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Review

Ambient Assisted Working Solutions for the Ageing Workforce: A Literature Review

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Abstract: The increase in older workers in industrialized countries has become evident in the past two decades. The need to support the ageing workforce to effectively perform their tasks has resulted in Ambient Assisted Working (AAW), consisting of developing "smart" systems that can adapt themselves to workers' needs by exploiting ambient intelligence (AmI) solutions. In AAW, AmI provides flexible workplace adaptations for a wide range of older workers (including persons characterized by chronic conditions and disabilities), while ensuring the ageing workforce's safety and comfort within the workplace. This work proposes a systematic literature review with the aim of identifying trends among existing AAW solutions specifically designed for older workers. The review adopted the PRISMA methodology, focusing on journal articles and surveying more than 1500 works. The review underlined an absence of articles completely devoted to this research question. Nonetheless, by extending the research question to existing AmI solutions for workers that could potentially be able to support older workers in performing their working activities, it was possible to draw some considerations on the adoption of AmI for the ageing workforce. Among them, the review identified the different types of supporting AmI solutions provided to AAW, which technologies were adopted, and which workplaces were investigated the most. Finally, this work leveraged the findings of the review process to sketch some future research directions for AAW as a discipline.

Keywords: ambient assisted working; ageing workforce; ambient intelligence; smart office

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1. Introduction

In the past two decades, the ageing of society has become evident. In particular, European, American, and Asian industrialized societies are facing issues related to ageing, with researchers from many fields investigating possible solutions to tackle ageing's issues effectively. Ambient Assisted Living (AAL) has illustrated how ICT technologies can be effectively adopted to support older adults during daily living, increase their wellbeing, and provide personalized services. With the contributions of Internet of Things (IoT) technologies and increasing attention towards ambient intelligence (AmI), AAL solutions have become increasingly sophisticated in providing inhabitants with smart environments able to adapt themselves to the context.

The ageing of industrialized societies has brought out the problem of an ageing workforce (AW): higher life expectancy, late retirement policies, and low birth rates significantly contribute to increasing the proportion of older workers in Western countries every year. The AW is characterized by workers aged 55 or older who may also be characterized by physical and cognitive limitations [1]. Older workers may be affected by the physiological and physical consequences of ageing, such as chronic conditions, loss of muscular strength, and decline in vision and hearing. From a cognitive perspective, it was pointed out that older workers may face a gradual deterioration of fluid abilities—i.e., abilities necessary to process information [2]. In addition, the AW's skills face obsolescence, which might hinder their productivity. However—as investigated in some studies (e.g., [3])—the presumption of a connection between a decline in skill and working abilities and increasing age in older workers is incorrect. Older workers are willing and able to work longer, as their expertise and abilities—developed over many years of work—are precious in many industries [4].

The share of older adults in industrialized societies is destined to increase progressively in the next decades. In European countries, the AW accounted for the 12% of the total workforce in 2004; in 2019, this share grew to 20%. Aging Europe's report illustrates that more than 40 million older workers are employed in the EU-27 (with 22.4 million people aged between 55 and 59, 12.8 million people aged between 60 and 64, and 5.1 million people aged more than 65) [5]. In the USA, the Bureau of Labor Statistics highlighted a consistent increase in the percentage of older workers, which increased by 117% between 1994 and 2014. In 2018, older workers' share reached 24% (ten years before, the share amounted to 18%) [6]. In addition, the share of younger workers is expected to reduce in the next eight years, while older workers' share is projected to increase considerably by 2030 [7]. A recent work indicated that the participation of older adults in the labor force in developing Asian countries has been consistent since the 1990s, marking 60% of individuals aged 60 and over as actively employed [8] (rates vary across countries: e.g., Thailand reached "only" 56.9%, while Indonesia rose up to 64.9%).

These data show that the AW poses some organizational, management, and health challenges. Older workers may be affected by some health issues, including chronic conditions. These modifications in their health conditions may impact their productivity—in terms of leaves of absence due to illness or inability to perform work tasks. Working activities can exacerbate ill health conditions, thus increasing sickness absence rates. For example, 40% of older European workers reported that work affected their musculoskeletal and psychosocial symptoms, including stress [9]. In Europe, more than a quarter (28%) of the workforce report suffering from a chronic condition. Therefore, policymakers are concerned about the rising share of older workers that may become unable to sustain their employment because of chronic health issues [10]. Longstanding illness can result in limitations on their ability to work, according to the nature and severity of the condition, and may result in workplace accommodations—i.e., employers adapting the physical workplace or the working activities to accommodate workers' health needs. Similar data characterized the USA in 2015, where cardiovascular, respiratory, and metabolic diseases could hinder the work ability of older workers—although not always resulting in complete disability [11].

During the last decade, it has become evident that older adults require dedicated support systems and policies to help them work efficiently, cope with their chronic health conditions, and prevent their abilities' deterioration. The emergence of AmI and the IoT in health-related areas and the possibility to enhance older adults' quality of life provided by AAL solutions has led to a new paradigm—Ambient Assisted Working (AAW) [12,13]. Often seen as a consequential step towards AAL, AAW consists of the development of systems able to adapt themselves to workers' needs. It exploits AmI to provide flexible workplace adaptations for a wide range of older workers, including persons characterized by chronic conditions and disabilities, while ensuring the AW's safety and comfort within the workplace. In other words, AAW is aimed at supporting older workers in a variety of workplaces, helping them in different activities through the deployment of technologies that can range from wearable and environmental sensors to cyber-physical systems, as well as involving artificial intelligence (AI) to analyse data. Taking into account the evolution of technologies and their pervasiveness in different working environments, AAW has the potential to revolutionize working activities for the AW, shifting the paradigm from "societal issue" to "economic and productive resource".

In the wake of the interest in AmI, it is worth asking whether there exist any AmI or "smart" solutions specifically designed for the AW's needs (RQ1) and which trends are guiding the development of "smart solutions" for older workers (RQ2). Considering the increasing amount of the AW, these questions are urgent to enable older workers to efficiently continue their working activity without incurring health-related issues. In particular, RQ1 investigates which existing AAW solutions are currently being investigated to effectively tackle the demographic transition that may influence key industries in the USA, Europe, and Asia [14], thus avoiding drawbacks to nations' economies. RQ2 attempts to identify which technologies are being exploited as enablers of AAW: considering that AAW—similarly to AAL—adopts different technologies, the possibility of understanding the trends of this discipline can guide researchers and employers in their activities towards more reliable and easy-to-deploy solutions. Therefore, this work aims at the following:

- RQ1: Identifying all the existing AAW solutions specifically designed to support the AW in one or more activities or workplaces;
- RQ2: Identifying the main AmI technologies underlying the solutions retrieved in RQ1 to which researchers have devoted particular attention.

This review contributes to the research on AAW by enabling the identification of the existing (and different) solutions described in the scientific literature and the recognition of the main AmI technological trends for older workers guiding the development of novel solutions in this field. Moreover, the review approach can also reveal research gaps that must be investigated to allow AAW to reach its full potential.

