

Research Synergies between Sustainability and Human-Centered Design

Subjects: Ergonomics

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There are several topics being addressed in the intersection areas linking human-centered design (HCD) and sustainability, and this introduces an innovative array of opportunities for the design research community. Findings demonstrated that the complexity of issues related to sustainability has stimulated the research community in the development of a multitude of design visions and approaches that go beyond the mere consideration of environmental features. Indeed, a huge sample of works have clearly showed the interest in connecting the social, economic, and cultural aspects of sustainability and the need to progress the theoretical debates with practical experimentations. Together, these behaviors contribute to the increase in best practices.

Keywords: sustainability ; human-centered design ; research synergies ; research trends ; sustainable development goals

1. Introduction

In the contemporary context of global debates on environmental and socio-economic issues, both design and Human Factors and Ergonomics (HFE) communities have sought to identify the links between sustainability and human-centered design (HCD) ^[1]. This is reflected in the production of a significant number of studies dealing with aspects that are paramount for all scales of intervention, both macro and micro, tangible and intangible. However, despite the wide number of studies and experimentations produced, no noteworthy work made was able to properly explain disciplinary and interdisciplinary research links between these areas.

Since the publication of the Brundtland Report ^[2], and later developments made from it ^{[3][4]}, the term 'Sustainable Development' became popular across many scientific communities. In design studies, the idea of sustainability was used to put the accent on the ecological, economic, and social features of designable artefacts and more broadly on the implication of the work performed by designers in making sustainable solutions ^[5]. In recent years, HCD has become a popular design methodology to address the hierarchy of human needs ^[6]. HCD helps designers to develop eco-friendly and inclusive solutions while trying to serve both customers and society. According to Giacomini ^[7], HCD has its roots in disciplines like HFE, Computer Science, and Artificial Intelligence. It is a strategy that places a focus on the 'human element' of designs and ensures that users of goods or services are involved in their creation—i.e., co-design. Furthermore, ISO ^[8] defines HCD as 'an approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying HFE and usability knowledge and techniques'.

In the scenario of transition toward more sustainable and inclusive ways of living, the design communities working within the HFE domain have naturally and intuitively operated to match the conversations around the planet's future with the need to make solutions that are enjoyable and useable by all users ^[9]. Whilst international organizations worked to lessen their harmful effects on the environment, they have also understood how crucial it is to develop solutions that benefit all parties involved ^[10]. Particularly, it has been recognized that new generations of sustainable and human-centered artefacts are essential to help society make the necessary transition to more conscious ways of living and consuming the available resources ^[11]. It has been stated that HCD may play a crucial role in stimulating and supporting the transition toward the creation of sustainable artefacts (i.e., products, services, systems of solutions, buildings, city areas, etc.). Consequently, HCD-related pushes have changed because of mounting knowledge that designs that do not consider effects on people frequently have detrimental social effects, such as increased health risks, environmental damage, and economic losses.

The scenario of synergies between sustainability and HCD is particularly interesting in terms of research methodologies and analysis of both cultural and design implications ^[12]. This phenomenon seems to be crucial when compared with the official definition of HFE endorsed by the International Ergonomics Association, where it is stated that 'HFE works at the holistic interaction between human behaviours, innovative design techniques, and the sustainability of the environments in

which actions are performed' ^[13]. Thus, when integrated into a design domain, or a scenario, HFE and sustainability express shared goals, interests, and values ^[14], and it is widely acknowledged that humans who operate informed actions through designed systems of solutions within defined contexts of use are an important factor to consider ^[15].

2. Research Synergies between Sustainability and Human-Centered Design

2.1. Main Research Topics Linking Sustainability and HCD

2.1.1. Design Research Methods for Sustainability

Articles in the first cluster indicate that sustainability influences the quality of design research methods used to develop HCD-related solutions and in general studies around such topic. Studies in this cluster reflect the interest in developing original insights linking procedural methods and tools to tackle the complexity of sustainability as well as transposing it at the participatory and learning dimensions. Specifically, the thirty articles composing this cluster are further organized into two sub-clusters described as follows.

