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# Advancing Sustainability in the Future of Work through the Design of Post-Pandemic Work-from-Home Systems

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**Abstract:** The COVID-19 pandemic accelerated and solidified the adoption of work-from-home systems (WFHSs) across all economic sectors, and finding ways to incorporate sustainability into these systems is a fundamental aspect of a sustainable future of work. Designing sustainable WFHSs requires an innovative approach capable of understanding complex interrelationships between multiple systems. This paper applies the sustainable system-of-systems (SSoSs) framework to find innovative design solutions for post-pandemic/endemic WFHSs. First, the SSoSs framework is depicted using examples of applications in systems to clarify its main ideas and concepts. Then, the literature on WFHSs is considered to discuss the impacts of COVID-19 on work from a systemic perspective. This provides inputs for the factors to be considered at each level of the SSoSs analysis. Finally, the SSoSs framework is applied to analyze the WFHSs' requirements in the context of COVID-19. The nature of the application of this framework is theoretical, facilitating the provision of a multi-layered perspective on sustainability in work systems that are increasingly prevalent across various economic sectors. This study contributes to research and practice by characterizing the various relevant systems and their impact on the design of sustainable WFHSs and identifies multiple intervention points to make predictions about how they might influence other systems.

**Keywords:** sustainability; sustainable work; healthy workplace; remote work; systems thinking; systemic approach; post-pandemic; COVID-19; complex systems



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## 1. Introduction

As of October 2023, COVID-19 has caused over 771 million cases and over 6,96 million deaths [1] with an economic cost of about USD 12.5 trillion through 2024 [2]. With an impact of this magnitude, it is clear that pandemics such as COVID-19 represent an existential threat [3]. However, humans are more likely to react to a threat if it is concrete (i.e., not ambiguous), immediate (i.e., not at some indeterminate point in the future), and certain [4], and complex problems, such as sustainability issues and pandemics, meet none of these qualities [5]. For this reason, specialists have called for systemic approaches capable of addressing problems from a multidisciplinary, multi-level perspective, from simple, single-system interventions to the understanding of complex multi-geographical systems [6].

While the intensity of the COVID-19 pandemic has waned, a growing chorus of scientists and researchers has been sounding the alarm about a multitude of potential threats that could spawn new pandemics [7]. These include the Nipah virus originating from bats in Asia [8], mosquito species in the Western Hemisphere [9], the Mers virus from camels in Africa [10], intensive factory farming creating ideal conditions for a new swine flu outbreak [11], yellow fever from monkeys in South America [12], and the Buruli ulcer from possums in Australia [13]. According to Donthu and Gustafsson [14], COVID-19 is a

sharp reminder that pandemics have happened in the past and will continue to happen in the future, and it has demonstrated to the world that the systems that underpin human activities, such as healthcare, transportation, and work systems, are unprepared [15]. Given the criticality of these events and the potential for new ones to occur, it is necessary for society, including all stakeholders, to be better prepared.

Salmon et al. [3] argued that systems ergonomics and human factors (E/HF) is suited to tackle major global and societal issues, such as pandemics, as they support the description of entire systems, their component parts, and importantly the relationships and interactions between these parts. E/HF is the scientific discipline concerned with understanding interactions among humans and other elements of a system [16], in which researchers in the discipline have devised systemic approaches to address sustainability issues.

The sustainable system-of-systems (SSoSs) framework developed by Thatcher and Yeow [17,18] provides a systemic approach to sustainable systems' design. The SSoSs framework has been applied in different contexts, such as electric vehicle design [17], extreme natural events [18], and farmers' transitions to sustainability [19]. The SSoSs framework allows one to characterize the various relevant systems and their impacts on an effective, sustainable solution, to identify multiple intervention points and to make predictions about how they might influence other systems, and to predict how often one will have to intervene with a new iteration of the intervention [17,18].

Given the context presented, this paper aims to apply the SSoSs framework to find innovative design solutions for WFHSs in a late-pandemic and post-pandemic world. First, the SSoSs framework is depicted using examples of applications in work systems to clarify its main concepts. Then, the literature on sustainable work systems is considered to understand the impacts of COVID-19 on work from a systemic perspective. This provides inputs for the factors to be considered at each level for the SSoSs analysis. Finally, attention is directed to WFHSs and the application of the SSoSs framework to analyze the system requirements contributing to the development of sustainable work systems.

This paper addresses the urgent need to integrate sustainability principles into the design of WFHSs, a pressing concern amplified by the widespread adoption of WFHSs during and after the COVID-19 pandemic. While WFHSs have become increasingly prevalent across all economic sectors, the sustainability aspect of these systems is underexplored. This paper fills a critical research gap by focusing on sustainability within the context of post-pandemic/endemic WFHSs, a topic that has gained prominence due to the pandemic's enduring impacts.

By applying the SSoSs framework to tackle the challenges of designing sustainable WFHSs, this paper provides an innovative approach capable of comprehending complex interrelationships between multiple systems, offering a fresh perspective on addressing the sustainability concerns associated with the evolving work landscape. Furthermore, it provides valuable insights into the factors that need to be addressed at different levels of analysis. Ultimately, this research contributes to both academia and practical applications by characterizing the relevant systems and their influence on the design of sustainable WFHSs. Additionally, it identifies multiple intervention points and predicts their potential influence on other systems, offering actionable guidance for organizations seeking to develop more sustainable work-from-home practices in an ever-changing work environment.

## 2. Theoretical Background

### *2.1. Systems Frameworks for Work System Sustainability*

There are several systems approaches in the E/HF academic literature, each offering unique perspectives and methodologies for understanding and analyzing complex systems in different contexts. Table 1 displays relevant E/HF frameworks that consider various aspects of the sustainability of a work system.

**Table 1.** Frameworks addressing diverse aspects of work system sustainability.

| Framework | Design Focus | Key Reference |
| --- | --- | --- |
| AcciMap | Risk management | [20] |
| Cognitive Work Analysis (CWA) | Workplace technology design | [21] |
| Event Analysis of Systemic Teamwork (EAST) | Analysis of teamwork | [22] |
| Functional Resonance Analysis Method (FRAM) | Accident prevention | [23] |
| Human Factors Analysis and Classification System (HFACS) | Human error | [24] |
| System Safety Analysis Method (STAMP) | Safety | [25] |
| Sustainable System of Systems (SSoSs) | All dimensions of sustainability | [17,18] |

Originally developed for proactive risk management, the AcciMap approach primarily serves as an accident analysis tool. It maps contributing factors to accidents across six levels, encompassing government policy, regulatory bodies, technical management, and outcomes [20]. With a different focus on guiding technology design for workplace use, CWA places the emphasis on understanding how work is performed and tailoring technology to fit those work processes [21]. EAST was initially designed for teamwork analysis and has expanded to address various levels within sociotechnical systems including the dynamics of teamwork, communication, and coordination [22]. FRAM describes outcomes as a result of everyday performance variability, highlighting how small variations can lead to different outcomes. It is valuable for understanding system behavior under different conditions [23].

Originally designed for aviation, HFACS is a comprehensive framework for analyzing human factor aspects of accidents and incidents across multiple industries [24], whereas STAMP takes a top-down approach to analyzing accidents by examining interactions between system components, emphasizing the control of accidental emergent properties and accident prevention [25].