2. Methodology

To identify the different AmI solutions adopted for the AW, a systematic literature review was performed. The process of source selection and analysis followed the PRISMA statement [15], which allowed us to identify and include different works on the topic at hand in a transparent and replicable way. The review considered journal articles published in English from 2010 to 2022 (November).

The whole process could be divided into three main steps:

1. Identification of relevant works. In this step, the ISI Web of Science, Scopus, and PubMed databases were selected for retrieving scientific articles pertaining to topics of the AW—summarized by keywords "Ambient assisted AND work*", "Ageing workforce", "Smart workplace", "Smart office", "Ambient Intelligen* AND work*". The databases' searches were restricted to the engineering and computer science subject areas, while limitations in timespan were not specified. The integration of the results retrieved via the different keywords enabled us to cover a wide range of journals. For each article retrieved, the title, abstract, and author list were collected. A total of 1598 records were retrieved.
2. Selection and inclusion. The records retrieved during the previous step were limited to English peer-reviewed articles and purged of duplicates: a total of 1589 journal articles were recorded as a result of these activities. The titles and abstracts of these works were thoroughly scanned separately by the researchers to avoid personal bias while keeping the review process consistent. The articles were selected or excluded based on the criterion that an article's title and abstract should refer explicitly to solutions dedicated to workers. At the end of this step, 55 papers met the criterion and were selected for the following step.
3. Full-text reading. In this step, the 55 papers were carefully scrutinized to understand whether the solutions described were specifically dedicated to the AW. No relevant journal articles from references were found while reading the papers. None of the 55 papers was found meeting this criterion.

As a result of step 3, RQ1—whether there existed some AmI solutions specifically designed to support older workers in their working activities—found an answer: the absence of works specifically devoted to describing AmI systems for working contexts characterized by older workers could indicate that the research filed was not yet mature enough, or that the emerging issues related to the AW were not yet tackled from an AmI technological perspective. Nonetheless, the papers retrieved in step 3 may present some worker-related solutions that might apply to older workers. Therefore, RQ1 was modified:

- RQ1a: Identifying existing AmI or "smart" solutions that could *potentially be able to support* older workers in performing their working activities, although not specifically dedicated to AW.

As highlighted in the Introduction, older workers may face different problems, ranging from physical disability to cognitive impairment. Age-related physiological and psychological changes can also significantly impact the AW's safety, organization of work, and perceived job demands [16–19]. To answer RQ1a, criteria must be identified to select the AmI solutions that could be potentially adopted in an AAW context.

As a consequence, we identified four criteria that were considered to identify solutions able to support the AW. As cognitive and physical decline and other health-related changes affect workers' reflexes and attention, AmI could propose systems to enhance older workers' safety during the execution of job-related tasks or working activities (e.g., solutions that prevent older workers from exposure to health risks) (*criterion 1*). Moreover, slower reflexes, deterioration of rapidity, back pain, and other musculoskeletal conditions might affect workers' physical ability to perform a job (or limit workers in performing some of its activities). A second criterion (*criterion 2*) regards the proposal of AmI solutions that could help older workers in coping with motor and muscular impairments and sensory disabilities (e.g., solutions that could help the AW in moving within the working environment). *Criterion 3* dealt with the cognitive sphere of workers: together with physical deterioration, cognitive decline may characterize older workers, thus constituting a problem for many professions. AmI solutions could help older workers in coping with cognitive impairments and organizational tasks (e.g., solutions to help the AW in memory-related tasks). There also exist conditions that do not impact on the working ability of the AW, but that might hinder workers' health in the medium and long terms (*criterion 4*): workers characterized by chronic health conditions (e.g., cardiovascular problems, respiratory issues, COPD, etc.) may have their work ability hindered by environmental conditions. Therefore, the fourth criterion regarded AmI solutions that could enhance the comfort and wellbeing of older workers while performing working activities (e.g., solutions to avoid environment-related exacerbations of health issues).

Therefore, papers retrieved at the end of step 2 underwent full-text reading (step 3) again to understand whether the AmI solutions described could be used to support the AW according to at least one of the criteria from (a) to (d). A total of 19 papers were found meeting the criteria underlying RQ1a. Figure 1 summarizes the outcome of the review steps.

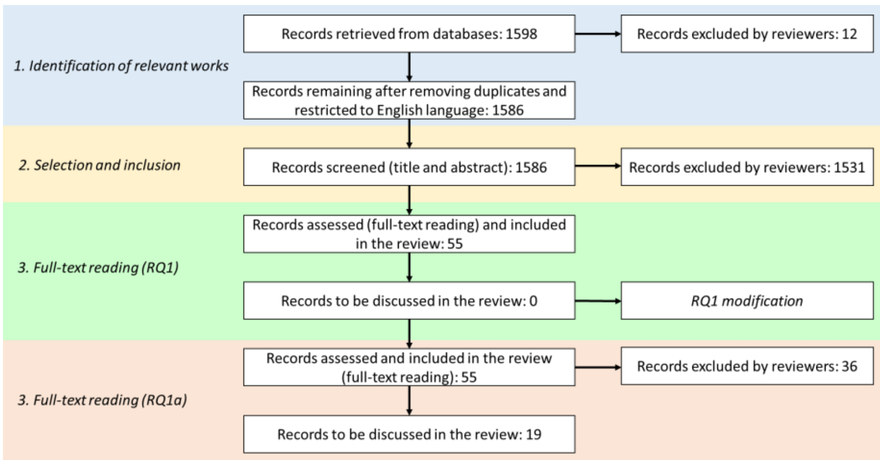

Figure 1. Overview of the literature review steps.

3. Results

This section analyses the review process results from temporal, geographical, and journaling perspectives of the articles, as well as from the side of their content.

3.1. Temporal Distribution of the Articles

The distribution of the articles according to the year of their publication is represented in Figure 2. It illustrates that the first scientific contribution advancing research on one of the four criteria for RQ1a belonged to 2010.

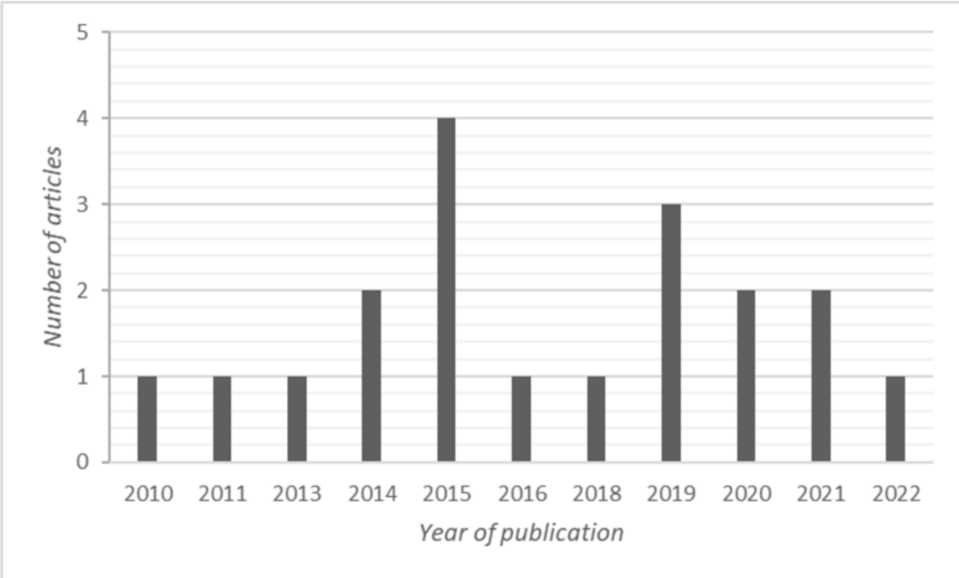

Figure 2. Distribution of the articles by year of publication.