The sub-cluster entitled 'Participatory design processes for sustainable interventions' points out the attention on the value of design process at the community level, underlining the importance of adopting co-design processes to lead sustainable transformations that are paramount to reshape processes and practices to integrate sustainability within HCD intervention. Articles in this sub-cluster identify four main research lines:

- A small set of studies discuss the impact of sustainability and HCD in terms of the design process, dealing with issues related to collaboration ^[16] and the role of the design process for the built and social environment, e.g., ^[17].
- A significant group of works discuss the contribution of sustainability and HCD in terms of design thinking, discussing university–industry collaborations ^[18], its impact on health-related issues, innovative methodologies, e.g., ^[19], and new cultural impacts ^[20].
- An interesting group of studies focus on co-design, mainly in terms of contribution of universities to SDGs ^[21] and generation of smart sustainable communities ^[22].
- Finally, articles discussing the value of participation, e.g., ^[23], examine the contribution of bottom-up long-lasting design processes in increasing the quality of life of rural communities.

The sub-cluster entitled 'Pedagogical and research aspects for sustainable interventions' mainly gathers articles and experimental projects dealing with design research and design education. Here, the attention revolves around the implications of sustainability and HCD on teaching and learning (T&L) contexts and their use to progress the cultural and pedagogical debates around the creation of sustainable human-centered solutions. Articles in this sub-cluster discuss two main themes:

- Design research methods to improve HCD artefacts through sustainability-led angles at product ^[24], procedural ^[25], and scenario levels ^[26].
- Disciplinary and interdisciplinary issues related to design education. Articles grouped under this theme discuss the T&L pathways toward sustainability, the development of skills to tackle the complex scenarios related to it ^[27], experiments made to develop educational programs, innovative methods for aware teachings ^[28], and general reflections on the social side of design for sustainability, e.g., ^[29].

2.1.2. Health for a Sustainable Society

Articles in the second cluster raise attention to the interplay between sustainability and health in its broader sense, and the role played by human-centered solutions in qualitatively (perception of the change) and quantitatively (measurable efforts) increasing the people's wellbeing under given contextual circumstances. Accordingly, studies in this cluster show contributions at multiple intervention levels (i.e., child health, mental health, social health, etc.) as well as smart design interventions developed to face emerging issues. The twenty articles grouped in this cluster are organized into two sub-clusters.

The sub-cluster entitled 'The dimensions of health in the sustainable society' gathers work from multiple disciplinary fields discussing the contribution of HCD on sectorial experiments and narrowed thematic studies involving health and its relationship with sustainability; this group of works clearly identifies health as one of the driving topics to implement

suitable levels of sustainable development within small- and large-scale communities as well as a research foci. The attention is therefore addressed in three main research lines:

- Studies connecting health with HFE domain, where the attention is mainly focused on healthcare systems, e.g., [30], and on the design of ergonomically coherent solutions for health.
- How health is mirrored in the mental, child, and public dimensions, e.g., [31], and then how the design of health-oriented solutions contributes to foresee wealthy scenarios where people can live better and longer [32].
- Another group of works analyses the contribution of health research in two research trajectories. The first one discusses design-led principles and research methods for the development of technology-led solutions for health [33], including services and toolkits [34], whilst the second one deals with creative methods for improving the adoption of health systems [35].

The sub-cluster entitled 'New issues on health and wellbeing' focuses on the emerging topics for health influencing the quality of life of people from the health point of view and that have direct links with sustainability and HCD. Alongside traditional health-related issues, this group of studies only considers those recent phenomena that impact at the social and relational levels and for which only an integrated contribution of sustainable human-centered solutions is able to mitigate the negative effects for human health. Studies in this sub-cluster discuss:

- The contribution of HCD in the development of smart age-friendly solutions, e.g., [36], seen as a media to improve the sustainable quality of life of elderly people, which ultimately mirrors a better life for all users.
- The role of HCD in the design of solutions for contemporary health issues, such as COVID-19 [37], or the quality of life of users through participatory design processes and behavioral techniques [38].

