Review

Research Synergies between Sustainability and Human-Centered Design: A Systematic Literature Review

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Abstract: A significant number of publications demonstrate the growing interest in connecting studies on sustainability with HCD-related interventions, though a complete analysis of all endogenous and exogenous dynamics of research lines currently developed has never been made. A study depicting the main cross-sectoral results developed in the recent years would help researchers in design-related areas to improve sustainable design processes and practices, as well as the knowledge needed to identify the unexplored research niches to focus on in the future to produce non-redundant advances toward sustainability's goals. A systematic literature review of a sample of 122 works allowed us to identify and describe the main themes within this integrated research area and to provide future research trajectories for applied research and practice on sustainable HCD connected to the SDGs. Data found in this work show that studies linking sustainability and HCD produced a complex research framework mainly articulated into four principal design areas: (i) health and wealth, (ii) education, (iii) industrial innovation, and (iv) built environment and living communities. Finally, this study provides designers and researchers working in the HFE and sustainable design macro-domains an overview of the current and future trends where research synergies between sustainability and HCD are likely to develop.

Keywords: sustainability; human-centered design; systematic literature review; 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 Giacomin [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]. As a result, a clear interdependency between sustainability and HCD can be observed. Therefore, while both the design and the HFE communities continue in performing studies merging both disciplinary areas, a complete review of studies made by the research community around the dynamics that regulate the links between sustainability and HCD would be helpful to map all available knowledge in the field. Necessary topics to clarify are, for instance, what has been conducted so far, what worked well, past and present dynamics, as well as what can be conducted in the future to strengthen the possible contributions that can be developed in this emerging interdisciplinary research area.

It must be noted that only recently has the HFE community formally expressed the need to map the contributions of sustainability into HFE [16,17], though a cultural interest was always expressed [18]. However, studies specifically voting to explore the links between sustainability and HCD do not exist, although the HFE research community has clearly shown a natural interest to operate in a design-led way [16].

In order to develop meaningful and sustainable products and services, as well as to provide guidance to researchers and designers interested in developing novel artefacts that are both sustainable and human-centered, this study will examine the interactions between the notions of sustainability and HCD at the scientific level. The primary goal is to present the first and most comprehensive overview of main studies that explicitly or implicitly link sustainability to human factors and human capital development, and vice versa. This paper will give a thorough grasp of the connections between sustainability and HCD by a detailed analysis of the main extant literature in the topic performed using bibliometric methodologies. Accordingly, this work intends to pursue two primary research objectives: RO1, identifying the main literature published in the last years (circa twenty years) linking sustainability and HCD, and RO2, inferring and outlining future design-led research trajectories linking sustainability and HCD.

2. Materials and Methods

A systematic review of the literature [19] to understand the links between sustainability and HCD was conducted using PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [20]. Two methods were employed: (i) search of documents within bibliographic databases (Section 2.1) and (ii) visualization of bibliometric networks (Section 2.2).

2.1. Main Research Topics Linking Sustainability and HCD

The search of relevant documents was performed in late 2022 using the Scopus database. Scopus was preferred to other sources like WoS (Web of Science) for its completeness and authority [21], and because it provided a more complete set of results in relation to sustainability and HCD. Initial iterations conducted via WoS using equivalent search queries related to sustainability and HCD revealed that WoS provided a lower number of records. Therefore, Scopus was objectively preferred for numerical reasons. However, all papers later included in this study are also accessible and citable via WoS. The Scopus search was conducted using a specific search query: ((TITLE-ABS-KEY (sustainab*) AND TITLE-ABS-KEY ("human centred design") OR TITLE-ABS-KEY ("human-centred design") OR TITLE-ABS-KEY ("human centered design") OR TITLE-ABS-KEY ("human-centered design") OR TITLE-ABS-KEY ("human centred") OR TITLE-ABS-KEY ("human-centred") OR TITLE-ABS-KEY ("human centered") OR TITLE-ABS-KEY ("human-centered") OR TITLE-ABS-KEY (hcd)) AND (LIMIT-TO(DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re") OR LIMIT-TO (DOCTYPE, "English")). The query identified a first sample of 313 documents pairing sustainability and HCD, with different semantic interpretations. This searching strategy provided a complete set of records from which to start bibliographic analyses. Consistent with the aim to provide the most impartial picture of studies in this research area, the analysis was restricted to only journal articles and reviews.

