] Brunoro CM, Bolis I, Sigahi TFAC, et al. Defining the meaning of "sustainable work" from activity-centered ergonomics and psychodynamics of Work's perspectives. *Appl Ergon*. 89. Epub ahead of print 2020. DOI: 10.1016/j.apergo.2020.103209.
- [28] Ribeiro JDC, Bolis I. Sustainable work, a relationship between ergonomics and sustainability. In: Black NL, Neumann WP, Noy I (eds), *21st Congress of the International Ergonomics Association. Book of extended abstracts – Part 2*. Springer, 2021, pp. 951-3.
- [29] Bolis I, Brunoro CM, Szelwar LI. Mapping the relationships between work and sustainability and the opportunities for ergonomic action. *Appl Ergon*. 2014;45:1225-39.
- [30] Sigahi TFAC, Kawasaki BC, Bolis I, et al. A systematic review on the impacts of Covid-19 on work: Contributions and a path forward from the perspectives of ergonomics and psychodynamics of work. *Hum Factors Ergon Manuf Serv Ind*. 2021;31:375-88.
- [31] Saravia-Pinilla MH, Ivorra-Peñafort LR. Identifying Sustainability Attributes of Products/Services with Ergoecol-

- ogy. In: Black NL, Neumann WP, Noy I, (eds.) *Proceedings of the 21st Congress of the International Ergonomics Association. Vol. II: Inclusive Design*. Springer, 2021, pp. 560-5.
- [32] Moray N. Ergonomics and the global problems of the twenty-first century. *Ergonomics*. 1995;38:1691-707.
- [33] Wisner A. Understanding problem-building: Ergonomics work analysis. *Ergonomics*. 1995;38:595-605.
- [34] Thatcher A, Waterson P, Todd A, et al. State of Science: Ergonomics and global issues. *Ergonomics*. 2018;61:197-213.
- [35] Sigahi TFAC, Szelwar LI. Restricted and General Complexity in Ergonomics. In: Black NL, Neumann WP, Noy I, (eds.), *Proceedings of the 21st Congress of the International Ergonomics Association. Vol. I: Systems and Macroergonomics*. Springer, 2021, pp. 792-8.
- [36] Elford W, Eggers K. Scaling Micronarrative with Machine Learning to Model Human and Environmental Wellbeing in Macro, Meso and Micro Systems. In: Black NL, Neumann WP, Noy I, (eds.), *Proceedings of the 21st Congress of the International Ergonomics Association. Vol. II: Inclusive Design*. Springer, 2021, pp. 512-20.
- [37] Thatcher A, Yeow PHP. A sustainable system of systems approach: A new HFE paradigm. *Ergonomics*. 2016;59:167-78.
- [38] Reiman A, Jounila H, Kauppila O. Buyer Networking in Supplier HSEQ Development – A Macroergonomics Analysis in a CSR Framework. In: Black NL, Neumann WP, Noy I, (eds.), *Proceedings of the 21st Congress of the International Ergonomics Association. Vol. II: Inclusive Design*. Springer, 2021, pp. 552–559.
- [39] Guibourdenche J. Do user experience time series exhibit complex system properties? In: Black N, Neumann WP, Noy I, (eds.), *Proceedings of the 21st Congress of the International Ergonomics Association. Vol. II: Inclusive Design*. Springer, 2021, pp. 776-9.
- [40] Thatcher A. Uncovering Sustainable System-of-Systems elements in the design of a greywater treatment system for urban informal settlements. In: Black NL, Neumann WP, Noy I, (eds.), *Proceedings of the 21st Congress of the International Ergonomics Association. Vol. II: Inclusive Design*. Springer, 2021, pp. 611-9.
- [41] Thatcher A, Guibourdenche J, Cahour B. Sustainable system-of-systems and francophone activity-centered approaches in ergonomics: Converging and diverging lines of dialogue | Système de systèmes durables et approches francophones centrées sur l'activité en ergonomie: Convergences et divergences. *Psychol Fr*. 2019;64:159-77.