2.1.3. Technological Contexts for Sustainable Innovations

Articles in the third cluster explore the relationship between technology and production systems to generate sustainable innovations impacting both design and industrial contexts where innovations are naturally produced. At a general level, studies in this cluster focus on the top-down innovation dealing with the implementation of technological pushes to produce consistent human-centered sustainable applications. Works grouped in this cluster discuss both the technological side of sustainable innovation and the contextual features surrounding the correct implementation of HCD-related advances. Specifically, the twenty articles composing this cluster are further organized into two sub-clusters described as follows.

The sub-cluster entitled 'Use of enabling technologies for sustainable innovation' gathers original studies discussing the impact of sustainability and HCD on the side of technological innovation, which includes technology-led emerging trends and end-of-pipe innovations. Therefore, articles in this sub-cluster identify four main research lines:

- Four studies discuss the technological advances for human-centered sustainability in the industry sector and point out the attention on data management, sustainable manufacturing, e.g., [39], and simulation and services.
- The contribution of ICTs is discussed by a group of three studies that have a direct connection with design studies: specifically, the role of ICTs in the creation of HCD services for modern urban communities, and local–global applications, e.g., [40][41].
- AR/VR technologies are generally discussed in relation to process design, which comprises educational contexts for sustainable design [42], and the design of vehicles, e.g., [43].
- Finally, the theme of innovation in large-scale industrial contexts is discussed in four studies, e.g., [44], which point out the relevance of HCD and sustainability to mitigate organizational and strategic risks.

On the impact of sustainability and HCD in industry, the sub-cluster entitled 'Sustainable industrial contexts' describes the implication of studies on sustainability and HCD mainly in two industrial sectors: Industry 4.0 and Industry 5.0. Specifically:

- Studies around Industry 4.0 generally discuss the contribution of HCD to a wide spectrum of sustainable applications, such as workstations [45], workers' wellbeing, IoT [46], as well as new design research lines.
- The Industry 5.0 paradigm is discussed in two interesting publications that introduce relevant insights for the HCD dimension of industrial production, with a particular emphasis on the human–machine teamwork [47] and user

experience models ^[48].

2.1.4. Design of Sustainable Artefacts

Articles included in the fourth cluster debate the implementation of sustainability and HCD at different design levels, discussing both practical experimentations at product, service, and system design levels, as well as built environment, smart cities, and community design. Overall, works in this cluster portray a wide range of explorations performed by the design community on different themes surrounding the combination of sustainability and HCD, with particular emphasis on the sides related to 'making sustainable human-centered innovation in place'. Accordingly, studies in this cluster reflect the interest of the scientific community to develop original solutions as an informed action to look at future scenarios of originality and competitiveness. The thirty-five articles composing this cluster are organized into three sub-clusters described as follows.

The sub-cluster entitled 'Design of sustainable product-service systems' portrays original studies on product and service innovation, where the sustainable qualities of designed artefacts are balanced by novel human-centered features bringing people and designers closer through informed design processes. Consistently, studies included in this sub-cluster allow the identification of the following two main research lines:

- Sustainable product design, helping people to live better and healthier ^[49], or in a re-imagined sustainable urban environment ^[50].
- Sustainable service design, bridging user experience, transformative design, and environmental performance, e.g., ^[51].

The sub-cluster 'Sustainable spatial design' gathers a significant portion of studies of this cluster and discusses the contribution of sustainability and HCD in the spatial design dimension, such as urban planning. This sub-cluster emphasizes the human-spatial interaction and the need to develop original solutions helping people live in 'sustainable harmony' within the environment where they perform actions. Three main research lines can be identified:

- The concept of a smart city and its implication on the definition of sustainable living conditions are widely examined in a group of studies that discuss geographical issues, the role of technologies, e.g., ^{[52][53]}, ethics, and best practices to adopt, e.g., ^[54].
- Urban planning is another relevant topic discussed by seven papers. The attention of the research community is focused on the idea of sustainable regeneration ^[55], the role of placemaking and design processes, the interventions at a human scale, and business models related to planning practices, e.g., ^[56].
- The last concept discussed in this sub-cluster portrays a subset of studies and design experimentations widely referring to the design of the built environment. Studies in this group discuss the relevance of wellbeing in building design and dwellings, e.g., ^[57], innovative ecological approaches to sustainable design, e.g., ^[58], research frameworks ^[59], and technical issues.