Each approach has its strengths and is suited to particular domains and objectives. The choice of approach depends on the specific needs of the analysis or design project and the complexity of the system under consideration.

Thus, the SSoSs framework emerges as the most appropriate choice for designing sustainable work systems due to its systemic approach and versatile capabilities. Unlike other frameworks that may focus on specific aspects or levels of analysis, SSoSs provides a system-of-systems perspective, allowing for a comprehensive understanding of how multiple systems interact and contribute to sustainability [18]. Its capacity to characterize different relevant systems and predict their impacts on sustainability is key for designing work systems that not only meet immediate needs but also consider long-term environmental, social, and economic consequences. SSoSs empowers decision makers to identify multiple intervention points and iteratively refine solutions, ensuring adaptability and resilience in the face of evolving sustainability challenges. In today's dynamic and interconnected world, the SSoSs framework is a powerful tool for crafting work systems that not only thrive in the present but also contribute positively to a sustainable future [17].

### *2.2. Sustainable System-of-Systems (SSoSs) Framework*

In our interconnected global context, sustainability challenges such as pandemics, the depletion of natural resources, pollution, and substandard working conditions transcend geographical borders. Effectively tackling these challenges necessitates a transformative shift within the domain of sustainable work systems, moving beyond a confined, linear model understanding to embrace a more comprehensive systems perspective [26]. To this end, Thatcher and Yeow [17,18] introduced the SSoSs framework, which amalgamates the prevailing hierarchical comprehension of potential E/HF interventions (micro-, meso-, and macro-ergonomics) with significant principles derived from the sustainability discourse. Rooted in the realm of green ergonomics [27], the SSoSs framework draws inspiration from

the intricate interplay between E/HF and ecological systems. Since its inception, the SSoSs framework has undergone refinement and the assimilation of novel concepts (Table 2).

**Table 2.** Evolution and main concepts of the SSoSs framework.

| SSoSs Components and Concepts | | References |
|---|---|---|
| 1. Hierarchical nested systems | Nested systems, Parent–sibling–child systems | [28,29] |
| 2. Multiple goals | Triple bottom line | [30] |
| 3. Time dimension | Natural systems' lifespan, Ecological systems' phases | [28,31] |
| 4. Adaptive cycles | Revolt and remember processes, Resilience | [31,32] |

Source: Authors.

When Thatcher and Yeow [17,18] first proposed the SSoSs framework, three main components were stated: (i) nested hierarchy of systems; (ii) a focus on the achievement of multiple, simultaneous goals; and (iii) a time dimension for a system to be sustainable. A revised SSoSs framework was presented later by deepening the discussion on the time perspective of sustainable work systems and including a fourth component: adaptive cycles (Figure 1).

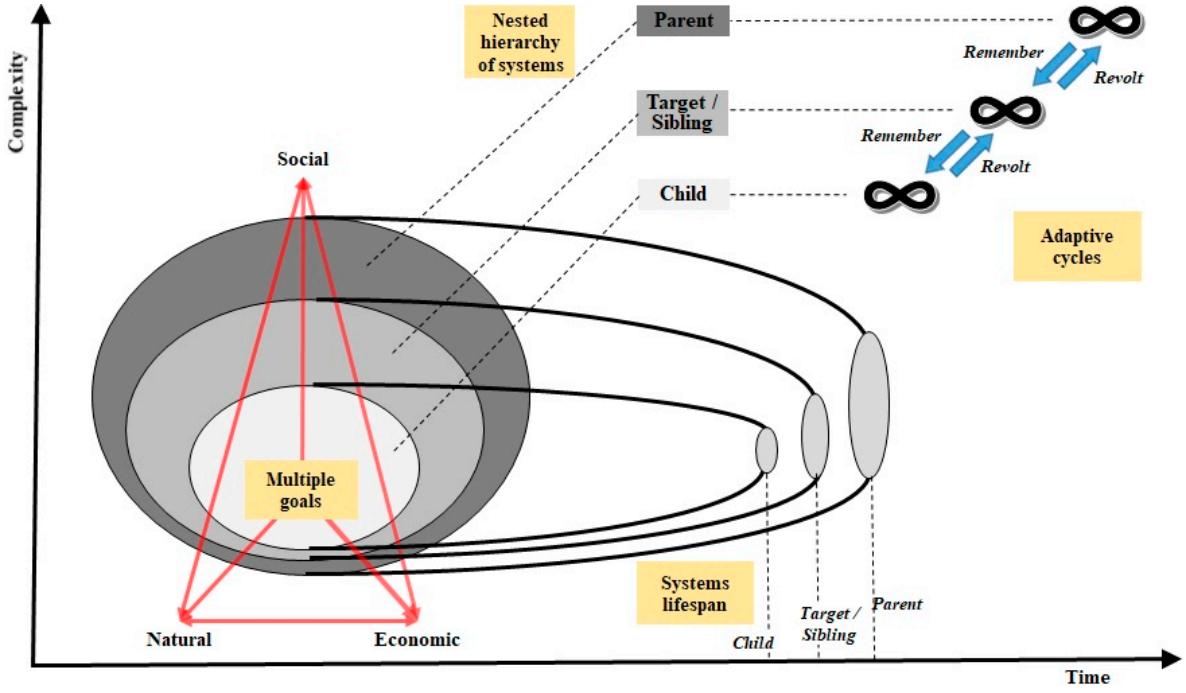


**Figure 1.** The main components of the sustainable system-of-systems framework. Source: Authors' own creation.

The academic community has promoted further discussions on the SSoSs framework and has expanded to topics beyond the scope of this paper, among which are the integration of the SSoSs framework and the Francophone activity-centered ergonomics approach and relevant E/HF complex systems tools. The next sections focus on the concepts related to the SSoSs framework, providing an overview of each component with examples to illustrate its application.

#### 2.2.1. Nested Hierarchy of Systems

The nested hierarchy of systems, a primary facet within the SSoSs framework, is a recurring pattern observed in nature, where smaller, simpler systems are nested within larger, more intricate systems [28]. Similarly, within the domain of E/HF, systems can also be delineated in a nested hierarchical manner. For instance, human–task and human–tool

systems are encompassed within a human–work system, which is nested within a team system and ultimately nested within an organizational system. This hierarchical structure serves as a tool to illustrate how conventional systems of interest in the field of sustainable work systems can be logically extended to the ecological level.

The SSoSs framework employs Wilson's [29] terminology of parent–sibling–child systems to depict hierarchical relationships between these systems. The central system of concern is referred to as the "target" system. This target system interacts with "sibling" systems (systems of comparable complexity and spatial influence), "parent" systems (more complex or spatially extensive systems than the target), and "child" systems (systems of lesser complexity and narrower spatial influence than the target).

It is important to acknowledge that a specific work system could be a target system in one context and a sibling, parent, or child system in another context. Historically, the E/HF approach has involved identifying a target system and treating all other interacting systems as the "environment". In contrast, the SSoSs approach considers these child, sibling, and parent systems as integral components of the same interconnected "family" of systems.

