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TESIS DOCTORAL

SOLUCIONES TIC PARA ENVEJECIMIENTO ACTIVO Y SALUDABLE EN EL HOGAR, EN EL PUESTO DE TRABAJO Y EN LA SOCIEDAD

Presentada por D. Francisco José Melero Muñoz para optar al grado de Doctor
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Dirigida por:
Dra. María Victoria Bueno Delgado

Codirigida por:
Dra. Josefina Garrido Lova

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Artículo 1.-: Krejcar, O., Maresova, P., Selamat, A., **Melero, F. J.**, Barakovic, S., Husic, J. B., Herrera-Viedma, E., Frischer, R., & Kuca, K., 2019. Smart furniture as a component of a smart city—definition based on key technologies specification. IEEE Access, volumen 7. https://doi.org/10.1109/ACCESS.2019.2927778. Factor de Impacto (2019): 3.745, Q1 Computer Science, Information Systems / Engineering, Electrical and Electronic (4 puntos) [1].

Artículo 2.-: Barakovic Husic, J., Melero, F. J., Barakovic, S., Lameski, P., Zdravevski, E., Maresova, P., Krejcar, O., Chorveb, I., Garcia, N.M, & Trajkovik, V., 2020. Aging at Work: A Review of Recent Trends and Future Directions. International journal of environmental research and public health, volumen 17 https://doi.org/10.3390/ijerph17207659. Factor de Impacto (2020): 3.390, Q1 Public, Environmental and Occupational Health (4 puntos) [2].

Artículo 3.-: Dimitrievski, A., Filiposka, S., Melero, F. J., Zdravevski, E., Lameski, P., Pires, I. M., Garcia N.M., Lousado, J.P. & Trajkovik, V., 2021. Rural Healthcare IoT Architecture Based on Low-Energy LoRa. International Journal of Environmental Research and Public health, volumen 18. https://doi.org/10.3390/ijerph18147660 Factor de Impacto (2021): 4.614, Q1 Public, Environmental and Occupational Health (4 puntos) [3].

Artículo 4.-: Melero, F. J., Bueno, M.V., Martínez, R., Maestre, R., Beteta, M.A., Puebla, T., Bleda, A.L., Sánchez, G., Pérez, R. & Álvarez, M., 2022. Design and Development of a Heterogeneous Active Assisted Living Solution for Monitoring and Following-up with Chronic Heart Failure Patients in Spain. Sensors, Volumen 22, https://doi.org/10.3390/s22228961. Factor de Impacto (2021): 3.847, Q2 Engineering, Electrical and Electronic (3 puntos) [4].

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Resumen

La presente tesis doctoral compendia las publicaciones resultado de varios años de trabajo en el marco de tres líneas de investigación relacionadas con envejecimiento activo y soluciones *e-health* y *Ambient Assisted Living* para la población de edad más avanzada: Mobiliario inteligente y espacios inteligentes, envejecimiento activo y saludable, y soluciones de las Tecnologías de la Información y las Comunicaciones (TIC) enfocadas al cuidado de la salud en general y a las personas mayores en particular.

Dichos trabajos muestran los resultados de un análisis del estado del arte, patentes y otros, para poder establecer una definición precisa del concepto de Mobiliario Inteligente con el objetivo de destacar sus propiedades en cuanto a funcionalidad y al elemento digital activo y conectado. Además, es necesario destacar que el mobiliario inteligente debe ser considerado como un ente integrado en el concepto de ciudades inteligentes o calidad de vida. Por ello la investigación del estado del arte se centra en envejecimiento de la población activa, tendencias recientes, direcciones futuras y envejecimiento en el trabajo. El objetivo es poder extraer conclusiones en cuanto a los principales problemas de motivación y proponer respuestas eficaces que apoyen el envejecimiento en el trabajo y soluciones *e-health* que permita a la población senior vivir de manera independiente durante más tiempo a través, tanto de una arquitectura IoT de bajo rango para ayudar a abordar los retos de despliegue de servicios e-health en áreas rurales, como de un sistema de teleasistencia basado en el cuidado proactivo, el envejecimiento activo, la prevención y las necesidades de los usuarios y sus entornos.