To create the final sample, every document was meticulously examined to isolate only the ones that demonstrated a connection with this work's aim. As a result, the criteria for inclusion demanded that an essay shows a clear connection between HCD and sustainability and presents a contribution to both fields. The PRISMA screening technique [22] (Figure 1) was used to identify the final sample of works to include in the analysis. To determine eligibility, researchers independently reviewed all documents; later, they compared their evaluations of each article and arbitrated any disagreements iteratively by consensus. Particular attention was also paid to the analysis of studies published in 2022 because works published in this period were often available in the form of pre-print, such as unpublished works, works awaiting editorial assignations, open papers, etc. To comply with the PRISMA [22], these works were assessed before the inclusion. Overall, a sample of 122 studies was obtained at the end of the screening.
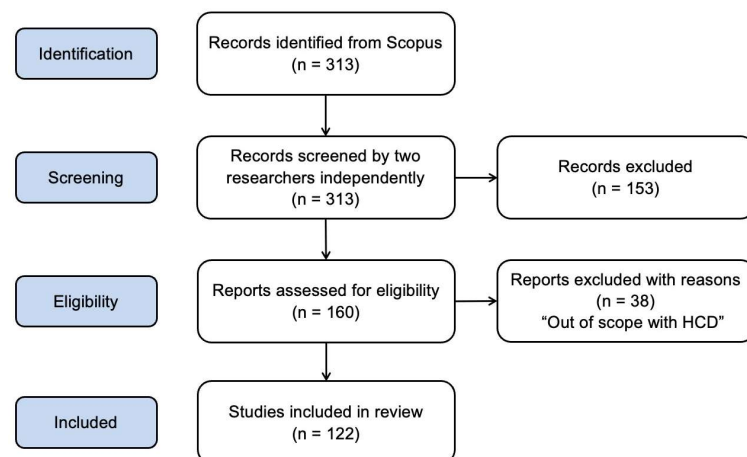
Figure 1. PRISMA Protocol: Screening procedure and sample of works included in the study.

2.2. Network Visualization and Data Refinement

Mixed methodologies were used to accomplish the primary research goal of understanding and critically assessing the contributions of sustainability to the wider concept of HCD, and related sub-design domains, through the literature review.

To conduct this, the network analysis software VOSviewer (Version 1.6.19) [23,24] provided help for the quantitative side of the study by allowing the extraction of data from the studied literature through visual representations. The use of VOSviewer was preferred to others due to the possibility to use bibliographic data to generate visual maps showing thematic links and research clusters to be used to visualize similarities (i.e., co-occurrence network). Furthermore, VOSviewer also allows researchers to visually identify explicit and hidden relationships between research topics. Finally, datasheets in electronic form were used to support the qualitative investigations.

To address the RO1, this study was conducted in three stages, described as follows. Using VOSviewer and the authors' keywords, a co-occurrence network analysis was carried out in the first phase. Although data produced by co-occurrence network analysis might generate some biased interpretations, for the aim of this work, this technique was useful to identify thematic clusters grouping certain sub-design topics. Thus, this co-occurrence network found seven groupings of co-occurring terms. In the second stage, articles from the seven categories were analyzed to determine the key themes for each group. In the third stage, researchers grouped these themes into distinct clusters based on how similar their contents were. Eleven sub-clusters were created to provide completeness and characterization, and they were categorized as clusters and sub-clusters, lowering the total number of clusters from seven to five. To assure the highest level of impartiality and data congruity, both authors controlled this interpolation. The results of the systematic literature review linking sustainability and HCD were therefore based on the third phase.

Two methods were employed to fulfil the RO2. Firstly, clusters and sub-clusters identified from data produced to achieve RO1 were used to determine the overall prospects for study and practice linking sustainability to HCD. Secondly, to find new application areas, papers from the systematic literature review were compared with the Sustainable Development Goals (SDGs) of the United Nations [25] to identify significant themes that are predominant in this emerging study niche and to provide critical comments to identified research trends. This part was also performed with the aim to provide analytical guidance to both designers and researchers operating at the intersection between sustainability and HCD, to address future research lines.

3. Results

Research results discussed in this section follow the operational and methodological setting proposed in Section 2 of this work and provide answers to both ROs stated in Section 1. Specifically, data concerning RO1 are discussed in Sections 3.1 and 3.2, whilst evidence confuting RO2 is discussed in Section 4.