#### 2.2.2. A Focus on Multiple, Simultaneous Goals

The second major component of the SSoSs framework is the focus on multiple, simultaneous goals linked to the sustainability agenda. Thatcher and Yeow [17] highlighted Elkington's [30] triple bottom line objectives as an instance where achieving equilibrium among social, economic, and natural resources is essential. This aligns with the notion of a panarchy put forth by Gunderson and Holling [31]. The term "panarchy" is derived from "pan", symbolizing the deity of nature in Greek mythology, and "archy", representing a hierarchy. Within the framework of nature and sustainability, panarchy signifies that upper-tier systems (with the Earth system as the highest level in this context) exercise authority over subordinate systems. In the SSoSs framework, prioritizing higher-level goals is imperative, as the existence of all human systems is contingent upon the preservation of nature.

Thatcher and Yeow [17] emphasized that the attainment of multiple objectives is not only essential, but these diverse objectives are interconnected and might even clash. As an illustration, the imperative for a laborer to secure decent working conditions (a social objective) could potentially contradict the worker's necessity for employment irrespective of working conditions, solely to earn income for sustenance (an economic objective).

Furthermore, conflicts between goals can extend across distinct hierarchical tiers. To illustrate, the desire for satisfactory working conditions by employees (a social objective) could be at odds with the organization's pursuit of profitability (an economic objective). E/HF approaches can enhance the sustainability of a system by recognizing where multiple objectives can be met considering their different nature and hierarchical levels.

#### 2.2.3. Time Dimension

The third significant element within the SSoSs framework involves recognizing inherent properties tied to natural lifespans. This infuses a temporal dimension into our comprehension of systems and their interactions. There are three fundamental implications regarding the temporal aspect within the system-of-systems context.

Firstly, a system's lifespan should harmonize with its position within the nested hierarchy of systems [28]. In essence, larger, more intricate systems possess extended natural lifespans in comparison to their smaller, less intricate counterparts. For instance, a person–task–tool system is expected to exhibit a briefer lifespan than a person–job system.

Secondly, the persistence of child systems beyond the duration of their parent systems introduces fragility into the system of systems. As an illustration, work systems that outlast their natural lifespan result in outdated work practices and inadequate workplace layouts unable to adapt to the evolving work landscape.

Thirdly, an untimely termination of a parent system induces instability within the system of systems. For instance, abrupt changes or terminations of public transportation networks

lead to instability as employees grapple with punctuality issues. Thatcher and Yeow [17] argued that both researchers and practitioners must be mindful of the hierarchical alignment of the target system within the system-of-systems structure. Attending to the inherent pace of change and the longevity of a system aids in classifying it as a child, sibling, or parent system.

#### 2.2.4. Adaptive Cycles

The adaptive cycle constitutes the fourth facet of the SSoSs framework. According to Gunderson and Holling [31], the prevailing notion is that systems typically do not undergo mere termination; instead, they experience a continual process of evolution. These authors stated that this is a dynamic process with parallels to ecological lifecycles consisting of four stages: growth/development (A), conservation/consolidation (B), release/creative destruction (C), and re-organization/destructuring (D) (Figure 2).

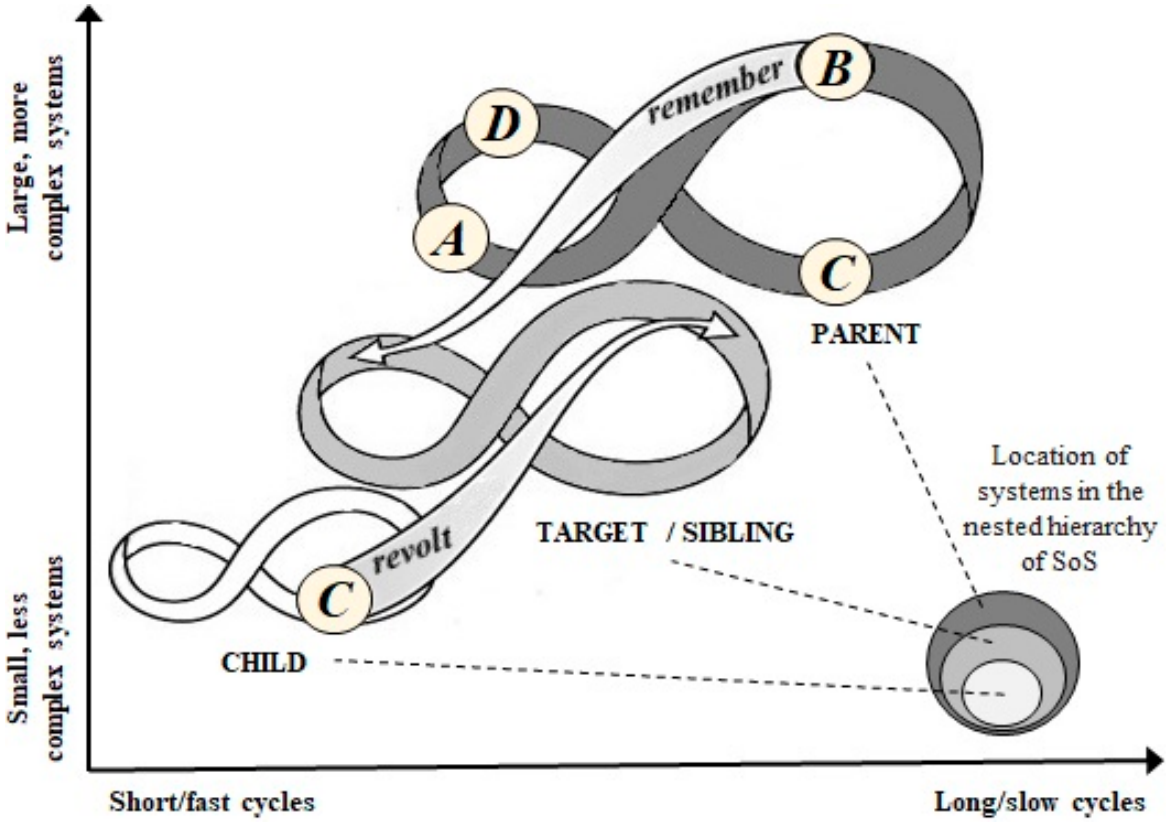


**Figure 2.** Adaptive cycles and revolt/remember processes. Source: Authors' own creation.

The SSoSs framework proposes that when a swift and diminutive system (termed a child system) reaches the release phase, these transformative and disruptive changes offer an avenue to influence modifications in more gradual and sizable systems (referred to as parent systems), especially those systems exhibiting diminished resilience at the culmination of their conservation/consolidation phase. Gunderson and Holling [31] coined this process as "revolt". In the context of sustainable work systems, pinpointing child systems in the release stage could potentially propel alterations in parent systems. Likewise, when a small and agile system enters the reorganization stage, the novel processes will be constrained by the mechanisms present within the larger and more unhurried system in its conservation/consolidation stage, a phenomenon they termed the "remember" process. For instance, the organizational culture (the parent system), situated in the conservation stage, will act as a steadying influence on any changes in the workplace layout (the child system). Essentially, the organizational culture will delimit the scope of alterations in the workplace

layout. These hierarchical interactions within intricate adaptive systems underscore how higher-level and lower-level systems co-evolve harmoniously (Thatcher and Yeow [17]).