Palabras Clave

Mobiliario Inteligente, Mueble, Redes de Sensores Inalámbricas, Envejecimiento en el puesto de Trabajo, Discriminación, Crecimiento, Déficit, Asistencia, Políticas, Legislación, Salud Conectada, LoRa, IoT, AAL, Prevalidación, Insuficiencia Cardíaca, Piloto a gran escala, H2020.

Abstract

The present doctoral thesis summarises a set of publications resulting from several years of work within the framework of three research lines on active ageing and e-health solutions and *Ambient Assisted Living* for the ageing population: Smart furniture and Smart habitats, active and healthy ageing and Information and Communication Technology solutions focused on health care in general and on the adult population in particular.

Such works show the results of an analysis of the state of the art, patents, and others, to establish a precise definition of the concept of Smart Furniture to highlight its properties in terms of functionality and the active and connected digital element, and to underline that smart furniture must be considered as an integrated entity in the concept of Smart Cities or Quality of Life. For this reason, the state-of-the-art research focuses on the aging workforce, recent trends, future directions, and aging at work. The aim is to draw conclusions on the main motivational issues and to propose effective responses that support the concept of aging at work, as well as e-health solutions for the senior population to live independently for longer through both, a low-range IoT architecture to help address the challenges of deploying a e-health system in rural areas, and a tele-assistance system based on proactivity, prevention, and users' needs and their environments.

Keywords

Smart Furniture, Furniture, Wireless Sensor Networks, Aging at Work, Discrimination, Growth, Deficit, Assistance, Policy, Legislation, Connected Health, LoRa, IoT, AAL, Prevalidation, Chronic Heart Failure, Large-Scale Pilot, H2020.

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1. Objetivos de la tesis

Las publicaciones presentadas en este compendio son un subconjunto de los resultados de investigación publicados tras varios años de trabajo en el marco de envejecimiento activo, y soluciones *e-health*, *Ambient Assisted Living* (AAL) y *Smart Habitat* para personas mayores. En concreto, se ha trabajado sobre tres líneas de investigación principales: *(1)* mobiliario inteligente y espacios inteligentes, *(2)* envejecimiento activo y saludable, *(3)* soluciones de la Tecnología de la Información y la Comunicación (TIC) enfocadas al cuidado de la salud en general y a las personas mayores en particular.

El trabajo se ha desarrollado en el marco de la Acción COST CA16226 (*Living Indoor Space Improvement: Smart Habitat for the Elderly - Sheldon*), coordinada por el doctorando, y el proyecto europeo Pharaon (Pilots for Healthy and Active Ageing).

Sheldon consiste en una red internacional y multidisciplinar de expertos cuyo objetivo es fomentar el intercambio y transferencia de conocimiento y el desarrollo de una agenda de investigación conjunta en términos de diseño y desarrollo de entornos multifuncionales que satisfagan las necesidades de la población europea, promoviendo al mismo tiempo un envejecimiento seguro y saludable.

Bajo el marco de la red Sheldon, nació el proyecto Pharaon: Pilots for Healthy and Active Ageing, finaciada *topic* DT-TDS-01-2019 Smart and Healthy Living at Home del programa europeo de investigación e innovación Horizon 2020, que tiene como objetivo tender un puente entre los desafíos tecnológicos y un envejecimiento activo y saludable mediante el desarrollo de seis experiencias piloto a gran escala en distintos países europeos: Italia, Eslovenia, Países Bajos, Portugal y España.

La Región de Murcia es el escenario de uno de los pilotos de Pharaon, que persigue establecer las bases de un nuevo sistema de teleasistencia. Dicho sistema irá más allá del actual modelo presencial que se activa cuando los pacientes necesitan ayuda, permitiendo a los usuarios permanecer en sus casas al tiempo que se les ofrece un servicio de atención más personalizado, no intrusivo y eficiente.