3.1. Main Research Topics Linking Sustainability and HCD

The co-occurrence network produced by VOSviewer (Figure 2) led to the seven groupings characterized by different colors. The analysis only considers authors' keywords that were utilized by two or more papers, to provide a sufficient number of items in relation only to keywords that were relevant for studies considered. Because 'Sustainability' and 'HCD' were used as primary search terms to find the sample of papers, they were removed from the interpolation to prevent interpretative biases in the network's creation. Additionally, a thesaurus was developed to combine recurrent words with the same meaning but various spellings (e.g., 'Sustainability' versus 'sustainable development', or 'HCD' rather than 'human centered design' or 'human-centered design', etc., which basically depict the same concept though authors often use them interchangeably).
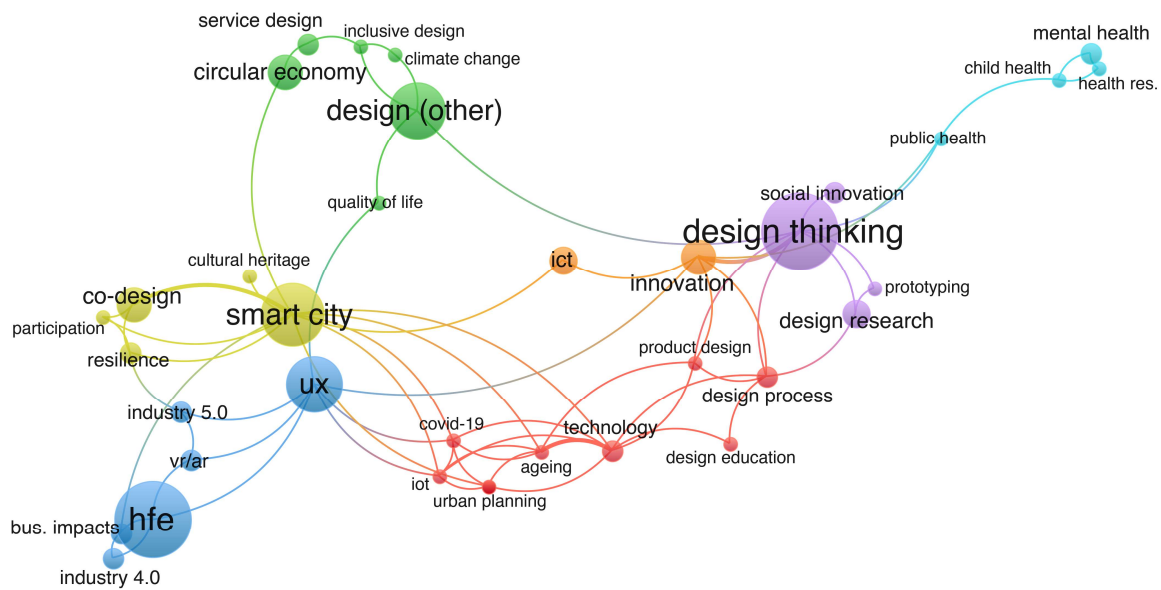
Figure 2. Co-occurrence network of authors' keywords generated through VOSviewer software (using a thesaurus).

According to the process outlined above, Table 1 lists the frequency (in parentheses) of each grouping's keywords.

Table 1. Groups of keywords extracted from VOSviewer: Co-occurrence network [1].

Groups	Keywords
Red	Design process (3), Technology (3), Ageing (2), COVID-19 (2), Design education (2), IoT (2), Product design (2), Urban planning (2)
Green	Design (other) (8), Circular economy (5), Service design (3), Climate change (2), Inclusive design (2), Quality of life (2)
Dark Blue	HF/E (11), UX design (8), Business impacts (3), Industry 4.0 (3), Industry 5.0 (3), VR/AR (3)
Yellow	Smart city (9), Co-design (5), Resilience (3), Cultural heritage (2), Participation (2)
Purple	Design thinking (11), Design research (4), Social innovation (3), Prototyping (2)
Light Blue	Mental health (3), Child health (2), Health research (2), Public health (2)
Orange	Innovation (5), ICT (4)

[1] Numbers indicate the intensity of co-occurrence found for each keyword included in the network (using a thesaurus).

It must be acknowledged that the use of keywords may result in two inherent biases for the interpretation of the works considered, and this drove the authors to conduct a second data refinement to maintain the highest scientific level of analysis possible. Specifically, the first bias relates to the type of keywords chosen by authors, which frequently reflect primary and secondary scopes in positioning the investigations regarding the paper's objectives and the aim of studies. Secondly, it is well known that journals frequently offer condensed collections of key words to choose from, which ultimately leads to the adaption of the nature of papers to promotion practices. A thorough content analysis was carried out using the data in Table 1 to overcome these biases and achieve the goal of the study. This analysis allowed the information that was individually extracted from each article to be reframed into five main clusters and eleven sub-clusters, which are synthetically presented in Table 2 and are extensively discussed below and in Section 4.

Table 2. New clusters and sub-clusters identified.