The recognition of adaptive cycles within a system of systems signifies that timed and purposefully crafted interventions can trigger cascading effects across the entire system of systems and that interventions necessitate perpetual iterations, with the frequency of iteration for HFE interventions contingent upon the hierarchical level.

## 3. Methodological Approach

Thatcher and Yeow [33] put forward five essential aspects to take into account when utilizing the SSoSs framework for pioneering interventions: (i) pinpointing the pertinent systems, (ii) situating systems within the SSoSs hierarchy, (iii) gathering data from the interconnected and interplaying systems, (iv) recognizing points for intervention, and (v) ascertaining notions regarding the extent of alteration and the degree of repetition anticipated for an intervention to yield a discernible impact. Based on this, Figure 3 shows the research process of this study.

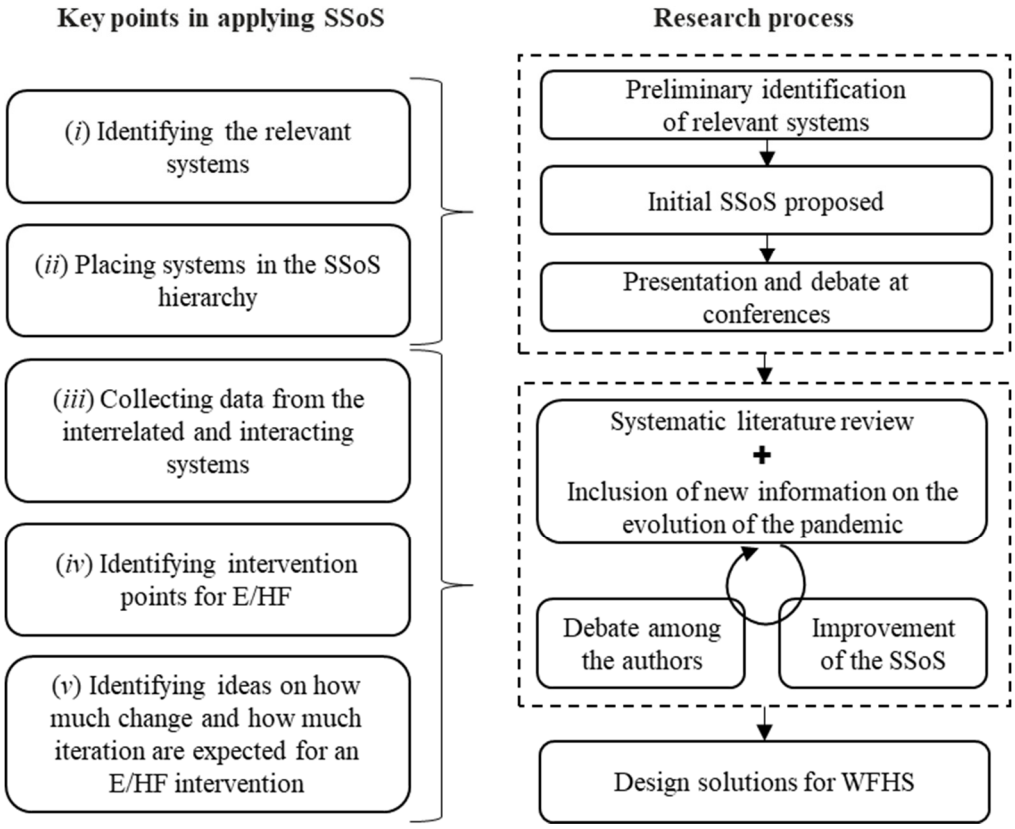


**Figure 3.** Research stages and steps. Source: Authors' own creation.

Initially, a preliminary study was conducted to identify relevant systems and how they interacted in the context of the COVID-19 pandemic (key points (*i*) and (*ii*)). Based on research team discussions and on the analysis of published reports from international institutions (e.g., WHO and IMF), a preliminary SSoSs hierarchy was proposed. This proposal was presented and debated at an academic conference, receiving contributions from the academic community.

This initial proposal served as the basis for the next step consisting of the iterative process of bibliographic research, improvement, and debate among the authors. Literature-based studies were conducted to understand the impacts of COVID-19 on work from a systemic perspective (the results of which were published in [34,35]), which provided inputs for the factors to be considered at each level for the SSoSs.

The SSoSs hierarchy was continually improved through debates among the authors, taking into account new information as the pandemic evolved (e.g., vaccine development and the emergence of variants) and fostering the generation of ideas about intervention points and practical considerations (key points (*iii*), (*iv*), and (*v*) in applying the SSoSs). This iterative process allowed us to identify innovative design solutions for WFHSs using the SSoSs framework as presented in the following sections.

The following sections present the results obtained from this process. Key points (*i*) and (*ii*) are addressed in Sections 4.1 and 4.2, respectively. Meanwhile, key point (*iii*) is discussed in Section 4.3. Finally, key points (*iv*) and (*v*) are the focus of Sections 4.4 and 5, respectively.

## 4. Applying the SSoSs Framework for Sustainable WFHSs

### *4.1. Systemic Perspective on Work in Times of COVID-19*

Multiple issues related to COVID-19 that impact work systems were identified and organized considering different systems (Table 3).

**Table 3.** Impacts of COVID-19 on relevant systems related to work.

| Systems | Issues Related to COVID-19 That Impact Work | References |
| --- | --- | --- |
| Natural system | • Systemic impacts of the pandemic, affecting all aspects of everyday life. | [36] |
| | • The pandemic's short-term carbon emission reductions through lockdowns may divert resources and attention from long-term climate action. | [37,38] |
| | • The pandemic redirected resources and attention from climate change mitigation, delaying investments in renewable energy, and emissions' reductions. | [39,40] |
| | • Ongoing environmental degradation persisted, impacting conservation efforts due to resource diversion. | [41] |
| | • Conservation programs faced funding shortages and fieldwork disruptions, affecting ecosystem and wildlife protection. | [41] |
| Government policies and strategies | • Low public mobilization and education on infection prevention. | [42] |
| | • Lack of situation awareness of the population and social actors. | [43] |
| | • Need for protection of the frontline workforce. | [44,45] |
| | • Government policies, including lockdowns, disproportionately affected marginalized communities, exacerbating existing inequalities. | [46] |
| | • The pandemic heightened political polarization, hindering cohesive government policies. | [35] |
| | • Disinformation has eroded public trust, undermining accurate government guidance. | [35] |