El trabajo realizado por el doctorando, en colaboración con su directora y codirectora de tesis así como con otros autores y coautores, ha sido objeto de diseminación en tres congresos internacionales [5], [6], [7], y nueve publicaciones en revistas con índice de impacto [1-4], [8], [9], [10], [11] y [12], cuatro de las cuales [1-4], se resumen en este trabajo de tesis por compendio. La elección no ha sido casual, sino para poder mostrar al menos una contribución destacada de cada línea de trabajo.

El trabajo realizado en [1] corresponde a la temática de investigación de mobiliario inteligente y espacios inteligentes, y su objetivo principal es realizar un análisis del estado del arte, patentes, etc., para establecer una definición precisa del concepto mobiliario inteligente, identificar las tecnologías, usuarios y casos de uso más utilizados en las soluciones de mobiliario inteligente analizadas para proveer de una guía de referencia para los actores involucrados y potenciales interesados y resaltar la necesidad de colaboración entre investigadores en la temática y autoridades responsables del desarrollo de políticas relacionadas con este campo en innovación, crecimiento económico social e inclusivo y sostenibilidad.

El trabajo realizado en [2] corresponde a la temática de investigación sobre envejecimiento activo y saludable, y su objetivo principal es el de revisar el estado del arte sobre envejecimiento en el trabajo, utilizando una herramienta de procesamiento de lenguaje natural (NLP), para extraer conclusiones en cuanto a los principales problemas de motivación y soluciones para apoyar el concepto de envejecimiento en el trabajo y valorar la necesidad de crear un marco de transformación laboral que lo contemple, proponiendo una hoja de ruta destinada a los responsables en la toma de decisiones a nivel público o privado y en la formulación de políticas sobre envejecimiento en el trabajo.

Los trabajos realizados en [3] y [4]corresponden a la temática de investigación sobre soluciones TIC enfocadas al cuidado de la salud en general y a las personas mayores en particular. El trabajo [3] tiene como objetivo principal analizar los retos de despliegue de arquitecturas IoT para dar servicios de salud y cuidado en áreas rurales y proponer una arquitectura novedosa basada en IoT de bajo consumo que haga un uso eficiente de la energía utilizada en los dispositivos y comunicaciones empleados, mientras que el trabajo realizado en [4] muestra la solución AAL propuesta en el piloto murciano del proyecto Pharaon, detallando la metodología, resultados y conclusiones de la fase de prevalidación para el conjunto de tecnologías del Internet de las Cosas (IoT) que se integran en la plataforma AAL, siendo este el primer paso obligatorio antes del despliegue de un piloto a gran escala que ayudará a llevar la innovación del sistema desde su actual nivel de preparación tecnológica (Technology Readiness Level - TRL6) al mercado (TRL9).

2. Introducción y estado del arte

La domótica o automatización del hogar, junto con los servicios de teleasistencia médica, son parte del mercado AAL. Dentro de este concepto, el mobiliario inteligente y multifuncional juega un rol importante a la hora de promover la salud y el bienestar, la gestión de la fragilidad física y mental, así como de otros deterioros causados por el envejecimiento, y ayuda a reducir el impacto de aquellas barreras físicas y cognitivas que impiden a los trabajadores seguir activos y productivos en su puesto de trabajo durante los últimos años de su etapa laboral.

Las industrias del sector del hábitat en general, y del mueble en particular, están continuamente innovando hacia el diseño y desarrollo de soluciones que ayuden a un envejecimiento activo y saludable de la sociedad, en el hogar y en el entorno laboral. En los escenarios bajo análisis el objetivo es común: mejorar la calidad de vida y autonomía de la población, sobre todo la envejecida, haciéndoles partícipes en la sociedad, y ayudándoles a actualizar/reciclar sus habilidades laborales. Desde sencillos mecanismos integrados en mobiliario tapizado que asisten al usuario cuando éste se sienta y se levanta, pasando por sensorización del mobiliario, hasta sistemas de redes de sensores en el hogar capaces de monitorizar de manera no intrusiva al usuario para poder definir patrones de comportamiento, realizar recomendaciones de vida saludable o identificar posibles situaciones de emergencia que de forma automática generen una alarma que puedan recibirla familiares, cuidadores o profesionales de la salud.