Clusters	Sub-Clusters
1. Design research methods for sustainability	1.1. Pedagogical and research aspects for sustainable interventions 1.2. Design research methods for sustainability
2. Health for a sustainable society	2.1. The dimensions of health in the sustainable society 2.2. New issues on health and wellbeing
3. Technological contexts for sustainable innovations	3.1. Use of enabling technologies for sustainable innovation 3.2. Sustainable industrial contexts
4. Design of sustainable artefacts	4.1. Design of sustainable product-service systems 4.2. Sustainable spatial design 4.3. Sustainable design for inclusion
5. Transition studies and socio-economic sustainability	5.1. Circular models 5.2. Elements of social innovation

3.1.1. 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 [26] and the role of the design process for the built and social environment, e.g., [27].
- A significant group of works discuss the contribution of sustainability and HCD in terms of design thinking, discussing university–industry collaborations [28], its impact on health-related issues, innovative methodologies, e.g., [29], and new cultural impacts [30].
- An interesting group of studies focus on co-design, mainly in terms of contribution of universities to SDGs [31] and generation of smart sustainable communities [32].
- Finally, articles discussing the value of participation, e.g., [33], 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 [34], procedural [35], and scenario levels [36].
- 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 [37], experiments made to develop educational programs, innovative methods for aware teachings [38], and general reflections on the social side of design for sustainability, e.g., [39].

3.1.2. 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., [40], and on the design of ergonomically coherent solutions for health.
- How health is mirrored in the mental, child, and public dimensions, e.g., [41], and then how the design of health-oriented solutions contributes to foresee wealthy scenarios where people can live better and longer [42].
- 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 [43], including services and toolkits [44], whilst the second one deals with creative methods for improving the adoption of health systems [45].

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., [46], 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 [47], or the quality of life of users through participatory design processes and behavioral techniques [48].

3.1.3. 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., [49], 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., [50,51].
- AR/VR technologies are generally discussed in relation to process design, which comprises educational contexts for sustainable design [52], and the design of vehicles, e.g., [53].
- Finally, the theme of innovation in large-scale industrial contexts is discussed in four studies, e.g., [54], 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 [55], workers' wellbeing, IoT [56], 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 [57] and user experience models [58].

3.1.4. 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 [59], or in a re-imagined sustainable urban environment [60].
- Sustainable service design, bridging user experience, transformative design, and environmental performance, e.g., [61].

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., [62,63], ethics, and best practices to adopt, e.g., [64].
- Urban planning is another relevant topic discussed by seven papers. The attention of the research community is focused on the idea of sustainable regeneration [65], the role of placemaking and design processes, the interventions at a human scale, and business models related to planning practices, e.g., [66].
- 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., [67], innovative ecological approaches to sustainable design, e.g., [68], research frameworks [69], 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 [70].
- Inclusive design, at the spatio-social [71] and demographic dimensions.

3.1.5. 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., [72,73].
- 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., [74], and communities, e.g., [75].

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., [76].
- Speculative studies and experimentations related to social innovation, e.g., [77].

3.2. Interpretative Framework of Studies Linking Sustainability and HCD

Figure 3 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 3 also suggests qualitative considerations (see Sections 3.2.1 and 3.2.2) in relation to RO1, which are later used to discuss the achievement of RO2.
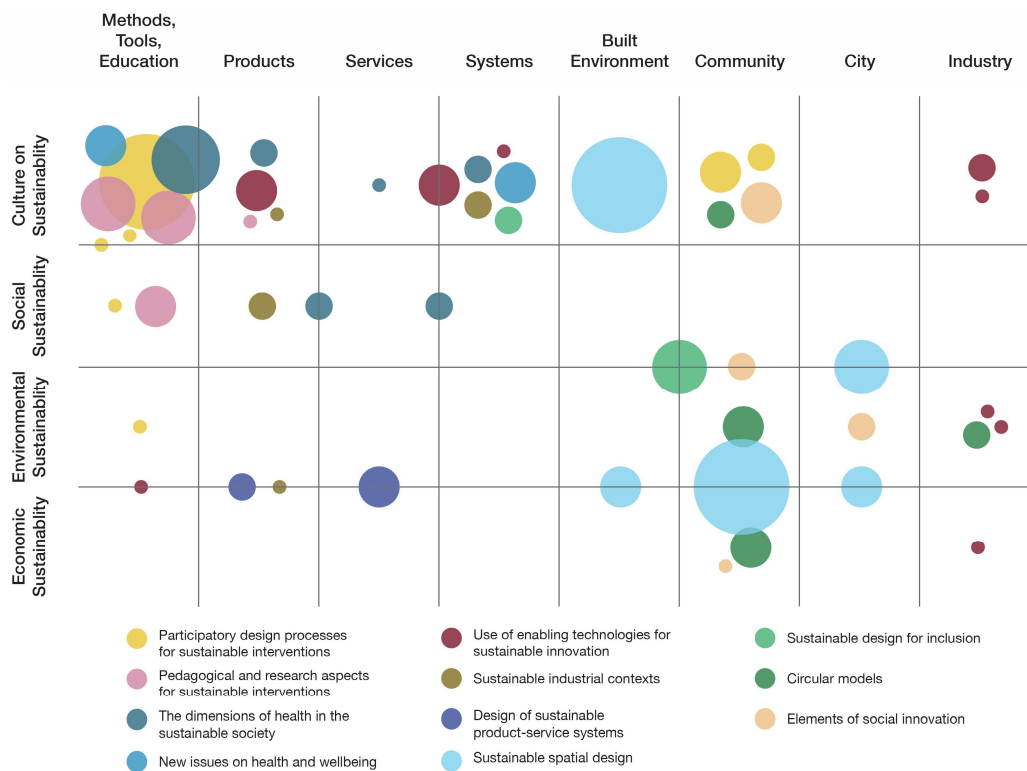
Figure 3. Interpretative framework of studies linking sustainability and HCD.