**Table 3.** *Cont.*

| Systems | Issues Related to COVID-19 That Impact Work | References |
| --- | --- | --- |
| Healthcare system | • Poor communication channels of state public health department. | [47] |
| | • Unpreparedness and collapse of the health system. | [48] |
| | • Healthcare workers faced increased workloads, stress, and burnout, with long hours and emotional toll. | [49] |
| | • Shortages of personal protective equipment (PPE), ventilators, and essential medical supplies strained healthcare systems. | [49,50] |
| | • Rapid telehealth adoption exposed disparities in internet access and digital literacy, limiting healthcare access for some populations. | [51] |
| | • Lockdowns and disruptions in healthcare services led to delays in non-COVID healthcare. | [49] |
| | • Growing pressure on the healthcare system in all dimensions (e.g., operation, communication, and workforce). | [35,45,52] |
| Vaccine roll-out system | • Misinformation and data delay on the evolution of the pandemic. | [42] |
| | • Infodemic, anti-vaccination campaigners, and anti-science movements. | [35,53] |
| Community culture | • Conflicting goals related to return from lockdown from different communities with regards to health and safety and economics. | [3] |
| | • Reduced interaction, safety, and accessibility within public spaces. | [54] |
| Organizational culture | • Insufficient or inconsistent legal obligations of organizations related to worker's health. | [55] |
| | • Power imbalances between management and workers in decision making for COVID-19. | [56] |
| | • Lack of guidelines for managers in organizations. | [35] |
| | • Need for effective corporate actions to promote workers' health. | [57,58] |
| | • Need for organization's leadership commitment to protect workers. | [59] |
| | • Need to increase worker engagement in safe and healthy behaviors. | [60] |
| Organizational childcare policies | • Lack of gender-sensitive organizational policies. | [61] |
| Information systems | • Need for rapid deployment of virtual teams. | [62,63] |
| | • Poor inter- and intra-organizational communication. | [64] |
| Community support networks and family system | • Unequal distribution of household and family care tasks between men and women during working hours. | [61] |

**Table 3.** *Cont.*

| Systems | Issues Related to COVID-19 That Impact Work | References |
| --- | --- | --- |
| Work-from-home systems | • New ways of working, especially technological solutions. | [62,65] |
| | • Stressors affecting team performance and training. | [66,67] |
| | • Reorganization and redesign of work. | [57,68] |
| | • Physical and mental health issues in remotely working. | [35,69] |
| | • Inappropriate home-based workstation. | [67,70] |
| | • Increased ergonomic risks at work, including working from home. | [55,66] |
| Home office E/HF | • Inadequacy of telework environment. | [71] |
| | • Need for restorative environments in the home office. | [72] |
| Individual work systems | • Unclear assignment of tasks. | [42,67] |
| | • Work as imagined vs. work as done. | [36] |
| Family routine and tasks | • Difficulties related to work–home equilibrium, especially for women. | [73] |

Source: Authors.

At the broadest level, the COVID-19 pandemic brought about short-term reductions in carbon emissions due to lockdowns, but it is important to critically analyze the fact that the focus on crisis response diverted resources and attention from long-term climate action [37,38]. As a result, investments in renewable energy and emissions' reductions were postponed, environmental degradation persisted, and conservation programs faced funding shortages and disruptions, hampering efforts to protect ecosystems and wildlife [39,40]. This highlights the delicate balance between addressing immediate crises and maintaining a commitment to long-term sustainability and environmental conservation [41]. In addition, it should be noted that WFHSs can help reduce carbon emissions by reducing the need to travel. However, there are also negative aspects of WFHS including the need to heat and cool workspaces, provide lighting for workspaces, and to power laptops, Wi-Fi, and other equipment in many distributed venues rather in a centralized location which can benefit from the sharing or controlling of these resources.

Researchers have observed many issues related to conflicting goals and the dissemination of information about COVID-19. Salmon et al. [3] highlighted that the objective of curtailing virus transmission contradicts the goal of reverting to economic activity levels and societal norms resembling the pre-pandemic era. To illustrate, efforts to reduce physical interactions and enhance adherence to restrictions clash with endeavors to boost economic activity and curtail job losses. Restriction measures and the population's fear of contamination have negative impacts on community interaction, safety, and accessibility within public spaces [54]. Finding solutions to face these problems is hampered by false, concealed, delayed, or omitted reporting on COVID-19 [42] associated with the poor usability of state public health department websites for communication during a pandemic [47]. This reinforces the infodemic and the action of anti-vaccination campaigners and anti-science movements [35,53]. All these issues contribute to an inadequate public mobilization, publicity, and education on infection prevention [42] and to the lack of situation awareness of the risks, potential impacts, and appropriate responses to the pandemic [43]. In addition, government policies, particularly lockdowns, often hit marginalized communities the hardest, exacerbating pre-existing inequalities [46]. Simultaneously, the crisis has amplified political polarization, making it challenging for governments to implement cohesive policies that effectively address the health and economic impacts of the pandemic. Moreover,

the prevalence of disinformation has further strained the situation, eroding public trust in official guidance and hindering efforts to provide accurate information during a time of crisis [35].

Specifically regarding healthcare systems, healthcare workers have faced not only increased workloads and stress but also burnout due to long hours and the emotional toll of caring for patients. Compounding these challenges, shortages of essential medical supplies like PPE and ventilators strained healthcare systems [49,50]. The pandemic also revealed disparities in healthcare access as the rapid adoption of telehealth services exposed inequalities in internet access and digital literacy, limiting healthcare options for some populations [51]. Furthermore, lockdowns and disruptions in healthcare services resulted in delays in non-COVID medical care, compounding the healthcare system's strain and affecting patients seeking other vital treatments [49].

At the meso level, external and internal issues to organizations can be noted. The lack of transparency and clarity in communication between the state, companies, and the population [47] contribute to the creation of insufficient laws (or the lack of them) that oblige organizations to give priority to workers' health [55]. This is further accentuated by the influence of power disparities that have been evident in the pressures exerted by various social factions. For instance, significant corporations advocated for the cessation of restrictions, and teacher unions expressed apprehension regarding health hazards associated with resuming in-person classes [36]. In this scenario, the protection of workers depends highly on the commitment of the organizations' leadership [59]. However, once committed, significant progress still needs to be made in the development and sharing of guidelines for managers on how to adapt work to workers in the context of COVID-19 and in the effectiveness of corporate actions based on internal protocols, specific training, health programs [58], and sick leave policies [59]. In addition, special attention is needed for health institutions and health workers, as they are physically and mentally overloaded and highly exposed to COVID-19 [44,52], and the collapse of health institutions would also represent the collapse of the functioning of society.

At the micro level, it is possible to point out several factors related to physical, cognitive, and organizational E/HF. Since the spread of COVID-19 and the implementation of restriction measures, organizations have been pressured to embrace new ways of working [62,65] and build and manage virtual teams [62,63]. Several work-related issues emerged from this scenario, such as unclear assignments of tasks [42] and processes of work [57], evidencing the need to understand the gap between work as imagined (prescribed work) and work as done [36]. Tannenbaum et al.'s [74] study on managing teamwork in the context of COVID-19 identified stressors that can affect team performance at different levels: individual (pertaining to personal health worries, excessive workload, and exhaustion), team (involving insufficient expertise among team members due to role changes and an unfamiliarity with new colleagues or processes), organizational (insufficient resources such as PPE and ventilators and financial stress), and work–life (concerns about family and friends and social isolation). Furthermore, a significant number of teams are spread across different locations, and it is imperative to harness technological advancements to offer team training strategies that effectively address the growing intricacies and diversification within teams [75].