3.2. Geographical Distribution of the Articles

The geographical distribution of the analysed works was conducted by considering the authors' affiliations. Each author was considered only once—therefore, the same authors contributing to different articles were counted as 1. Table 1 summarizes the authors' affiliations by geographical areas.

Table 1. Authors' affiliations by country (geographical area).

Country	Number of Authors
Brazil	3
France	1
Germany	9
India	9
Mexico	4
Portugal	4
Romania	5
Spain	29
South Africa	1
South Korea	16
Switzerland	1
USA	11

Institutions from Europe accounted for the majority of the contributions (with Spain constituting a considerable voice), although there were authors located in Asian areas and American areas.

3.3. Content Analysis

In this section, the papers are analysed according to different perspectives pertaining to the content.

3.3.1. Focus of the Articles

The analysed papers were clustered according to the four criteria drawn from the needs reported in Section 2. By leveraging these criteria, it was possible to hypothesize four clusters (H1) that supported recognizing specific workers' needs that the AAW solutions were supposed to aid.

Hypothesis 1 (H1). *Four clusters depicting the type of support for the AW.*

Hypothesis 1a (H1a). *Enhancing workers' safety*: In this cluster, articles proposing solutions primarily aimed at maintaining or enhancing the occupational safety of workers were collected. Therefore, it encompassed AmI solutions that were developed to support workers in working in a safe environment or enhance their safety awareness by using technologies deployed within the environment or worn by the workers.

Hypothesis 1b (H1b). *Supporting workers with motor or sensorial disabilities*. AmI solutions whose main aims were devoted to facilitating the coping of older workers with their motor or sensory disabilities were collected in this cluster. The technological solutions described in papers belonging to this cluster could concern any type of support granted to the human senses (e.g., hearing enhancement, vision-related aids, etc.), as well as any cyber-physical solutions devoted to overcoming the limitations imposed by a motor disability.

Hypothesis 1c (H1c). *Supporting cognitive and organizational tasks*. AmI solutions that actively assisted workers in complex cognitive tasks and in the organization of working activities (e.g., managing different data sources, monitoring several parameters, etc.) were included in this cluster. Articles describing technological solutions developed with the purpose of unburdening human operators of cognitive load or limiting workers' mental fatigue fell into this cluster.

Hypothesis 1d (H1d). *Enhancing workers' comfort and wellbeing while working*. This cluster included solutions adopting AmI to enhance indoor comfort metrics aimed to enhance workers' wellbeing or avoid the exacerbation of health issues related to environmental metrics (e.g., monitoring air-conditioning systems to avoid neck pain or adjusting luminosity settings to improve workers' productivity). As indoor comfort metrics can be related to workers' health conditions and productivity, any solutions addressing problems related to workers' comfort belonged to this cluster.

Table 2 reports for each cluster the articles proposing a solution devoted to tackling one or more aspects characterizing the cluster.

Table 2. Articles clustered according to the type of support they described for the AW.

Cluster	Articles
H1a. Enhancing workers' safety	Coughlin et al. [20]; Osunmakinde [21]; Pancardo et al. [22]; Bhatia & Sood [23]; Jo et al. [24]; Singh et al. [25]
H1b. Supporting workers with motor or sensorial disabilities	Bajo et al. [26]

Table 2. *Cont.*

Cluster	Articles
H1c. Supporting cognitive and organizational tasks	Irizzarry et al. [27]; Martin et al. [28]; Sanchez-Pi et al. [29]; Vales-Alonso et al. [30];Pimenta et al. [31]; Bogdan et al. [32]
H1d. Enhancing workers' comfort and wellbeing while working	Fernández-Montes et al. [33]; Muñoz et al. [34]; Naqi et al. [35]; Baedeker et al. [36]; Sun et al. [37]; Zhao et al. [38]

With the sole exception of (H1b), the criteria were consistently distributed (six papers for H1a, H1c, and H1d). Bajo et al. [26] was the only selected paper dedicated to supporting workers affected by a disability in performing their job (H1b); in particular, the article presented a solution to ease interactions between musicians with vision-related impairments and orchestra conductors. The system—named DIAMI—was specifically thought to help blind or vision-impaired musicians in working with other musicians and in learning contexts and symphonic orchestras.

Regarding workers' safety (H1a), Coughlin and colleagues [16] developed a system that supported drivers in facing stress, inattention, and fatigue to improve their on-the-road safety and performance. The authors mentioned the possibility that this system (AwareCar) might be particularly useful for older workers since they might have slower reflexes. Osunmakinde [21], Jo et al. [24], and Singh et al. [25] presented three solutions dedicated to the safety of miners—a category of workers often exposed to toxic gases. Monitoring the mine environment and the presence of gases, as well as controlling environmental conditions that can hinder workers' health (e.g., high temperature, humidity, etc.), is pivotal to ensuring miners' safety while working. The work in [23] leveraged AmI to monitor office workers and the environment to develop a predictive healthcare environment to prevent workers' risks. The proposed solution also acquired data to support clinical personnel in decision making over time. Pancardo et al. [22] described an AAW process for workers' heat stress estimation that was able to alert them in a timely manner when stress conditions rose; the proposed solution was devoted to those workers that worked in particularly hot environments and performed physical labor, thus facing the risk of heat stress (which may lead to heat strokes, occupational illness, and injuries).

The topic of supporting workers while performing tasks using technologies (H1c) was investigated in different ways in the sample of papers analysed here. The general adoption of AmI (and digital technologies) to help workers seemed to be dependent on the specific working activities addressed. For instance, Irizarry and colleagues [27] leveraged the AmI of Building Information Modelling and Augmented Reality to develop a collaborative environment to ease facility managers in decision making for healthcare facilities. An AmI tool was the basis for ES4HP [28], an application developed with the aim of supporting the personnel of hospitals' pharmacies in retrieving products in an easier way. In the area of professional volleyball training, Vales-Alonso et al. [30] combined digital and monitoring technologies to control exercise fatigue and effort for players, while acquiring data regarding players' movements to assess training quality. Sanchez-Pi et al. [29] enriched a petroleum plant working environment with AmI to develop a smart system devoted to facilitating alarm management; plant operators were supported in their interactions with the environment via a multiagent management system. Offices and industries are workplaces involving several millions of workers all over the world: mental fatigue may cause human errors, and AmI technologies could be used to support fatigue detection and acquire data to understand the interventions that could be deployed [31]. Bogdan et al. [32] integrated voice assistants in a smart office: assistants should be able to unburden office workers in the execution of some tasks, as well as automating them.