3.2.1. 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 [30].

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 [61]. 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 [69,78], 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 [67]. 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 [79–81], where ecological living qualities are linked to economic patterns to generate positive sustainable discontinuities in the ways of living [82]. 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.

3.2.2. Considerations Based on Domains of Sustainability

Data presented in this work allow us to clearly affirm that the culture of sustainability is one of the main parameters for many studies, both in terms of reflections on how to progress the corpus of methods and tools and in terms of cultural speculations used to trigger themed developments at the economic, environmental, and social levels. 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., [30,34]. 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 [33].

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 [64], 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.

4. Discussion

Consistent with the data discussed in Section 3, this part proposes a themed discussion on some future design research trajectories linking sustainability and HCD, which consider emerging trends for the potential 'Sustainable HCD' research field. Specifically, the sample of studies are linked to the Sustainable Development Goals (SDGs) of the United Nations [25] (see Section 4.1.) to accomplish RO2 (see Section 4.2.).

In relation to links with the SDGs, the aim of the qualitative analysis shown in Section 4.1. is to demonstrate hidden and apparent interdependencies between studies developed by the design community at the cultural, environmental, social, and economic level and the targets of the UN [25]. At the basis of this correlation is the will to show clearly where the attention of researchers is concentrated and what perspectives can be opened in terms of cultural development and progressions (see Section 4.2.)—c.f. [12].

4.1. Discussion of Studies in Relation to Sustainable Development Goals

Directly and indirectly, the results discussed in the whole of Section 3 show the current picture of works produced in the last twenty years linking sustainability and HCD, which were grouped into themed design-related clusters. However, the analysis has indirectly revealed hidden connections with the SDGs. Although this was somewhat predictable, it was frequently found that given studies clustered in a specific area were tied to multiple SDGs. For example, studies grouped in cluster 5 are linked to profoundly different SDGs, such as SDGs 2, 7, 8, 10, 11, 12, 14, and 15. The nature of this aspect can probably be found in the interdisciplinarity of design studies when related to the multidimensional aspects of sustainability, which requires researchers to adopt goal-oriented lenses to properly deal with the UN visions [3,4] rather than monodisciplinary strategies.

To provide better interpretations to findings discussed in Section 3, it seemed important to provide qualitative evidence of the distribution of studies considered and their adherence with the targets connotating the UN visions [3,4]. In particular, the sample of 122 studies considered for this work has been linked to all SDGs. The classification followed an analytical process described as follows:

- Studies were considered for their role to identify one or more SDG targets. In case of multiple matches, authors arbitrated on the best classification—see RO2.
- A visual map was created to show the correlations between sub-clusters and the SDGs. Distribution, magnitude, and relevance for interdisciplinary developments were also considered.