Considering the inevitability of working from home, Cuerdo-Vilches et al. [71] pose the following question: are our homes ready for teleworking? There are many findings from the literature that indicate the answer is no, for instance, the need for restorative environments in the home office [72], inappropriate home-based workstations [67,70], and increased E/HF risks [55]. All these factors have resulted in physical and mental health issues in remote working [35,69] and difficulties related to the work–home equilibrium, especially for women [73]. Even in the face of all these issues, working from home might remain for an extended period, whether due to the uncertainties regarding the end of the COVID-19 pandemic, the emergence of new variants or even new pandemics [14], or the will of companies and workers [65].

*4.2. Relevant Systems and Their Respective Positions within the SSoSs Hierarchy*

The analysis of the issues related to COVID-19 that impact work at the micro, meso, and macro levels allowed us to construct the SSoSs nested hierarchy (Figure 4).

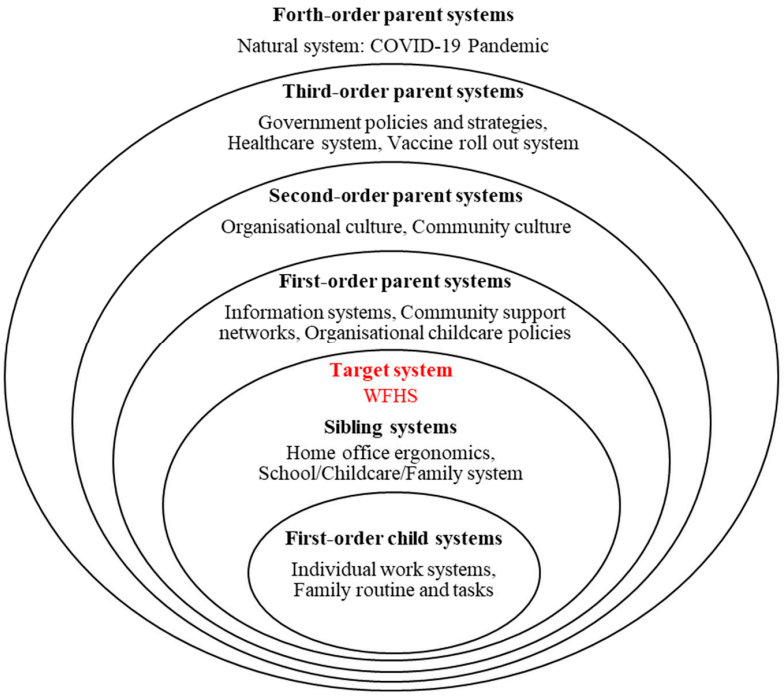


**Figure 4.** Nested hierarchy of systems for WFHSs in the context of the pandemic. Source: Authors' own creation.

Considering the impacts of COVID-19 on work at the lowest level, family routines and individual work systems are considered as relevant child systems. Family routines (e.g., bedtime, meal times, etc.) in most cases can adapt relatively quickly so that the residents of the house can adapt to new routines of work, leisure, household chores, and/or childcare. If work undergoes a permanent transformation, remaining predominantly online even after the relaxation of restrictions or the conclusion of the pandemic, individual work systems (referred to as the child system) may either resist or align with this change (revolt). For instance, the extensive use of personal laptops may require new security procedures and corporate gateways for services or e-learning, or the organization will have to provide compatible equipment. The design of the WFHS itself raises several design considerations, such as hardware processing power, end-user computing applications, internet connections, communications, devices, home workstations, and considerations of the "work" environment. Anthropometric, environmental, and psychosocial factors need to be taken into account in the design of WFHSs [70]. In addition, it is necessary to recognize the multiple goals to be pursued, for example, optimizing the cost of the construction and operation of the system (i.e., the economic goal), achieving a work–life balance (i.e., the social goal), and promoting a healthy work environment to avoid COVID-19 infection and community spread (i.e., the nature goal).

The analysis interconnecting the impacts of COVID-19 at the level of the target system (WFHSs) allows us to define four sibling systems: home office E/HF, school systems, childcare systems, and family systems. Home office E/HF includes restorative environments in the home office, adequate home-based workstations, and the suitability of the working environment for long-term seating and other work environment issues (e.g., noise from the kitchen, thermal comfort, and the availability of space to work). For working parents, the WFHS impacts and is impacted by school systems (e.g., appropriate place for studying, equipment for taking online classes, and learning support) and childcare (e.g., interruptions to look after children), and, more generally, by the family system (e.g., who is available

to look after a child, to cook dinner, to go to the shops to purchase groceries, etc.). In this regard, the relevant literature shows that it is necessary to consider the gender disparities during the design of WFHSs, highlighting the specific vulnerability of women in many societies to potential excessive domestic workloads and caregiving obligations [76,77].

As for parent systems, four layers with increasing complexity were defined. Issues related to schools and childcare also exist in a parent system context such as organizational childcare policies and community networks that support childcare, for example: public policies focused on the health and education of children and adolescents, the availability of places in daycare centers, and institutions for integral healthcare for children.

With a larger workforce operating more remotely than many information technology (IT) teams might have previously anticipated, organizations find themselves particularly exposed [62]. Thus, a relevant first-order parent system is the information system (IS) since most security architecture is based on intranet protection or company asset protection. The IS parent system needs to provide requirements for the WFHS such as tightening security through VPNs, authenticators, antivirus, and BYOD (bring your own device) client security measures. Due to a lack of cyber expertise among individuals, IT experts are urged to devise novel techniques for work supervision and policies that guarantee digital security for remote workers [68]. This could lead to escalated stress, a constant state of vigilance, feelings of surveillance, and apprehension related to continuous monitoring, ultimately impacting internal communication, interpersonal relationships, the organizational atmosphere, job contentment, organizational commitment, employee involvement, and employee well-being [64]. Other IS issues that can be mentioned in this layer are the help desk, ERP (Enterprise Resource Planning), CRM (Customer Relationship Management), and supply chain management (SCM) systems, all of which require greater resources. Business, customer, and supplier policies and processes provide the context for the development of IS. Thus, the critical incident management team (CIMT) can be considered as a second-order parent system. In the context of COVID-19, CIMT have to consider dual modes, i.e., online and offline service deliveries.

This hierarchical level mandates the requirement for IS to have the agility to swap quickly between the two modes or to run concurrently. For example, in the education industry, there have been swaps between online and offline learning, mixed with blended or hybrid learning. In many instances, the learning delivery systems have moved from face-to-face lectures with a Learning Management System (LMS) to full support for e-learning. As students return to campuses, new hybrids of face-to-face learning and LMS support are likely to emerge. This may affect WFHSs as they will have to have access to the LMS of both online and face-to-face systems. The WFHS must have alert systems to switch from one mode to another. The business policies also dictate the budget for the WFHS (i.e., an economic aspect) and a health component (i.e., a social aspect).

A third-order parent system, Government Movement Control Orders (MCOs), includes quarantines, lockdowns, mask wearing, social distancing, vaccine mandates, and restrictions on gatherings, which all influence businesses to comply, which in turn influences the company policy to change to partially/fully online. This will influence the WFHS to change accordingly. Organizations must consider the trends and predict the cycle of infections so as to determine the best business response (i.e., to go online/face to face/partial and for how long). This is directly affected by the vaccine policy (or lack thereof) systems as well as the public engagement and education on safety behaviors. The health system, including its management, infrastructure, accessibility of the population, and availability of the workforce, will be crucial for supporting businesses and government systems.