3.3.2. Technologies Involved

It was interesting to investigate what technologies were involved in the solutions proposed by the analysed papers. Considering the older workers' needs highlighted in Section 2, technologies should be aimed at reducing the health-related risks of the AW, monitoring environmental conditions to prevent the exacerbation or insurgence of any health-threatening or unsafe conditions, and assessing the activity of older workers. These adoptions of sensing technologies are also at the core of AAL solutions [39,40]; AmI requires sensing technologies to be deployed to gather data from different sources, aiming to assess different dimensions. Therefore, a hypothesis (H2) was made on the role AmI technologies played in the articles retrieved.

Hypothesis 2a (H2a). *Environmental sensors*: The papers belonging to this cluster foresaw the adoption of technologies devoted to monitoring the environment in which older workers worked (in terms of comfort metrics, such as temperature, humidity rate, illuminance, etc.).

Hypothesis 2b (H2b). *Workers' physiological data monitoring*: The articles falling into this cluster foresaw workers' physiological conditions (e.g., temperature, heart rate, stress, etc.) being monitored with wearable technologies while they performed working activities.

Hypothesis 2c (H2c). *Working activity monitoring*. This cluster collected articles that described the monitoring and assessment of workers' activities in terms of their output or job performance (e.g., the productivity of workers, the time workers started or finished an activity, etc.).

Table 3 provides an overview of the technologies (and their purposes) adopted by the articles.

Table 3. Articles clustered according to the type of technologies described in the solutions.

Article	Involved Technologies		
	Environmental sensors	*Worker monitoring*	*Working activity monitoring*
Bajo et al. [26]		✓	
Coughlin et al. [20]		✓	
Osunmakinde [21]	✓		
Fernández-Montes et al. [33]	✓		
Irizzarry et al. [27]	✓		
Martin et al. [28]	✓		
Pancardo et al. [22]	✓	✓	
Sanchez-Pi et al. [29]	✓		
Vales-Alonso et al. [30]	✓	✓	✓
Pimenta et al. [31]	✓		
Muñoz et al. [34]	✓	✓	
Bhatia & Sood [23]	✓	✓	
Jo et al. [24]	✓		
Naqi et al. [35]	✓	✓	
Baedeker et al. [36]	✓		
Sun et al. [37]	✓	✓	
Bogdan et al. [32]	✓		
Zhao et al. [38]	✓	✓	
Singh et al. [25]	✓	✓	

The possibility of monitoring environmental metrics in indoor workplaces was investigated in almost all of the papers analysed. Conversely, only 10 papers adopted technologies to monitor workers' physiological parameters as input for the AmI systems described. Directly monitoring workers' performance (or productivity) was explicitly stated in only one work.

Pancardo et al. [22] combined environmental monitoring using temperature and humidity sensors placed on smartphones with heart rate to calculate real-time heat stress levels and make use of basal metabolic rate and metabolic-equivalent tasks to estimate the workloads workers were subjected to. Physiological measurements (heart rate, oxygen concentration in the blood, performance-related parameters) and the positions of players on a volleyball court were the center of the solution described by Vales-Alonso et al. [30], while in [34], office workers were asked to configure their own automation rules in an emotion-aware AmI application to foster productivity and performance; by leveraging semantic representations of a smart office environment, emotions were used to adapt the environment (music, indoor lighting, image broadcasting) to worker's preferences. The smart office described in [23] was aimed at providing efficient healthcare service and acquiring data regarding workers' vital signs (heart rate, blood pressure, body temperature), activity (walking, sitting, laying, standing), and environment (air quality, temperature, noise level) via a network of smart wearables and ambient sensors. Naqi et al. [35] addressed the topic of energy savings in buildings while enhancing workers' comfort; they proposed a smart office that monitored workers' presence, temperature, and humidity while sitting on a chair to enable indoor comfort (intervening in the HVAC system). Working environment optimization was the focus of Zhao et al. [38], who acquired several pieces of data from users (heart rate, respiration rate, facial features, and electroencephalogram) to adapt a working space via mediated atmospheres (lighting, sound, and video projections within the office environment). A real-time surveillance helmet for mine workers developed in [25] recorded the miners' location and heartbeat, as well as the presence of hazardous gases and dusts in the environment, while Sun et al. [37] proposed a system leveraging wearables and biosensors to capture workers' locations, physical and cognitive states (measuring heart rate, temperature, electrocardiogram, electroencephalography, electromyography, blood pressure, galvanic skin response, eye tracking, weight insole, and glucose level), and environmental metrics (lighting, indoor temperature, humidity rate, CO_2 concentration, volatile organic components, pressure) to enable a holistic workforce health management and analytics platform.

Monitoring the movement of an orchestra conductor's baton was the core of the AmI system suggested by Bajo et al. [26] to support vision-impaired musicians in playing: in this case, the environment was limited only to the baton movements performed (and tracked) within a specific space (the range of the sensor). Similarly, the AwareCar system [20] focused attention on measuring a drivers' state, limiting environmental description to the weather and traffic conditions.

Osunmakinde [21] and Fernández-Montes et al.'s [33] focuses were mostly on the environment. In the first case, the aim of the AmI solution proposed was to enhance miners' safety by identifying dangerous gases within the environment, while in the second article, a prototypical smart office aimed at gathering workers' habits regarding indoor comfort metrics for energy-saving purposes was presented.

With regard to workers' productivity measurement, the article by Vales-Alonso et al. [30] was the only work that measured the performance of workers directly. In this case, the workers were professional athletes; therefore, measuring their performances during training was pivotal for the proposed system to assess training quality. In [20,31,34,36,37], workers' productivity (or performance) enhancement was explicitly mentioned as a consequence of the deployment of the AmI solutions described; nonetheless, it was not detailed how performance or productivity were measured.

3.3.3. Workplaces Involved

The analysed papers focused their attention on specific working situations, most of which were envisaged within a particular type of workplace. Table 4 summarizes the workplaces for which the AmI solutions described by the articles were developed.

Table 4. Articles paired with the type of workplace they were focused on.

Article	Workplace
Bajo et al. [26]	Orchestra
Coughlin et al. [20]	Driver's seats/Road
Osunmakinde [21]	Mine
Fernández-Montes et al. [33]	Office
Irizzarry et al. [27]	Healthcare facility/Hospital
Martin et al. [28]	Healthcare facility/Hospital
Pancardo et al. [22]	Industry, plants, mines, tunnels (any place where workers may be affected by heat stress)
Sanchez-Pi et al. [29]	Petroleum platform
Vales-Alonso et al. [30]	Volleyball court
Pimenta et al. [31]	Office/Industry
Muñoz et al. [34]	Office
Bhatia & Sood [23]	Office
Jo et al. [24]	Mine
Naqi et al. [35]	Office
Baedeker et al. [36]	Office
Sun et al. [37]	Industry
Bogdan et al. [32]	Office
Zhao et al. [38]	Office
Singh et al. [25]	Mine

The predominant workplace was the office (eight articles), followed by mines (four articles) and industry (three papers). Healthcare facilities accounted for two papers, while the other analysed works investigated heterogeneous industries. It is worth noticing that some articles described solutions that could be applied to different types of workplaces.