En el estado del arte existen varios estudios que revisan el concepto y las tendencias en cuanto a Mobiliario Inteligente o *Smart Furniture* [13], [14], [15], [16], pero las definiciones que estas presentan se centran en el diseño, y no tanto en las propiedades basadas en funcionalidad, en cuanto al elemento digital activo y conectado, es decir, sin considerar el mobiliario inteligente como un subtérmino integrado en el concepto de Ciudades Inteligentes o Calidad de Vida, a pesar de que ahora mismo sean aspectos clave en países desarrollados.

Por tanto, parece necesaria una definición completa de *Smart Furniture* de la que puedan verse beneficiados los principales componentes del ecosistema: la Industria, representada por el sector del mueble y el hábitat, que aumentaría la competitividad del sector al poder acceder a nuevos segmentos de mercado; las empresas del sector TIC, abriendo la puerta a nuevos productos y aplicaciones; los usuarios, especialmente aquellos de edad avanzada o personas con necesidades especiales; y finalmente por la sociedad en general, ya que estas tecnologías permitirían a los usuarios disfrutar de una vida más independiente y continuar su vida laboral de manera eficiente por más tiempo. El trabajo nº 1 que se presenta en esta tesis por compendio, describe un análisis de la literatura y patentes publicadas, funcionalidades y usos descritos del término *Smart Furniture* y su definición, con el fin de establecer una definición completa que presente un impacto adecuado de todos los actores involucrados en el ecosistema: usuarios, fabricantes, investigadores, autoridades, etc.

Por otro lado, el cambio demográfico, junto con una más que evidente falta de mano de obra, y el retraso en la edad de jubilación, derivado en parte por la problemática en los sistemas de pensiones de los gobiernos [17], está generando nuevos retos en el envejecimiento activo y saludable en entornos laborales. Además, el avance de la medicina ha hecho posible que también la población adulta acceda a diagnósticos más tempranos sobre deterioros físicos o cognitivos, lo que significa un mayor porcentaje de adultos que deben afrontar su trabajo con un menor o mayor deterioro funcional, enfermedades crónicas, necesidad asistencial, etc. Por otro lado, la necesidad de reincorporar personal ya jubilado en el mercado laboral es más que probable en un futuro cercano.

Para que la población más adulta pueda continuar ofreciendo oportunidades a nivel social y económico y estimule la transformación tanto a nivel laboral como en la necesidad de bienes y servicios y en las estructuras transgeneracionales familiares y sociales, es necesario adoptar una visión inteligente y multidimensional sobre el envejecimiento [9]. La transformación laboral debe también enfocarse en el reconocimiento de las capacidades y las necesidades de la población más adulta. Los trabajadores más seniors no pueden realizar ciertas tareas por motivos físicos, por los que es necesario reevaluar sus capacidades actuales, modificar sus puestos de trabajo o asignarles nuevos cargos tras una formación adecuada [18].

Ciertos estereotipos y preconcepciones sobre la población más adulta como su nivel de productividad, o su correlación con delicados estados de salud [19], [20] son motivos suficientes para la búsqueda de soluciones potenciales en políticas y leyes en el ámbito laboral que eviten la discriminación laboral de este grupo de la sociedad y que promueva una imagen positiva de los empleados más seniors [21].

La Fundación Europea para la Mejora de las Condiciones de Vida y de Trabajo define el crecimiento sostenible en el entorno laboral como aquellas condiciones laborales que apoyen a la población más adulta en su involucración y continuidad en el trabajo por mucho más tiempo a lo largo de su vida laboral. Se requiere una transformación laboral que elimine aquellos factores desmotivadores para la entrada o continuidad de los trabajadores séniors en el mercado laboral [22], [23]. Aspectos de dicha sostenibilidad laboral como el crecimiento económico, las pensiones y la oferta de mano de obra, sugieren que una solución potencial para afrontar los problemas del aumento de la vida laboral y el retraso de la edad de jubilación sea una respuesta a nivel político [24], [25]. Además, un déficit de empleo exige una respuesta efectiva que equilibre las necesidades económicas y regulatorias, así como que influya a los puestos de trabajo, sus condiciones y las habilidades que estos requieren [26]. Los servicios de prestación de empleo, la seguridad social y los beneficios para desempleados son medidas que hacen frente a este problema [27], [28]. Sin embargo, se requieren nuevas políticas que faciliten la transición a nuevos empleos y que reduzcan el riesgo del desempleo de largo plazo. En este sentido, las políticas y leyes que fomenta la formación continua parecen ser efectivas para preparar a los empleados a cambiar de puesto de trabajo en caso de que fuera necesario [29].