- [42] Fréjus M. Designing sustainable situations. In: Black NL, Neumann WP, Noy I, (eds.), *Proceedings of the 21st Congress of the International Ergonomics Association. Vol. II: Inclusive Design*. Springer, 2021, pp. 521-9.
- [43] Rivetta C, Hu W, Rempel D. Modeling human decisions on Household HVAC system use to improve energy sustainability. In: Black NL, Neumann WP, Noy I, (eds.), *21st Congress of the International Ergonomics Association. Book of extended abstracts – Part 2*. Springer, 2021, pp. 934-6.
- [44] Schrills T, Rosenbusch L, Zoubir M, et al. Supporting interaction with CO2 as a resource with individual carbon footprint trackers as everyday assistants. In: Black NL, Neumann WP, Noy I, (eds.), *Proceedings of the 21st Congress of the International Ergonomics Association. Vol. I: Systems and Macroergonomics*. Springer, 2021, pp. 573-81.
- [45] Arend MG, Franke T. Eco-Drivers and Eco-Automation: A Case Study with Hybrid Electric Vehicle Drivers. In: Black NL, Neumann WP, Noy I, (eds.), *Proceedings of the 21st Congress of the International Ergonomics Association. Vol. II: Inclusive Design*. Springer, 2021, pp. 503-11.
- [46] Thatcher A, Lange-Morales K, García-Acosta G. A Future Ethical Stance for HFE toward Sustainability. In: Thatcher A, Zink KJ, Fischer K, (eds.), *Human Factors for Sustainability: Theoretical Perspectives and Global Applications*. CRC Press, 2020, pp. 51-73.
- [47] Bolis I, Morioka SN, Brunoro CM, et al. The centrality of workers to sustainability based on values: Exploring ergonomics to introduce new rationalities into decision-making processes. *Appl Ergon*. 2020;88:103148.
- [48] Rodrigues de Souza RL, Martins Fontes AR, Camarotto JA, et al. Work process and restrictions related to activities carried out in a waste sorting cooperative. In: Black NL, Neumann WP, Noy I, (eds.), *Proceedings of the 21st Congress of the International Ergonomics Association. Vol. II: Inclusive Design*. Springer, 2021, pp. 603-10.
- [49] Smith EM. The ergonomics of recycling mattresses in Australia. In: Black NL, Neumann WP, Noy I, (eds.), *Proceedings of the 21st Congress of the International Ergonomics Association. Vol. II: Inclusive Design*. Springer, 2021, pp. 582-287.
- [50] Thatcher A, Nayak R, Waterson P. Human factors and ergonomics systems-based tools for understanding and addressing global problems of the twenty-first century. *Ergonomics*. 2020;63:367-77.
- [51] Salmon PM, Stanton NA, Read GJ, et al. From systems ergonomics to global ergonomics: The world as a socio-ecological-technical system. In: *Contemporary Ergonomics and Human Factors. Proceedings of the International Conference on Ergonomics & Human Factors*. Stratford-Upon-Avon, Warwickshire, UK, Vol. 29, 2019.
- [52] Legendre A, Heddad N, Cerf M, et al. Experimenting sustainable orchards: How to cope with different territorial levels? In: Black NL, Neumann WP, Noy I, (eds.), *Proceedings of the 21st Congress of the International Ergonomics Association. Vol. I: Systems and Macroergonomics*. Springer, 2021, pp. 191-5.
- [53] Robert J-M, Béguin P. Reasoning territorial projects through the making of a milieu. In: Black NL, Neumann WP, Noy I, (eds.), *Proceedings of the 21st Congress of the International Ergonomics Association. Vol. I: Systems and Macroergonomics*. Springer, 2021, pp. 265-72.
- [54] Cunha L, Lacomblez M. Territory as a construct of work activity and an operative dispositive for and through action. In: Black NL, Neumann WP, Noy I, (eds.), *Proceedings of the 21st Congress of the International Ergonomics Association. Vol. I: Systems and Macroergonomics*. Springer, 2021, pp. 115-22.