4. Discussion

In this section, the results presented in the previous section are discussed.

The most relevant result to be discussed is that the original research question (RQ1: whether there exists AmI or smart solutions specifically designed for the needs of the AW) failed in finding results. In other words, no journal article regarding AmI systems specifically designed for older workers was retrieved. This highlighted that—notwithstanding the data and general concern about the rise of the AW in industrialized countries—more research is needed to tackle this social and economical issue effectively. Nonetheless, in other research areas, interest regarding the AW's needs and the challenges it entails is vivid—e.g., many studies in the field of safety and occupational health have emerged in recent years to offer possible solutions to tackle these challenges [41,42]. Therefore, it is plausible that researchers may soon turn their attention to AAW, as its issues should become more and more prominent in the upcoming decades. As mentioned in the Introduction, AmI technologies are mature to face AAW challenges, and there has been a general awareness about the possibility of adopting monitoring and environmental sensors to ease the working activities of older workers since the early 2000s [43].

In addition, the modification of the original research questions in RQ1a (existing AmI or "smart" solutions that could *potentially be able to support* older workers in performing their working activities, although not specifically dedicated to the AW's needs) underlined that workers and their needs are an investigated application field for many AmI researchers. In particular, the results summarized in Table 1 underlined that the majority of contributions come from those countries that are starting to face issues related to older workers and need to manage the AW on economic and societal levels. For example, Spain, Portugal, and Germany are among the EU countries characterized by high shares of older population (aged 55 and over) that reach 30% and are projected to reach 40% by 2025 [5]. In addition, South Korea is an emblematic case of ageing, with people aged 65 and over accounting for 20% of the national population by 2026 [44].

Again, the opportunities provided by AmI in working environments have been investigated since the early 2000s [12], and the focus on AAL—due to the emergence of the general ageing of populations in industrialized countries (of which the AW is a consequence)—has enabled researchers in improving and testing different solutions. However, the step towards AAW is not immediate, as some issues need to be faced—some of them inherited by AAL.

4.1. Open Challenges Inherited from AAL

Among the challenges AAW inherits from AAL, a relevant role is played by the willingness to accept AmI and their monitoring devices. As illustrated by the results in Table 3, half of the analysed papers relied on sensors or wearables to monitor some physiological or cognitive aspects of workers. Privacy and intimacy represent serious concerns for residents' acceptance of AAL solutions [45,46] and might hinder their full integration into daily life's domestic activities. The same issue may present itself in AAW: monitoring workers may pose ethical and legal concerns—many countries do not allow for workers' real-time monitoring, particularly if monitoring may result in automatic methods to assess workers' performances or productivity on the job.

In the sample of papers analysed in this review, only one work focused on monitoring workers' performance—a very particular case of professional athletes [30], where volleyball players monitored via wearables were assessed during training with the aim of enhancing their performance. This specific case may not raise any concern, considering that athletes should aim for the best performance possible; thus, they might be interested in having data that can support them in improving. However, some of the AmI solutions retrieved in the sample ([20,31,34,36,37]) took place in contexts where workers did not compete among themselves or on opposing teams (e.g., offices, industries, etc.), and these solutions explicitly mentioned their purpose of enhancing workers' productivity. It is worth noting that the mentioned works "lacked" in indicating *how* this productivity was measured and how the increase in productivity was related to the AmI systems. On the contrary, these papers assumed that an increase in environmental comfort conditions resulted in more productive workers. A possible explanation for the lack of precision in measuring productivity and its fluctuation might be related to the ethical concerns underlying the research question.

In addition, the proposed AmI solutions required workers to wear sensors and other equipment for different purposes. However, some workplaces (in particular, manufacturing factories, plants, construction sites, and mines) have standardized safety policies and protocols that might object to having workers excessively equipped, as some of the wearables might impede the regular course of their working activities.

While monitoring environment to support workers may not entail any ethical concern, monitoring the workers themselves—and directly or indirectly assessing their productivity—may result in a significant barrier towards the further deployment of AAW systems (from an ethical and practical perspective).

4.2. AAW and Industry 4.0

The issues presented above are shared with Industry 4.0 solutions—which also exploit AmI heavily. As pointed out in many works (e.g., [47]), companies and workers may not have enough knowledge of AmI systems to adopt them willingly. In addition, there is organizational resistance towards Industry 4.0 solutions [48]—including those not foreseeing the monitoring of the workers. In other words, if AAW solutions significantly resemble the AmI systems foreseen for workers in Industry 4.0, there might be the possibility that such solutions may undergo the same resistance. Therefore, similar to the issues brought up by Industry 4.0, a general lack of digital and technological culture characterizing older workers mixed with a resistance to change may hinder the adoption of AAW solutions. Moreover, AmI in AAW and Industry 4.0—as well as in AAL—raises a nontrivial problem: the risk deriving from data privacy. If in Industry 4.0 this problem is connected to security while sharing data in value chains [47], in AAW there might exist a problem related to workers' privacy and personal information (e.g., physiological and cognitive data, information regarding working hours, etc.).

It is interesting to note that, in the articles analysed in this review, Industry 4.0 was rarely mentioned—with the sole exception of Sun et al. [37]. The AmI solution proposed in this work stemmed from the Operator 4.0 concept (aimed at improving cooperation among human operators and machines in Industry 4.0 contexts). It foresaw workers wearing sensors to track their health-related metrics so that acquired data could be used to enable workforce health management. Except for this article, the other papers investigated lacked in positioning their solutions within the wider context of Industry 4.0 (this was particularly relevant for those papers whose solutions concerned industrial workplaces).

4.3. Identifying the Needs of the AW

To conclude this section, a final consideration emerges from scrutinizing the results presented in Section 3. Most of the solutions proposed in the analysed papers addressed specific problems concerning workers' safety in particular workplaces, enhancing workers' comfort while working, and assisting workers in performing specific tasks. However, the solutions proposed for each problem were hardly transferable to other types of workplaces, nor were they applicable to other professions aside from those for which they were developed. For example, it is not surprising that office workers do not require the solutions of Osunmakinde [21] or Singh et al. [25] to perform their jobs safely; however, not all office workers may need the solutions proposed by Baedeker et al. in [36] or [34]. Some offices may not gain many benefits from implementing some of the solutions (for example, an office populated by six or more workers may find it uncomfortable to have music or indoor lighting adapted each time workers' emotions change).

A general characteristic of older workers is the progressive loss of physical strength: the possibility of helping workers effectively cope with a sensorial or physical disability was investigated only in Bajo et al. [26]. However, it is arguable that supporting older workers in both perceiving themselves and being as efficient as their younger colleagues should be a priority. On the contrary, AmI solutions for AAL are mostly dedicated to the topic of supporting the independent and autonomous living of older adults.

It seems that, when applied to workers and workplaces, AmI solutions approach the challenges of workers dispersedly. The variety of problems characterizing the working contexts may pose a challenge in identifying a set of generic and common issues that might characterize different working contexts horizontally. A univocal and unambiguous identification of a set of characteristics pertaining to the AW may help focus the attention of AmI solution developers towards more generalizable solutions, which can still offer customized services to ad hoc workers by leveraging data acquired from sensors or activity monitoring.