Figure 4 contains the sample of 122 studies distributed along two axes: the horizontal axis portrays the seventeen SDGs, and the vertical axis shows the eleven sub-clusters (see Section 3.1). Figure 4 helps to qualitatively assess the distribution of studies linking sustainability and HCD in relation to the achievement of specific SDGs, also showing direct and indirect priorities in terms of usefulness and the impact of research efforts on society.
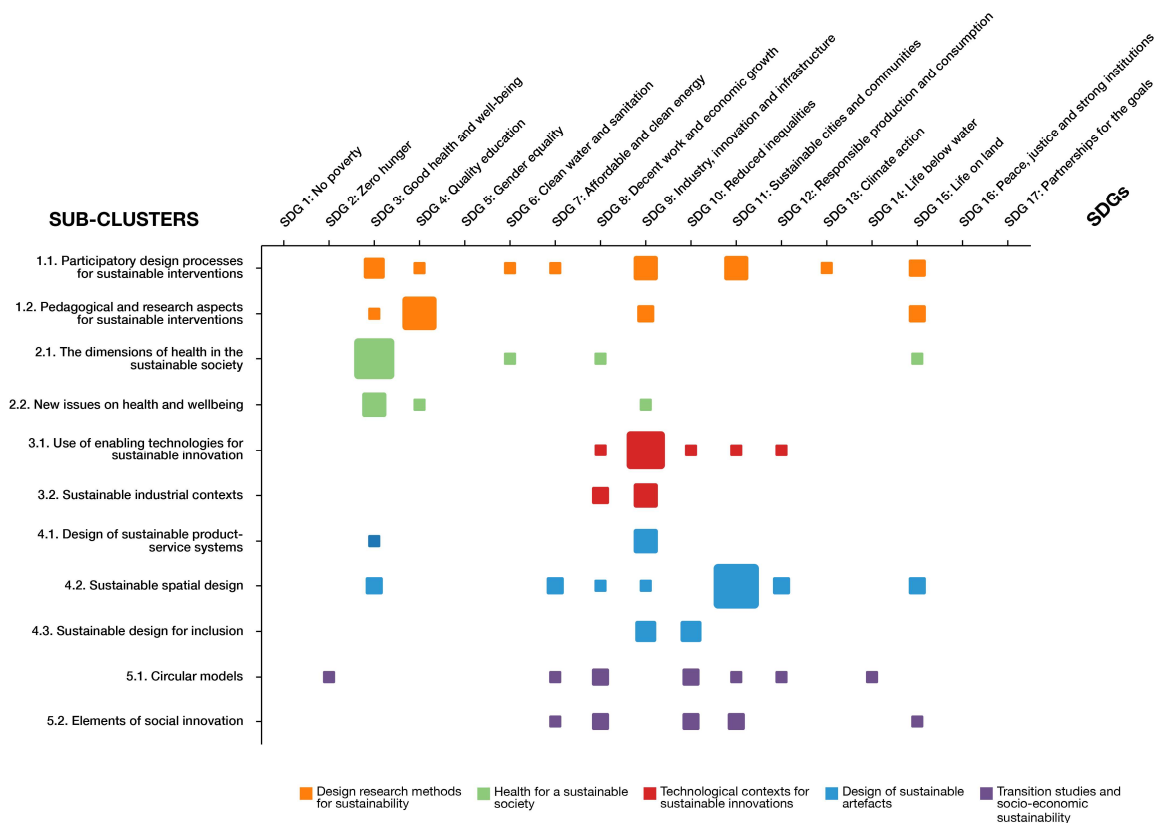

Figure 4. Correlation between sub-clusters and SDGs.

Studies in cluster 1 are distributed across eight SDGs, with an emphasis on three macro-areas: (a) education, (b) innovation, and (c) living ecosystems. Interestingly, studies on education are not the majority, and this aspect seems to echo the importance of making methodologies and methods in practice rather than emphasizing their theoretical/cultural value. Articles included in this cluster depict an archipelago of sub-areas that are relevant for HCD and echo traditional disciplinary topics for (design for) sustainability like (i) HCD studies on healthy systems, (ii) sustainability as a cultural asset for the HCD practice, (iii) HCD for the valorization of resources, (iv) studies for sustainable industrial innovation, and (v) HCD for communities and contemporary living scenarios.

Studies in cluster 2 are logically concentrated around SDG 3, with sporadic digressions on four other SDGs. It can be said that studies considered here are mainly focused on themed aspects of sustainability with only little consideration on the exteriorization of health-related issues. Interestingly, no significant studies show a primary contamination with other potential areas like industrial innovation.

Cluster 3 depicts a twofold dynamic: (i) pure industrial innovations and the value of sustainable processes and technologies for economic growth; (ii) interdisciplinary aspects related to technological innovation. Technology is recognized as a key force for the sustainable innovation toward human-centered systems, where it contributes to increasing the qualitative aspects of industrial production. Interestingly, no noteworthy examples can be found in other relevant SDGs, where it would be expected to see evidence, such as (a) environmental consumption through aware human–artefact interactions, (b) HCD and technologies for health, and (c) technological advances for environmental protection.