- [55] Boudra L, Souza M, Béguin P, et al. The territorial dimensions of solid waste management systems: A global-local dialectic for sustainable work systems. In: Black NL, Neumann WP, Noy I, (eds.), *Proceedings of the 21st Congress of the International Ergonomics Association. Vol. I: Systems and Macroergonomics*. Springer, 2021, pp. 61-9.
- [56] Fernandes Xavier A, Duarte F, Fernandes Xavier MR, et al. Food well-being: Territory, work and cooperation. In: Black NL, Neumann WP, Noy I, (eds.), *Proceedings of the 21st Congress of the International Ergonomics Association. Vol. I: Systems and Macroergonomics*. Springer, 2021, pp. 329-36.
- [57] Pereira IN, Brufato A, Loureiro F, et al. Situated relational networks: Empowerment and entrepreneurship in

- the Rocinha Slum. In: Black NL, Neumann WP, Noy I, (eds.), *Proceedings of the 21st Congress of the International Ergonomics Association. Vol. I: Systems and Macroergonomics*. Springer, 2021, pp. 240-7.
- [58] Gomes de Lima T, Broberg O, Esteves FA. Co-creation workshops for innovation in places: The role of boundary objects. In: Black NL, Neumann WP, Noy I, (eds.), *Proceedings of the 21st Congress of the International Ergonomics Association. Vol. I: Systems and Macroergonomics*. Springer, 2021, pp. 156-64.
- [59] Lange-Morales K, Thatcher A, García-Acosta G. Towards a sustainable world through human factors and ergonomics: It is all about values. *Ergonomics*. 2014;57:1603-15.
- [60] Le Bail C, Cerf M. Inter-organizational design for sustainable transition in agri-food systems: The case of the Paris-Saclay territory. In: Black NL, Neumann WP, Noy I, (eds.), *Proceedings of the 21st Congress of the International Ergonomics Association. Vol. I: Systems and Macroergonomics*. Springer, 2021, pp. 183-90.
- [61] Lange Morales K, García-Acosta G. From 'human being' to 'social subject': "Unfreezing" ergonomics and the implications for understanding and intervening health-disease process. *Work*. 2012;41:3101-8.
- [62] Polimeni JM, Giampietro M, Mayumi K. Conclusion. In: Polimeni JM, Mayumi K, Giampietro M, et al., (eds.), *The Jevons Paradox and the myth of resource efficiency improvements*. London: Earthscan, 2008, pp. 173-8.
- [63] European Commission. *Industry 5.0: Towards a sustainable, human-centric and resilient European industry*. R&I Paper. Luxembourg: Publications Office of the European Union., 2021.
- [64] Bentley T, Green N, Tappin D, et al. State of science: The future of work—ergonomics and human factors contributions to the field. *Ergonomics*. 2021;64:427-39.
- [65] ILO. More than 60 per cent of the world's employed population are in the informal economy, https://www.ilo.org/global/about-the-ilo/newsroom/news/WCMS_627189/lang-en/index.htm (2021, accessed 22 December 2021).
- [66] Albolino S, Beleffi E, Thatcher A. Ergonomics in a rapidly changing world. *Ergonomics*. 2020;63:241-2.
- [67] Thatcher A. Theoretical Definitions and Models of Sustainable Development that Apply to Human Factors and Ergonomics. In: *Proceedings of the 11th International Symposium on Human Factors in Organisational Design and Management and the 46th Annual Nordic Ergonomics Society Conference*, edited by Broberg O, Fallentin N, Hasle P, Jensen PL, Kabel A, Larsen ME, and TW. 2014.
- [68] Sarbat I, Ozmehmet Tasan S. Ergonomics indicators: A proposal for sustainable process performance measurement in ergonomics. *Ergonomics*. 2021;1-36.
- [69] Bolis I, Morioka SN, Sznclwar LI. Are we making decisions in a sustainable way? A comprehensive literature review about rationalities for sustainable development. *J Clean Prod*. 2017;145:310-22.
- [70] Bolis I, Morioka SN, Sznclwar LILI. When sustainable development risks losing its meaning. Delimiting the concept with a comprehensive literature review and a conceptual model. *J Clean Prod*. 2014;83:7-20.