5. Possible Future Research Directions for AAW

Considering the lack of works specifically dedicated to the AW, this review can only point at some possible future research directions for the AAW framework. Notwithstanding the interest in AAW, the paradigm remains little investigated. This might be due to barriers surveyed in the previous section or because addressing the AW's presence in industrialized countries is not yet a prominent issue.

The first research direction pertains to properly understanding the AW's needs and trying to generalize possible solutions. All of the papers adopted data acquisition (mostly real-time) with AI algorithms to draw conclusions (which translated into adaptations of the environment or worker-related alerts). Another approach (starting with AAL in the research area related to smart homes [49,50]) relies on knowledge representation. In this approach, knowledge engineering and Semantic Web technologies are adopted to formalize some general concepts regarding smart homes' inhabitants in ontologies—formal, computable, and shared models of a domain. Business rules are used to infer the environmental adaptations and the alerts an inhabitant should receive. A similar approach has been theorized in [51] and [52], where workers affected by chronic conditions may benefit from simple environmental adaptations to avoid exacerbations. Semantic technologies were rarely adopted in the sample of papers analysed: Muñoz et al. [34] exploited them to formalize emotions and provide rules able to adapt to the appearance and environment of a proposed smart office, while in Sanchez-Pi et al. [29], a domain ontology was used to model the processes and components of a petroleum plant, thus providing a formal description of equipment, actuators, sensors, alarms, and events. The main advantage of knowledge engineering in AAW is that it can foster a generalization of concepts, leveraging existing models pertaining to the physiological and clinical domain that are widely accepted by the scientific community. Instead of a massive set of workers-related data, ontologies can classify workers according to some clinical and retrievable information and then apply "if–then" rules to enable environmental adaptations.

As noted in Table 2 and in the previous section, only one article (Bajo et al. [26]) focused on supporting workers who may undergo a loss in motor or cognitive abilities. However, the AW's characteristics require more attention to be dedicated to supporting older workers in coping with the chronic effects of ageing. In this regard, AAW can draw approaches from AAL, which has devoted some works to these questions and has provided AmI solutions and cyber-physical systems to effectively help users in performing many tasks they would not have been able to perform otherwise [53,54]. Benefitting from the research direction suggested above, AAW can provide a significant contribution to helping older workers with physical or cognitive disabilities in both enhancing the way they work and acquiring new abilities.

Adopting a generalized approach leveraging business rules may also contribute to limiting the adoption of monitoring technologies, thus decreasing the perceived intrusiveness and privacy concerns typical of AmI solutions adopting monitoring technologies. Similar approaches can be found in the literature pertaining to AAL, in which combinations of a few currently adopted and widely accepted wearables (such as smartwatches or wristbands) enable a trade-off between the need for real-time data and the personalized adaptations to be delivered [39,40,55].

In any case, a relevant research direction to be pursued consists of the deployment of case tests in real companies. This type of deployment would allow the acquisition of more consistent data on the acceptance of AmI technologies in workplaces and might provide some hints on possible ways to overcome existing barriers to long-term adoption. Nonetheless, a strong commitment from the countries facing increases in older workers in order to effectively enable this type of research and the development of ad hoc policies (e.g., regulations for the use of AmI solutions in the workplace, policies for reducing the digital gap between older and younger workers, etc.) is also necessary.

An existing research direction that should be strengthened consists of investigating the relationships between AAW and Industry 4.0. The emergence of the AW is not a novelty, and Industry 4.0 first tackled this issue from a technological perspective. The adoption of cyber-physical systems, AmI solutions, and Big Data are among the most investigated aspects of Industry 4.0; however, workers still play a pivotal role and need to find a place in this industrial paradigm. Schinner et al. [56] noted that the adoption of technology-mitigated processes for bringing together individual competence management and human resource management (taking into account the demographic change in the worker population) was inevitable. The acceptance of new technologies in workplaces is pivotal, but to overcome barriers—especially among older workers—more effort should be put into explaining and nurturing transformation acceptance (i.e., companies' processes and workers' jobs may undergo significant changes). Therefore, it is relevant to investigate the transformative challenges related to the AW and Industry 4.0. Finally, according to [57], a research question still waiting for an answer is the AW's readiness to embrace Industry 4.0 technologies: workforce expertise and attitudes, as well as infrastructure availability, influence the research on this topic.

6. Conclusions

In the framework of AAW, this paper reviewed the scientific literature with the aim of retrieving articles describing AmI solutions dedicated to supporting older workers in performing their jobs. In the attempt to systematically review the literature on this topic, no pertinent articles were retrieved. Therefore, the research question was modified to identify AmI solutions supporting workers that could potentially be applied to the ageing workforce.

The results indicated that researchers equally described AmI solutions to foster workers' safety, AmI solutions to enhance comfort and wellbeing, and various solutions for supporting workers in performing specific tasks (organizational and cognitive). However, the use of AmI solutions to support workers in coping with a sensory or motor impairment was neglected. Environmental monitoring was essential in all the works, while a combination of environmental monitoring and worker monitoring was adopted by half of the articles analysed in this work. It was interesting to observe that monitoring workers' performances was scarcely investigated, with many works mentioning the possibility of applying AmI to increase workers' performance and productivity, but with one single paper describing a way to measure these metrics. AmI solutions were depicted mostly for offices and industrial workplaces.

There are still significant challenges that AAW needs to face, starting with those inherited from AAL (e.g., the role of monitoring in perceived privacy and intimacy, worker safety while using wearables, ethical issues derived from monitoring, etc.). In addition, AAW would benefit from taking advantage of older workers' needs and could learn some valuable lessons from older worker management tackled by Industry 4.0.

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References

1. Yaldiz, L.M.; Fraccaroli, F.; Truxillo, D.M. Aging workforce issues from a multilevel approach. In *Oxford Research Encyclopedia of Psychology*; Oxford University Press: Oxford, UK, 2017.
2. Heidemeier, H.; Staudinger, U.M. Age differences in achievement goals and motivational characteristics of work in an ageing workforce. *Ageing Soc.* **2015**, *35*, 809–836. [CrossRef]
3. Aaltio, I.; Salminen, H.M.; Koponen, S. Ageing employees and human resource management–evidence of gender-sensitivity? *Equal. Divers. Incl. Int. J.* **2014**, *33*, 160–176. [CrossRef]
4. Bal, A.C.; Reiss, A.E.; Rudolph, C.W.; Baltes, B.B. Examining positive and negative perceptions of older workers: A meta-analysis. *J. Gerontol. Ser. B Psychol. Sci. Soc. Sci.* **2011**, *66*, 687–698. [CrossRef] [PubMed]
5. Eurostat Ageing Europe—Statistics on Working and Moving into Retirement. 2020. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Ageing_Europe_-_statistics_on_working_and_moving_into_retirement (accessed on 14 January 2022).
6. Disease Control, C. for; Prevention Accommodate Aging Workforce Population. 2016. Available online: https://www.cdc.gov/workplacehealthpromotion/model/control-costs/benefits/aging-workforce.html (accessed on 14 January 2022).
7. Labor Statistics, U.S.B. of Employment Projections and Occupational Outlook Handbook News Release. Available online: https://www.bls.gov/news.release/archives/ecopro_09082021.htm (accessed on 23 December 2022).
8. Kikkawa, A.; Gaspar, R. Trends and Characteristics of Labor Force Participation Among Older Persons in Developing Asia: Literature Review and Cross-Country Assessment. *J. Popul. Ageing* **2022**, 1–25. [CrossRef]
9. Paoli, P.; Merllié, D. Third European Survey on Working Conditions 2000. 2001. Available online: https://policycommons.net/artifacts/1830735/third-european-survey-on-working-conditions-2000/2571485/ (accessed on 23 December 2022).
10. Vargas Llave, O.; Weber, T.; Vanderleyden, J. How to Respond to Chronic Health Problems in the Workplace? 2019. Available online: https://policycommons.net/artifacts/1845231/how-to-respond-to-chronic-health-problems-in-the-workplace/2589944/ (accessed on 23 December 2022).
11. Kachan, D.; Fleming, L.E.; Christ, S.; Muennig, P.; Prado, G.; Tannenbaum, S.L.; Yang, X.; Caban-Martinez, A.J.; Lee, D.J. Health Status of Older US Workers and Nonworkers, National Health Interview Survey, 1997–2011. *Prev. Chronic Dis.* **2015**, *12*, 150040. [CrossRef]