Studies in cluster 4 relate to eight SDGs, though a strong concentration can surprisingly be found in the domain of sustainable urban communities, rather than others related to product design where HCD is commonly associated. This trait is important because sustainable urban communities have been recognized as a promising testing ground through which to experiment with new HCD methods and technologies for sustainable change. Evidence also suggests that communities are pivotal socio-technical entities able to connect people, environments, and business models within an aware culture of sustainability. It is possible that designers are now more considering the co-design methodologies needed to work with communities through global–local patterns. About the intervention scales, this study clearly shows that the dimension of human-centered interventions is gradually moving from the product scale to the community one, opening at system theories and the artefact-mediated human–environment interaction. This is the first piece of evidence ever found demonstrating that a profound disciplinary evolution is happening within the HCD discipline due to the influence of sustainability: from the design of the artefact per se to the design of enabling living conditions. As a confirmation of these assumptions, a cross-disciplinary analysis of other SDGs seems to confirm the scientific attention of researchers, which is mainly focused on four areas: (a) health and wellbeing, (b) sustainable industrial innovation and product-led market competitiveness, (c) socio-economic conditions for economic growth, and (d) studies on the valorization of resources.

Finally, studies in cluster 5 depict two main macro-areas: (a) socio-technical systems for bottom-up sustainability and (b) community innovation for sustainable transitions. Both macro-areas perfectly meet the trends already found in other studies discussing design transition studies and design for social innovation. Although profoundly different in nature, cluster 5 can be linked to cluster 4 for what concerns the involvement of communities in the strategic design process needed to generate impacts in terms of innovative business models having higher social qualities.

Figure 4 is not just a simple taxonomy of studies; it provides qualitative evidence on the distribution—behavior—of studies in design and design-related fields. Overall, three main trends can be observed in terms of distribution of works:

- Works concerning traditional and/or consolidated issues, such as health (cluster 2) and technology (cluster 3), naturally concentrate themselves around one SDG. This is because the nature of studies is predominantly monodisciplinary, and the

areas of interventions benefit advances already produced within such knowledge domains. Consequently, the distribution of most works follows a 'research within Design' trend—e.g., [45]. Some contaminations in other SDGs can be observed when studies employ goal-oriented processes—e.g., [42].

- Works concerning emerging aspects for design studies, such as communities (cluster 4) and transition studies (cluster 5), are distributed along multiple SDGs. Figure 4 clearly shows that the behavior of studies is aligned to the 'research through Design' trend, which echoes interdisciplinarity—e.g., [72]. On a different look, studies in these clusters may suggest that systemic goal-oriented approaches are needed to tackle contemporary issues, as these entail multiple areas of intervention.

- Works discussing the culture of sustainability and HCD (cluster 1) apparently show a behavior like the one discussed for clusters 2 and 3. However, the analysis of studies grouped in this section documents that the trend is hybrid and more similar to a 'research for Design' model. The nature of contributions is mainly addressed to the phenomenological improvements of tools and methods—e.g., [33]—as well as the culture needed to properly face specific sustainability-related issues and how to improve the dialogue between researchers that use different methodological settings—e.g., [31].

4.2. Discussion of Future Design Research Trajectories for 'Sustainable HCD'

The analysis provided in Section 4.1. allows us to propose some future research trajectories for the 'Sustainable HCD' domain. Thirteen original trajectories for 'Sustainable HCD' (Table 3) consider the sample of works used for this study and try to open up innovative avenues through which to progress the corpus of theoretical, methodological, and design advances.

Table 3. Future design research trajectories for the 'Sustainable HCD' domain [1].

Research Trajectories	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Reducing inequalities by improving socio-economic driving forces for sustainable transitions	X		x		X
Innovative education to trigger the economic prosperity	X			x	x
Generating radical innovations in the food systems at all scales	x	X	x		x
The inclusive role of gender in the sustainable society		X			x
Health for All	x	X		x	
Aware use and consumption of natural resources			X	x	
Getting closer production and distribution systems to living environments	x		X	x	
Working safely			X	x	x
Proactive sustainable living scenarios		x		X	x
Sustainable human-centered systems and sets of solutions	x			X	x
Development of wealthy communities		x		x	X
Supporting the transition toward a more democratic and fair society	x				X
Fostering the cooperation for the sustainable transition	x	x	x	x	X

[1] 'X' means strongly relevant; 'x' means relevant.

5. Conclusions

This work proposes the first and most complete picture of studies published since 2000 linking sustainability and HCD, with a detailed analysis of all endogenous design and research dynamics made by the research community on the progressions of theoretical and methodological aspects on both topics considered.

Data discussed through the systematic literature review indicate that there are several topics being addressed in the intersection areas linking 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. Although a proliferation of approaches can be found, this is not equally counterbalanced by developments in all design fields; as shown in Figures 2 and 3, it is not possible to find a stable distribution of the research interests. From one side, this portrays the new opportunities introduced by transition studies on communities and design-led studies on social innovation; from the other side, it seems that the research community is fully aware that the product-service domain is not able to generate radical impacts on all dimensions of sustainability, and therefore it is not seen as a niche in which to invest in for progressing the reflections in the field.