The sub-cluster entitled 'Sustainable design for inclusion' identifies an emerging set of studies discussing the contemporary social aspects of the HCD in relation to sustainability—i.e., social sustainability. Specifically, studies in this sub-cluster define two main research trajectories:

- User experience design, in its wider notion ^[60].
- Inclusive design, at the spatio-social ^[61] and demographic dimensions.

2.1.5. Transition Studies and Socio-Economic Sustainability

The articles included in the fifth cluster depict an interesting perspective for studies on sustainability and HCD, because the attention of the design community addresses socio-technical innovations impacting the quality of life of people in the system and systemic dimensions. Accordingly, studies in this cluster mirror the contemporary research trends belonging to design for sustainability and design for social innovation, dealing with the application of economic models within circular patterns and the investigations of social pushes when spontaneous forms of community innovations can flourish. Specifically, seventeen articles included in this cluster define two main sub-clusters described as follows.

The sub-cluster entitled 'Circular models' identifies articles implementing sustainability and HCD at the level of system innovation, underlining the relevance of aware business models for the societal and socio-technical transformation. Accordingly, studies included in this sub-cluster allow for the identification of the following two main research lines:

- Models for circular economy depicting innovative strategies to 'regenerate' the quality of living and productive contexts, e.g., [62][63].
- A small group of studies discusses the value of generating sustainable business models positively impacting the quality of living contexts, which ultimately reflect an increase in social sustainability within SMEs, e.g., [64], and communities, e.g., [65].

The sub-cluster entitled 'Elements of social innovation' systematizes a subset of emerging studies discussing societal issues that have a direct impact on human life, both in terms of ecosystemic implications and use of human legacy to trigger societal innovations. Studies included in this sub-cluster define the following two main research lines:

- Studies on how to develop intelligent solutions to tackle energy challenges, e.g., [66].
- Speculative studies and experimentations related to social innovation, e.g., [67].

2.2. Interpretative Framework of Studies Linking Sustainability and HCD

Figure 1 shows a graphical representation of articles considered and distributed along two axes, to provide a qualitative interpretation of works and their relationships with both the fields of design intervention (horizontal axis) and the domains of sustainability (vertical axis). **Figure 1** also suggests qualitative considerations in relation to future design-led research trajectories linking sustainability and HCD.

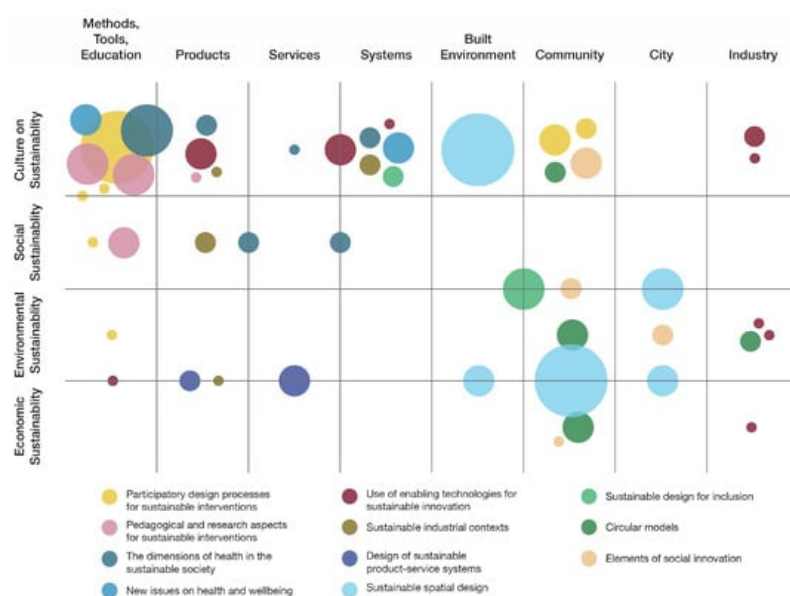


Figure 1. Interpretative framework of studies linking sustainability and HCD.