12. Bühler, C. Ambient intelligence in working environments. In *International Conference on Universal Access in Human-Computer Interaction*; Springer: Berlin, Germany, 2009; pp. 143–149.
13. Pancardo, P.; Wister, M.; Acosta, F.; Hernández, J.A. Ambient Assisted Working Applications: Sensor Applications for Intelligent Monitoring in Workplace for Well-being. In *Intelligent Data Sensing and Processing for Health and Well-Being Appli-cations*; Elsevier: Amsterdam, The Netherlands, 2018; pp. 81–99.
14. Thun, J.-H.; Größler, A.; Miczka, S. The impact of the demographic transition on manufacturing: Effects of an ageing workforce in German industrial firms. *J. Manuf. Technol. Manag.* **2007**, *18*, 985–999. [CrossRef]
15. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *Syst. Rev.* **2021**, *10*, 1–11. [CrossRef]
16. De Lange, A.; Taris, T.; Jansen, P.; Smulders, P.; Houtman, I.; Kompier, M. Age as a factor in the relation between work and mental health: Results from the longitudinal TAS survey. *Occup. Health Psychol. Eur. Perspect. Res. Educ. Pract.* **2006**, *1*, 21–45.
17. Geuskens, G.A.; Hengel, K.M.O.; Koppes, L.L.; Ybema, J.F. Predictors of the willingness and the ability to continue working until the age of 65 years. *J. Occup. Environ. Med.* **2012**, *54*, 572–578. [CrossRef]
18. Kanfer, R.; Ackerman, P.L. Aging, adult development, and work motivation. *Acad. Manag. Rev.* **2004**, *29*, 440–458. [CrossRef]
19. Varianou-Mikellidou, C.; Boustras, G.; Dimopoulos, C.; Wybo, J.-L.; Guldenmund, F.W.; Nicolaidou, O.; Anyfantis, I. Occupational health and safety management in the context of an ageing workforce. *Saf. Sci.* **2019**, *116*, 231–244. [CrossRef]
20. Coughlin, J.F.; Reimer, B.; Mehler, B. Monitoring, managing, and motivating driver safety and well-being. *IEEE Pervasive Comput.* **2011**, *10*, 14–21. [CrossRef]
21. Osunmakinde, I.O. Towards safety from toxic gases in underground mines using wireless sensor networks and ambient intelligence. *Int. J. Distrib. Sens. Netw.* **2013**, *9*, 159273. [CrossRef]
22. Pancardo, P.; Acosta, F.D.; Hernández-Nolasco, J.A.; Wister, M.A.; López-de-Ipiña, D. Real-time personalized monitoring to estimate occupational heat stress in ambient assisted working. *Sensors* **2015**, *15*, 16956–16980. [CrossRef] [PubMed]
23. Bhatia, M.; Sood, S.K. Exploring temporal analytics in fog-cloud architecture for smart office healthcare. *Mob. Netw. Appl.* **2019**, *24*, 1392–1410. [CrossRef]
24. Jo, B.W.; Khan, R.M.A.; Javaid, O. Arduino-based intelligent gases monitoring and information sharing Internet-of-Things system for underground coal mines. *J. Ambient Intell. Smart Environ.* **2019**, *11*, 183–194. [CrossRef]
25. Singh, N.; Gunjan, V.K.; Chaudhary, G.; Kaluri, R.; Victor, N.; Lakshmanna, K. IoT enabled HELMET to safeguard the health of mine workers. *Comput. Commun.* **2022**, *193*, 1–9. [CrossRef]
26. Bajo, J.; Sánchez, M.A.; Alonso, V.; Berjón, R.; Fraile, J.A.; Corchado, J.M. A distributed architecture for facilitating the integration of blind musicians in symphonic orchestras. *Expert Syst. Appl.* **2010**, *37*, 8508–8515. [CrossRef]
27. Irizarry, J.; Gheisari, M.; Williams, G.; Roper, K. Ambient intelligence environments for accessing building information: A healthcare facility management scenario. *Facilities* **2014**, *32*, 120–138. [CrossRef]
28. Martín, D.; Alcarria, R.; Sánchez-Picot, Á.; Robles, T. An ambient intelligence framework for end-user service provisioning in a hospital pharmacy: A case study. *J. Med. Syst.* **2015**, *39*, 116. [CrossRef]
29. Sanchez-Pi, N.; Leme, L.A.P.; Garcia, A.C.B. Intelligent agents for alarm management in petroleum ambient. *J. Intell. Fuzzy Syst.* **2015**, *28*, 43–53. [CrossRef]
30. Vales-Alonso, J.; Chaves-Diéguez, D.; López-Matencio, P.; Alcaraz, J.J.; Parrado-García, F.J.; González-Castaño, F.J. SAETA: A smart coaching assistant for professional volleyball training. *IEEE Trans. Syst. Man Cybern. Syst.* **2015**, *45*, 1138–1150. [CrossRef]
31. Pimenta, A.; Carneiro, D.; Neves, J.; Novais, P. A neural network to classify fatigue from human–computer interaction. *Neurocomputing* **2016**, *172*, 413–426. [CrossRef]
32. Bogdan, R.; Tatu, A.; Crisan-Vida, M.M.; Popa, M.; Stoicu-Tivadar, L. A practical experience on the Amazon Alexa integration in smart offices. *Sensors* **2021**, *21*, 734. [CrossRef] [PubMed]
33. Fernández-Montes, A.; Ortega, J.; Sánchez-Venzalá, J.; González-Abril, L. Software reference architecture for smart environments: Perception. *Comput. Stand. Interfaces* **2014**, *36*, 928–940. [CrossRef]
34. Munoz, S.; Araque, O.; Sánchez-Rada, J.F.; Iglesias, C.A. An emotion aware task automation architecture based on semantic technologies for smart offices. *Sensors* **2018**, *18*, 1499. [CrossRef] [PubMed]
35. Naqi, M.; Lee, S.; Kwon, H.-J.; Lee, M.G.; Kim, M.; Kim, T.W.; Shin, H.K.; Kang, S.; Gandla, S.; Lee, H.-S.; et al. A Fully Integrated Flexible Heterogeneous Temperature and Humidity Sensor-Based Occupancy Detection Device for Smart Office Applications. *Adv. Mater. Technol.* **2019**, *4*, 1900619. [CrossRef]
36. Baedeker, C.; Piwowar, J.; Themann, P.; Grinewitschus, V.; Krisemendt, B.; Lepper, K.; Zimmer, C.; von Geibler, J. Interactive design to encourage energy efficiency in offices: Developing and testing a user-centered building management system based on a living lab approach. *Sustainability* **2020**, *12*, 6956. [CrossRef]
37. Sun, S.; Zheng, X.; Gong, B.; Garcia Paredes, J.; Ordieres-Meré, J. Healthy operator 4.0: A human cyber–physical system architecture for smart workplaces. *Sensors* **2020**, *20*, 2011. [CrossRef]
38. Zhao, N.; Seitinger, S.; Richer, R.; Paradiso, J.A. Real-time work environment optimization using multimodal media and body sensor network. *Smart Health* **2021**, *19*, 100164. [CrossRef]