Finally, a fourth-order parent system is the natural virus system considering the lifecycle of the current COVID-19 pandemic, including new strains and the vaccination (or lack thereof) process. WFHS designers must evaluate whether the COVID-19 lifecycle is short term or long term so as to provide an optimized solution, considering which measures related to work organization will be maintained regardless of the course of the pandemic. This includes considering the uncertainties of new life cycles of COVID-19

(e.g., the Omicron variant) and the possibility of WFHSs becoming permanent in the lives of people and organizations, even if intermittently. Due to the systemic nature of a pandemic [35], both public and private entities holding rights to medical remedies must transcend their domestic boundaries and immediate economic concerns. Instead, they should consider the viewpoints of economically disadvantaged nations and marginalized social segments. In a pandemic scenario, isolated strategies tailored solely to individual countries prove unsustainable over time. Hence, interconnectedness prevails across all solutions [36], underscoring the necessity for adopting a system-of-systems perspective.

### *4.3. Multiple Goals and Their Conflicting and Overlapping Relationships*

As the pandemic affected many parties and systems, it involved several stakeholders. Table 4 illustrates some of these stakeholders and provides examples of their respective goals. It is not intended to be exhaustive.

**Table 4.** Stakeholders and examples of their goals.

| Stakeholders | Goals |
|---|---|
| Worker | Stay healthy<br>Work–life balance, Retain job/Job satisfaction |
| Worker's family | Study/work/Enjoy family routine |
| Systems design team | Home office E/HF, Comfort in the work environment Low cost, efficient, and easy to build |
| Organization (employer) | Cyber security, Enhance productivity, Low operation costs<br>Worker well-being |
| Customers | Quality of service/product |
| Partners | Supply chain efficiency |
| Hospitals | Treating patients infected with COVID-19<br>Treating patients with other illnesses/injuries |
| Government | Efficient measures to protect the population, Economic growth |
| Society | Health and well-being for all, Reduce negative impacts on SDGs<br>End pandemics |

Source: Authors.

The SSoSs framework helps to identify conflicting and overlapping relationships between the different goals of the stakeholders. Conflicts can occur within a system as well as between the different hierarchical levels of the system of systems. For instance, working from home can disrupt the family's work–life balance (i.e., within the WFHS) and reduce the worker's productivity (i.e., conflicting with the employers' goal of maintaining profits). It should be noted that there are also efficiencies, like saving on commuting time and being able to do two tasks at the same time (e.g., cooking a meal while attending an online meeting).

On the other hand, stakeholders can take actions where mutual goals are met. For example, the social goal of being protected from COVID-19 infection is shared by all stakeholders, from workers and their families staying healthy, to organizations and governments developing safety protocols, to society as a whole working towards ending the pandemic. From an economic perspective, workers aim to maintain their income to support the family, organizations aim for productivity and profit, and governments seek to recover the economy. Goals related to the natural environment may involve reducing pollution and energy use, resulting from a reduced use of transportation and company facilities. However, while the company's offices might reduce consumption, the resource consumption may be spread amongst multiple households. In effect, this might mean that overall consumption increases and the efficiencies of centralization are lost (e.g., the need for air conditioners in multiple households instead of an energy-efficient HVAC system in one building). Despite the need

to reconcile the multiple goals, the overarching goal should focus on the highest-level system goals (i.e., the natural system goals) such as the protection of humanity from current and future virus pandemics. All multiple goals must be aligned to achieve this goal.

### *4.4. Adaptive Cycles and Their Revolt and Remember Processes*

Closely related to the lifespan of systems is the importance of considering their adaptive lifecycles and system stages, as well as the complex relationships between them.

The most complex, largest system being considered is the natural system, i.e., the COVID-19 pandemic. As long as the pandemic remains in the conservation stage (e.g., continued virus circulation, continued population vaccination rates, and no new variants) it will act as a stabilizing force to any changes in government policies in what can be understood as a remember process [31]. The SSoSs framework proposes that the cascading impacts throughout the system of systems should be considered. In a situation where the pandemic is not fully controlled by immunizing the entire population, organizations will have to maintain policies and systems (e.g., WFHSs, safety work practices, and business policies) designed to keep functioning in times of lockdowns, workers will continue to work from home, and the tasks and modes of delivery will remain. However, when there is a shift from the conservation stage (i.e., new COVID-19 variants emerge, new vaccines or treatments become available, etc.), this will have a destabilizing effect on the system of systems requiring a re-think of available or new strategies.

From another perspective, the cascading impacts can be considered from less complex to more complex systems. Thatcher and Yeow [17] explain that when a smaller system reaches the release stage, it can provide an opportunity to influence change in larger systems. For instance, when individual work systems reach the release stage (e.g., changes in responsibilities), the WFHS will be required to modify so that workers can carry out their activities in a new way. This will mean that existing policies and systems need to be reconsidered by organizations (e.g., issues of safety and technology and equipment needed to support new work activities) and governments (e.g., worker protections, labor legislation, etc.). Finally, actions of governments and of society as a whole, such as accelerating the immunization of the population and respecting safety guidelines to avoid infection (and consequently, virus mutations), may impact the pandemic (e.g., prevent the emergence of new viral variants and the reduction of disease cases and deaths).

Figure 5 summarizes the power of SSoSs in designing WFHSs and shows how the higher level systems "remember" (provide constraints directly to the target system) and the lower levels "revolt".

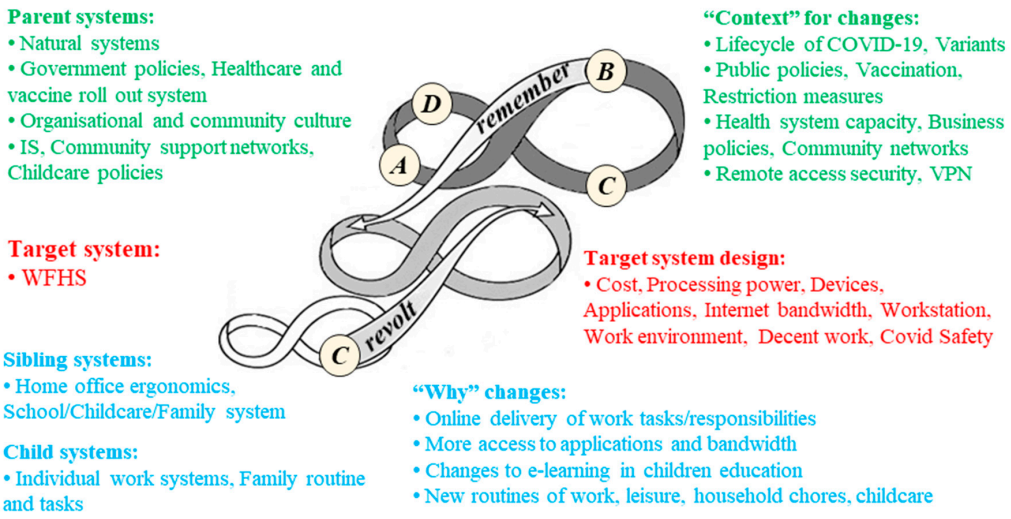


**Figure 5.** System requirements for WFHS design. Source: Authors' own creation. Note: Growth/development (A), conservation/consolidation (B), release/creative destruction (C), and reorganization/destructuring (D).