2.2.1. Considerations Based on Fields of Design Intervention

Methods, tools, and aspects related to education generate an important impact in terms of culture on sustainability. This aspect was somewhat predictable as a large group of studies discuss new methods and aspects aimed at improving the understanding of sustainability at different design scales [20].

Only a few studies consider sustainable products and services, and this aspect seems to be related to the fact that this macro-area is mainly tackled through disciplinary interventions dealing with either design for sustainability or HCD, where the corpus of methods is more consolidated [51]. This is also reinforced by the fact that the attention of designers and researchers is traditionally oriented on problem-solving practices that less consider interdisciplinary aspects coming from, for example, transition studies. Further developments in these areas are needed to advance HCD at the social, environmental, and economic levels. Developments in the design of sustainable and HCD systems are needed to properly explore social, economic, and environmental issues.

The area of built environment produces two interesting data observations: there is a significant cultural contribution in terms of theoretical and methodological studies [59][68], which is not counterbalanced by an equally high number of experimentations; only a few studies propose advances at the intersection between environmental and social sustainability [57]. As per product and service design, it can be deduced that this area excels in dealing with narrowed technical issues, whilst it lacks more holist experimentations.

Studies on community design, urban planning, and city design reveal an interesting portrait of research dynamics. Specifically, studies related to the design in/for communities extensively cover many topics of sustainability, with an interesting emphasis on environment and economy. This aspect is a natural consequence of studies on social innovation [69][70][71], where ecological living qualities are linked to economic patterns to generate positive sustainable discontinuities in the ways of living [72]. Cultural progresses are discussed by a significant group of studies, proving that a theoretical and methodological apparatus is needed to face complex scenarios at the macro-scale of intervention.

Finally, the industrial sector shows a predictable result about environmental sustainability, as it directly mirrors the relevance expressed by companies and industries on the development of sustainable interventions.

2.2.2. Considerations Based on Domains of Sustainability

The cultural relevance of topics related to sustainability and HCD, although not always directly identifiable, is a sensitive topic across many research communities, e.g., [20][24]. Interestingly, a big push comes from system design, design of the built environment, and community design areas. This can be intended as an important aspect for studies linking sustainability and HCD, which mirror the evolution of the culture of sustainable innovation from the product design domain to the design of community effects, which is to say, from solving problems to looking for opportunities for a sustainable change [23].

Social sustainability is mainly discussed at the product and service design levels. This seems to be in contrast with what stated before about the design in/for communities and the one related to city and urban planning; however, a possible justification of this can be found in the analysis of works linked to this area (i.e., studies on health), which really tries to link sustainability and HCD. It also seems that the research community does not consider products and services as valuable solutions to tackle the social issues, whilst communities and cities could offer more interesting testing grounds to assess the social improvements resulting from design experimentations, though now only in connection with environmental sustainability, which ultimately would suggest dealing with this area through a socio-environmental mixed lens.

Environmental sustainability is generally discussed within communities and cities [54], where the environmental issues relate to both social dynamics and economic aspects. Considering the tradition of studies within design for sustainability, this aspect echoes the design for social innovation aspects linking communities that use sustainable artefacts to generate innovations in the spatio-social and socio-economic dimensions. From one side, this analysis reveals the need to continue investing in this area; from the other side, more studies at the level of products and services could lead toward a new generation of sustainable and human-centered solutions for communities.

Finally, economic sustainability is mainly discussed at the community level, and this result was somewhat predictable due to the discussions provided before. The research community seems interested in investigating the value of spatial relationships as future testing ground for complex experimentations linking sustainability and HCD.

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