39. Spoladore, D.; Mondellini, M.; Sacco, M.; Trombetta, A. An ontology-based framework for a Less Invasive Domestic Management System (LIDoMS). In Proceedings of the 2020 16th International Conference on Intelligent Environments (IE), Madrid, Spain, 20–23 July 2020; IEEE: Piscataway, NJ, USA, 2020; pp. 29–35.
40. Stavropoulos, T.G.; Meditskos, G.; Andreadis, S.; Kompatsiaris, I. Real-time health monitoring and contextualised alerts using wearables. In Proceedings of the 2015 International Conference on Interactive Mobile Communication Tech-nologies and Learning (IMCL), Thessaloniki, Greece, 19–20 November 2015; IEEE: Piscataway, NJ, USA, 2015; pp. 358–363.
41. Ortiz-Barrios, M.; Silvera-Natera, E.; Petrillo, A.; Gul, M.; Yucesan, M. A multicriteria approach to integrating occupational safety & health performance and industry systems productivity in the context of aging workforce: A case study. *Saf. Sci.* **2022**, *152*, 105764.
42. Peron, M.; Arena, S.; Micheli, G.J.L.; Sgarbossa, F. A decision support system for designing win–win interventions impacting oc-cupational safety and operational performance in ageing workforce contexts. *Saf. Sci.* **2022**, *147*, 105598. [CrossRef]
43. Lavallière, M.; Burstein, A.A.; Arezes, P.; Coughlin, J.F. Tackling the challenges of an aging workforce with the use of wearable technologies and the quantified-self. *Dyna* **2016**, *83*, 38–43. [CrossRef]
44. Yoo, J.; Oh, J.; Kim, S.-Y.; Shin, J.; Kim, S.; Roh, C. Impact of Digital Device, Exercise, and Music Intervention Programs on the Cognition and Depression of the Elderly in South Korea: A Meta-Regression Analysis. *Int. J. Environ. Res. Public Health* **2022**, *19*, 4036. [CrossRef] [PubMed]
45. Balta-Ozkan, N.; Davidson, R.; Bicket, M.; Whitmarsh, L. Social barriers to the adoption of smart homes. *Energy Policy* **2013**, *63*, 363–374. [CrossRef]
46. Demiris, G.; Hensel, B.K.; Skubic, M.; Rantz, M. Senior residents' perceived need of and preferences for "smart home" sensor technologies. *Int. J. Technol. Assess. Health Care* **2008**, *24*, 120–124. [CrossRef] [PubMed]
47. Raj, A.; Dwivedi, G.; Sharma, A.; de Sousa Jabbour, A.B.L.; Rajak, S. Barriers to the adoption of industry 4.0 technologies in the manufacturing sector: An inter-country comparative perspective. *Int. J. Prod. Econ.* **2020**, *224*, 107546. [CrossRef]
48. Machado, C.G.; Winroth, M.; Carlsson, D.; Almström, P.; Centerholt, V.; Hallin, M. Industry 4.0 readiness in manufacturing companies: Challenges and enablers towards increased digitalization. *Procedia Cirp* **2019**, *81*, 1113–1118. [CrossRef]
49. Chen, L.; Nugent, C. Ontology-based activity recognition in intelligent pervasive environments. *Int. J. Web Inf. Syst.* **2009**, *5*, 410–430. [CrossRef]
50. Spoladore, D.; Mahroo, A.; Trombetta, A.; Sacco, M. DOMUS: A domestic ontology managed ubiquitous system. *J. Ambient Intell. Humaniz. Comput.* **2022**, *13*, 3037–3052. [CrossRef]
51. Cilsal, T.; Spoladore, D.; Trombetta, A.; Sacco, M. A Semantic-Based Collaborative Ambient-Assisted Working Framework. In *Working Conference on Virtual Enterprises*; Springer: Berlin, Germany, 2022; pp. 348–355.
52. Spoladore, D.; Cilsal, T.; Sacco, M. An Ontology-Based Ambient Intelligence Framework for Ageing Workforce. In *Proceedings of SAI Intelligent Systems Conference*; Springer: Berlin, Germany, 2023; pp. 339–353.
53. Cedillo, P.; Sanchez, C.; Campos, K.; Bermeo, A. A systematic literature review on devices and systems for ambient assisted living: Solutions and trends from different user perspectives. In Proceedings of the 2018 International Conference on eDemocracy & eGovernment (ICEDEG), Ambato, Ecuador, 4–6 April 2018; IEEE: Piscataway, NJ, USA, 2018; pp. 59–66.
54. Queirós, A.; da Rocha, N.P. Ambient assisted living: Systematic review. In *Usability, Accessibility and Ambient Assisted Living*; Springer: Berlin, Germany, 2018; pp. 13–47.
55. Jara, A.J.; Blaya, F.J.; Zamora, M.A.; Skarmeta, A.F. An ontology and rule based intelligent information system to detect and predict myocardial diseases. In Proceedings of the 2009 9th International Conference on Information Technology and Applications in Biomedicine, Larnaka, Cyprus, 4–7 November 2009; IEEE: Piscataway, NJ, USA, 2009; pp. 1–6.
56. Schinner, M.; Calero Valdez, A.; Noll, E.; Schaar, A.K.; Letmathe, P.; Ziefle, M. 'Industrie 4.0' and an aging workforce—A discussion from a psychological and a managerial perspective. In *International Conference on Human Aspects of IT for the Aged Population*; Springer: Berlin, Germany, 2017; pp. 537–556.
57. Wissemann, A.K.; Pit, S.W.; Serafin, P.; Gebhardt, H. Strategic guidance and technological solutions for human resources management to sustain an aging workforce: Review of international standards, research, and use cases. *JMIR Hum. Factors* **2022**, *9*, e27250. [CrossRef] [PubMed]