## 5. Transforming the SSoSs Concept into Practical Actions

The SSoSs framework does not provide a step-by-step approach to systemic innovation. Instead, it allows one to characterize the various relevant systems and their impact on an innovative, sustainable solution, to identify multiple intervention points and to make predictions about how they might influence other systems, and to predict how often one will have to intervene with a new iteration of the intervention. In this sense, finding innovative design solutions for WFHSs involves considering the possibilities and frequency of intervention at each level of the SSoSs, as well as the social context in which they would take place.

### *5.1. Identifying Intervention Points for Sustainable Interventions*

Thatcher and Yeow [33] pointed out that according to the SSoSs framework, it is possible to intervene in the following ways: top-down, bottom-up, and target system interventions. Top-down intervention is important due to the constraints posed by COVID-19 to organizations to switch to an online/hybrid mode of work. Bottom-up intervention is also important due to the "revolt" process [31], for example, the change in work tasks in online delivery that demand the WFHS to scale up in terms of processing power, bandwidth, access to information systems, and security features. Lastly, the target system intervention (i.e., the direct requirements of the WFHS) should be considered. For instance, this might include the type of end-user computing software, remote access, hardware, networks, the work procedures, the user interface, job scope/title, and database access. Congruent to the complex adaptive cycle, the target system has to co-evolve together with the higher- and lower-level systems. Thus, its requirements must be driven not only by itself but by the child, parent, and sibling systems.

To cultivate sustainable and systemic innovations geared towards shaping the framework of the WFHS design, the intervener can opt for either or both of the following strategies: (i) attain a more profound insight into the parent systems, assessing their readiness for transformative change (innovation) and/or (ii) harness the relatively swift pace of change in child systems to instigate innovation within the target system (i.e., propelling the target system towards the release phase). A comprehensive comprehension of SsoSs' dynamics may also unveil the reasons behind an intervention's lack of success. For instance, the intervention might not have garnered support from overarching parent systems, or the intervener's projections regarding the pace of change might not align with the natural lifecycle of the child system. However, delving into such revelations will necessitate the adaptation of the existing toolkit for systems' analysis [3,78].

### *5.2. Iteration of Systemic Interventions*

The SSoSs framework highlights that interventions within adaptive systems are not isolated events; they inherently involve a process of iteration, and the frequency of iteration is contingent on the hierarchical positioning of the target system. Interventions concerning relatively simpler systems will necessitate more frequent iterations compared to relatively more intricate systems, irrespective of the meticulousness of their planning and timing.

Furthermore, it is important to acknowledge that the pace of iteration hinges on the specific locus of intervention by the practitioner. If the intervention focuses on work practices, the intervener will need to engage in a higher number of work design iterations compared to interventions aimed at altering organizational policies, for instance, the urgency for swift transitions to online meetings followed by subsequent rapid adjustments to establish appropriate meeting protocols (like toggling cameras, document sharing, and breakout rooms). As a result, the target system (in this case, WFHSs) must stay responsive to the rapidly changing dynamics of lower-level systems, as these changes have the potential to trigger a transformation (revolt) within the system.

## 6. Conclusions

The COVID-19 pandemic accelerated the adoption of WFHSs across various sectors, making them a central element of the evolving work landscape. This study aimed at applying the SSoSs framework to find innovative design solutions for WFHSs, underscoring the critical importance of integrating sustainability principles into the design of WFHSs in a post-pandemic world.

Sustainability within the context of WFHSs is a pressing concern, yet it is underexplored. This paper fills a significant research gap by focusing on sustainability aspects within post-pandemic/endemic WFHSs, highlighting their increasing relevance. The application of the SSoSs framework represents a novel approach to address the sustainability challenges associated with the WFHS design. It provides a system-of-systems perspective capable of comprehending complex interrelationships among multiple systems, offering a fresh and comprehensive viewpoint on this evolving work paradigm.

This study recognizes that sustainability in WFHSs is a multifaceted issue that involves various interrelated systems. This perspective is crucial for understanding how to incorporate the multiple sustainability dimensions in work systems. Furthermore, this research contributes to both academia and practical applications by characterizing relevant systems and their influence on the design of sustainable WFHSs, enabling organizations to make informed decisions. The identification of multiple intervention points and predictions of their potential impact on other systems offer practical guidance for enhancing WFHSs' sustainability. Thus, this study not only addresses a timely and critical research gap but also offers actionable insights for organizations navigating the evolving work landscape, highlighting the essential role of sustainability in the WFHS design, and paving the way for more resilient and sustainable future work systems.

Regarding the limitations of this study, conceptual and methodological points should be noted. First, this study is focused only on the SSoSs framework, and other systems' analysis frameworks, such as AcciMap [20], CWA [21], EAST [22], FRAM [23], HFACS [24], and STAMP [25], can be used to add value to understanding the nested hierarchy of systems and the specific aspects of sustainability in WFHSs. Second, the identification of relevant systems and the collection of data from the interrelated and interacting systems can be reinforced through the extension and updating of published studies given the growing scientific production on sustainable work systems. Third, conducting empirical and practical studies is fundamental to test and validate the proposals for design solutions for WFHSs generated in this study. It should be emphasized that this study did not aim to create an exhaustive list of issues related to COVID-19 that impact work at various system levels. Therefore, it is important to stress the importance of future empirical studies, not only to validate the issues we have pointed out but also to identify new ones.

Building upon the insights gained from this study, several promising avenues for future investigation emerge. Future research should delve deeper into assessing the long-term sustainability impacts of WFHSs. This entails examining how WFHS adoption affects environmental, social, and economic sustainability over extended periods. Longitudinal studies can provide valuable data on WFHSs' enduring effects and can guide policy and organizational decisions. Another important research avenue is related to the socioeconomic implications of WFHSs, which warrant further exploration. Research can focus on issues such as access to WFHSs' resources, equity in remote work opportunities, and the effects of WFHSs on job security and income disparities. Understanding these aspects can help design more inclusive and equitable WFHSs.

Given the increasing role of technology in WFHSs, future research should continue to explore innovative technological solutions that enhance sustainability. This includes investigating the environmental footprint of WFHSs' technologies and developing eco-friendly solutions. Additionally, studies on the integration of emerging technologies like augmented reality and virtual reality into WFHSs can provide insights into future work scenarios.

Finally, future research efforts should consider that the health and well-being of remote workers are vital aspects of sustainability. Future research can delve into the physical and mental health effects of prolonged WFHSs, as well as strategies to enhance well-being in remote work environments. As WFHSs become a prominent aspect of the work landscape, governments and organizations will require effective policies and regulations. Future research can focus on developing and evaluating policy frameworks that promote sustainability in WFHSs, including incentives for eco-friendly practices and guidelines for remote work infrastructure.

As previously discussed, and as supported by expert views and scientific evidence, it is not pessimistic but rather realistic to anticipate the occurrence of future pandemics. The discussion should not focus on whether there will be an outbreak but rather on when new outbreaks will happen [14]. Thus, if one desires a sustainable future, now is the time to understand how to develop a new paradigm in sustainable work systems.

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