En respuesta a todos los problemas expuestos, durante la última década se han publicado numerosos estudios que contribuyen al entendimiento, las motivaciones y soluciones en este contexto. Sin embargo, no parece existir una revisión sistemática de estas motivaciones y soluciones que apoyen a la mano de obra más adulta. El trabajo nº2 que se presenta en esta tesis por compendio muestra un análisis del estado del arte relacionado con la mano de obra más adulta en términos de tendencias recientes y perspectivas futuras, y captura las principales motivaciones y soluciones que apoyan el concepto de envejecer en el entorno laboral.

Finalmente, en una sociedad europea que envejece rápidamente, es cada vez más necesario aplicar soluciones TIC y herramientas digitales que mejoran la calidad de vida, la independencia y la salud general de la población de edad más avanzada. En este contexto, el concepto de Inteligencia Ambiental (AmI) aparece para lograr un futuro en el que la tecnología rodee a los usuarios y les ayude en su vida diaria [30]. AmI da lugar a plataformas de vanguardia denominadas plataformas AAL [31,32]. Las soluciones IoT [33] también han surgido como un conjunto de tecnologías, sistemas y principios de diseño [34,35] que permiten la automatización en muchos campos, como los sistemas sanitarios remotos e inteligentes, desempeñando un papel importante en las plataformas AAL y en la asistencia sanitaria.

Un entorno IoT típico consta de interfaces de comunicación, sensores, algoritmos avanzados e interfaces en la nube [36]. Los sensores se encargan de recopilar datos de diversos dispositivos. Asimismo, diferentes tecnologías de comunicación como las redes de sensores inalámbricos (WSN), proporcionan infraestructuras de red y comunicación [37] y algunos algoritmos avanzados se utilizan para analizar y procesar los datos [38]. En el entorno de la nube se pueden intercambiar numerosas peticiones cliente/servidor y permitir a los usuarios acceder a varios tipos de servicios simultáneamente [39,40]. La computación en la nube se utiliza para superar limitaciones que la emergente red 5G trae consigo, como la latencia, fiabilidad o las limitaciones de recursos, y ejecutar las mismas aplicaciones en cualquier lugar cerca de los usuarios con análisis en tiempo real y funciones de toma de decisiones eficientes [41, 42].

Se pueden encontrar diversas iniciativas en investigación y desarrollo para integrar tecnologías IoT, comunicaciones [43] y bases de datos [44] para desarrollar plataformas AAL estandarizadas e integradas [45], pero la diversidad de estos tipos de sistemas ha creado un mercado muy fragmentado y una falta de estándares para dichas arquitecturas y protocolos [46].

En el ámbito de la salud, los sistemas sanitarios se están revolucionando con el paradigma del IoT [47]. Desempeña un papel importante en la monitorización tanto en el hospital y como en el hogar para ancianos con enfermedades crónicas [48]. El uso de estas tecnologías puede ayudar a los sistemas sanitarios a reducir los tiempos de respuesta para detectar anomalías, mejorar la atención asistencial, reducir los costes de hospitalización y contribuir a aumentar la esperanza de vida [47].

En el caso concreto de la Insuficiencia Cardíaca, es la enfermedad más frecuente entre personas de avanzada edad y aumenta con el envejecimiento [49], el uso de un sistema IoT no intrusivo para la monitorización de los pacientes con insuficiencia cardíaca puede suponer un mejor control de la enfermedad, mejorando la atención sanitaria de manera proactiva y reduciendo la interacción innecesaria entre pacientes y médicos, el número de hospitalizaciones y el ahorro en gastos sanitarios.