In terms of the distribution of studies, it must be noted that most works considered refer to the last five years (Figure 5). This aspect seems interesting when compared to the long tradition of cultural debates around sustainability (30+ years). A possible reason for this could be found in the low readiness of the HCD domain, which has traditionally shown interest only toward products and services. Contrarily, the analysis demonstrated that the future areas of innovation are the industry market and the domain of living communities, which have only recently gained attention due to engineering-led pushes—i.e., Industry 5.0—and transition studies.
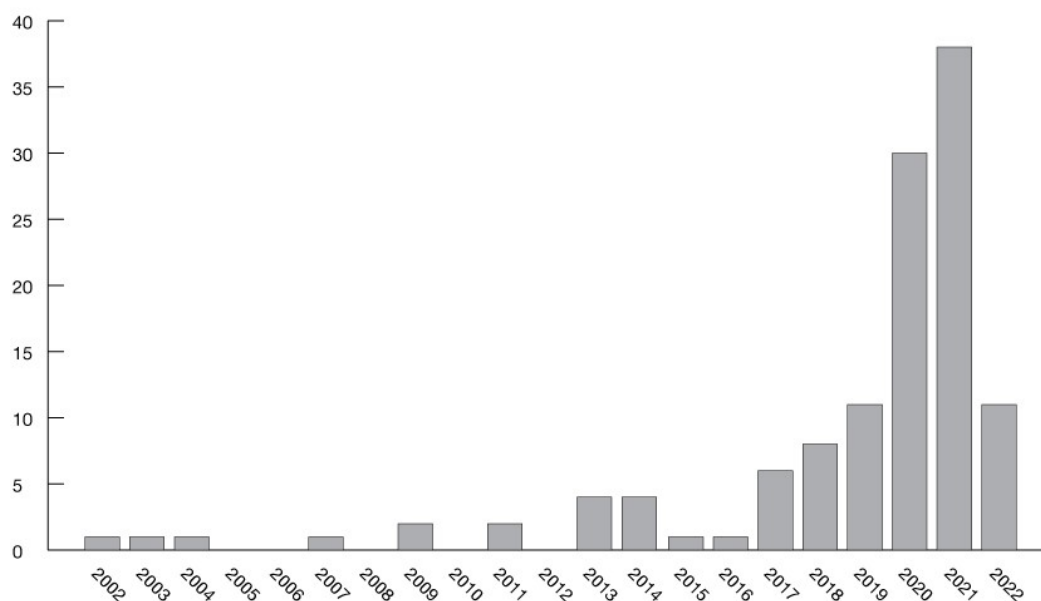

Figure 5. Distribution of studies linking sustainability and HCD over time.

Another emerged aspect deserving mention concerns the multitude of 'languages' spoken by researchers. The analysis of keywords suggests that researchers must start to use a common glossary of terms from which to set up new studies as this makes the

search of samples to be used for next studies easier. Beyond that, the results of this study also contributed to clarify the most diffused topics used by researchers for their work, which is an important baseline on which to reflect in order to operate reviews and updates of existing literature, even in the perspective of knowledge synergies. Accordingly, the discussion provided in Section 4 aims to guide future studies toward promising research avenues that more consider the existing body of knowledge in the field. Even though many of the pertinent SDGs have been only cursorily addressed, it is instead interesting to note that few SDGs have received significant attention from the HCD community. So, there is a wealth of evidence that the SDGs demand work in order to enable the 'design' of a sustainable future.

The analysis of studies in relation to the SDGs provided a new interpretation for HCD and sustainability. As discussed in Section 4, the interest of the research community is currently focused on four main themes: (i) health and wealth, (ii) education, (iii) industrial innovation, and (iv) cities and living communities. A general scarcity of works can be found in the remaining areas, which, however, open up future research trajectories within a possible 'Sustainable HCD' research domain—see Table 3.

In terms of limitations, it must be said that the intrinsic methodological limitations derived in the use of a bibliometric analysis based on the use of keywords only partially resulted in inherent biases for the interpretation of the works considered. From the qualitative point of view of the ROs considered, this limitation has not produced a gap between the expected results and findings achieved.

To conclude, this work details the contribution of sustainability into HCD. A set of clusters and sub-clusters have been identified and discussed in detail to provide a comprehensive picture of what has been conducted so far. However, this goal has also provided the opportunity to critically reflect on the opportunities currently unexpressed by the body of studies in the field, which ultimately has led to the creation of in-depth analyses of existing thematic clusters as well as considerations on future research avenues that may link sustainability and HCD closer.

Institutional Review Board Statement: Not applicable.

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Data Availability Statement: The data used for this study (list of 122 studies considered for this work) will be available from corresponding authors on reasonable request.

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