La insuficiencia cardíaca es la principal causa de hospitalización, representando el 1-2% de todos los ingresos hospitalarios [50,51]. En España, la prevalencia de la IC se sitúa en torno al 5% (mayor que en otros países de la UE y EEUU) - la tasa aumenta con la edad hasta el 8% entre los 65 y 74 años, y hasta el 16% en personas de 75 años o más [52]. Estas tasas suponen altos recursos sanitarios; por ejemplo, en España, durante el periodo 2015-2019, los costes de los pacientes con insuficiencia cardíaca ascendieron a 15.373 euros por paciente, siendo las hospitalizaciones por insuficiencia cardíaca el factor más determinante (51,0%). Los costes de la medicación representaron solo una pequeña proporción de los costes totales [53]. Los últimos datos publicados por Eurostat revelan que, en 2018, la insuficiencia cardíaca causó 19.142 muertes en España, constituyendo el 4,5% de todas las muertes, el 3,4% en hombres y el 5,6% en mujeres [54]. En este marco de referencia, cardiólogos y médicos de familia consideran que la clave para un mejor control de estos pacientes es impulsar una solución sanitaria proactiva a través de un sistema de monitorización no intrusivo e integrado que unifique la historia clínica de los pacientes y la ponga a disposición de todos los profesionales sanitarios pertinentes. Esto mejorará la seguridad y la eficiencia de la asistencia sanitaria al aumentar la disponibilidad de la información de los pacientes en tiempo real. Además, la comunidad sanitaria y asistencial está convencida de que es crucial promover el autocuidado de los pacientes proporcionándoles a ellos y a sus cuidadores educación y formación sanitaria, así como otros recursos sociales y sanitarios.

3. Copias y resúmenes de los trabajos que constituyen el compendio

3.1. Artículo 1: Smart Furniture as a Component of a Smart City—Definition Based on Key Technologies Specification

En este primer trabajo, el análisis de la literatura se centró en artículos basados en la guía PRISMA [55] y publicados en inglés en distintas bases de datos con el término *Smart Furniture* o Mobiliario Inteligente, y se evaluaron las referencias de los artículos recuperados con el fin de identificar otros posibles trabajos relevantes, incluyendo así otros resultados. La búsqueda de patentes se llevó a cabo a través de ESPACENET, y se enfocó en las tendencias del sector del mobiliario inteligente y en las patentes que incluían tanto en el título como en el resumen los términos *Smart* y *Furniture*, se buscaron definiciones adecuadas del término.

Dicho análisis llevó a proponer una definición del término basándose en la frecuencia con la que las palabras clave aparecían tanto en las bases de datos de artículos y patentes, y en el análisis del contenido de los estudios y patentes incluidos en el presente estudio de acuerdo con los criterios de inclusión y exclusión.

La revisión sistemática de la literatura se centró en 23 artículos, se identificaron los autores más activos que se enfocaban en definir el término *Smart Furniture* y sus propiedades y las principales especificaciones que caracterizan al mobiliario inteligente, y se analizaron las palabras clave usadas con más frecuencia en la literatura en las que los autores se basaban para proponer las definiciones del término.

En cuanto al análisis de patentes, la revisión sistemática se centró en 6 patentes, en el análisis de las palabras clave usadas con más frecuencia, así como la distribución total de patentes por país y el número de compañías que tienen en su nombre el término *Smart Furniture* y las solicitudes de patentes activas. Los autores recopilan y analizan las especificaciones más relevantes que aparecen en las patentes identificadas en cuanto al término *Smart Furniture*, siendo las más relevantes aquellas relacionadas con la identificación del usuario, configuración, conectividad y recopilación de datos del usuario.

El análisis de los estudios y las patentes identificadas permitió enmarcar el concepto de mobiliario inteligente en el contexto de distintos ámbitos: casas inteligentes, dispositivos inteligentes, entornos inteligentes y usuarios, junto con los principales elementos del concepto de mobiliario inteligente: mobiliario, sensores, conectividad, sistemas embebidos, recursos energéticos y actuadores, y así presentar una definición de mobiliario inteligente.

En cuanto a los retos en la investigación del ámbito del Mobiliario Inteligente, los autores se centran en cuestiones tecnológicas, identificándose la mayoría de ellas en el nivel micro y relacionadas con el perfil del usuario, los servicios que pueden ofrecer y geolocalización. Siendo también importante la concienciación y la formación de los usuarios en materia de mobiliario inteligente. Las cuestiones tecnológicas en los niveles mezzo y macro se relacionaron con cuestiones de las ciudades inteligentes. Más allá de dichos retos, el trabajo indica que las futuras investigaciones en el ámbito deberían considerar distintas estrategias que aborden la innovación sostenible, casos de uso y que también incluyan a los cuidadores como parte de los usuarios, así como la elaboración de políticas sociales en cuanto a comunidades inteligentes, los datos obtenidos como parte integrante de las ciudades inteligentes, y aspectos de privacidad y seguridad. Estas estrategias y políticas ayudarán a crear una conexión entre lo normativo y lo empírico en el Mobiliario Inteligente como parte integral de la investigación de las Ciudades Inteligentes.

Finalmente, en el trabajo se enfatiza la necesidad de iniciar y consolidar la colaboración entre la investigación TIC y la investigación socioeconómica debido a la naturaleza interdisciplinar que trae consigo la investigación de las ciudades inteligentes, donde el mobiliario inteligente tiene un papel importante [56]. También se remarca la importancia de integrar, dentro de la investigación del Mobiliario Inteligente, el desarrollo de políticas enfocadas a la innovación, crecimiento económico social e inclusivo y la sostenibilidad, y considerar el escalado de dichas investigaciones y las consideraciones políticas en el más amplio del debate interdisciplinar.

Durante el desarrollo del presente trabajo, el doctorando participó activamente en la búsqueda de patentes a través de ESPACENET, la selección de trabajos y patentes de acuerdo con los criterios de inclusión y exclusión definidos, la identificación de definiciones del término “Mobiliario Inteligente” y en la definición del término “Mobiliario Inteligente” junto con los demás autores. Además, colaboró en la escritura y revisión de las distintas versiones del documento.

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SPECIAL SECTION ON URBAN COMPUTING & WELL-BEING IN SMART CITIES: SERVICES, APPLICATIONS, POLICYMAKING CONSIDERATIONS

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Smart Furniture as a Component of a Smart City–Definition Based on Key Technologies Specification

ONDREJ KREJCAR[1], PETRA MARESOVA[2], ALI SELAMAT[1,3,4,5], (Member, IEEE), FRANCISCO JOSÉ MELERO[6,7], SABINA BARAKOVIC[8], JASMINA BARAKOVIC HUSIC[9], ENRIQUE HERRERA-VIEDMA[10,11], ROBERT FRISCHER[1], AND KAMIL KUCA[1,3]

[1]Center for Basic and Applied Research, Faculty of Informatics and Management, University of Hradec Kralove, 500 03 Hradec Kralove, Czech Republic
[2]Department of Economics, Faculty of Informatics and Management, University of Hradec Kralove, 500 03 Hradec Kralove, Czech Republic
[3]Malaysia Japan International Institute of Technology (MJIIT), Universiti Teknologi Malaysia, Kuala Lumpur 54100, Malaysia
[4]Media and Games Center of Excellence (MagicX), Universiti Teknologi Malaysia, Johor Bahru 81310, Malaysia
[5]School of Computing, Faculty of Engineering, Universiti Teknologi Malaysia (UTM), Johor Bahru 81310, Malaysia
[6]Technical Research Centre of Furniture and Wood of the Region of Murcia, 30510 Yecla, Spain
[7]Technical University of Cartagena, Telecommunication Networks Engineering Group, 30202 Cartagena, Spain
[8]Faculty of Transport and Communications, University of Sarajevo 71000, Sarajevo, Bosnia and Herzegovina
[9]Faculty of Electrical Engineering, University of Sarajevo 71000, Sarajevo, Bosnia and Herzegovina
[10]Andalusian Research Institute in Data Science and Computational Intelligence, University of Granada, 18071 Granada, Spain
[11]Department of Electrical and Computer Engineering, Faculty of Engineering, King Abdulaziz University, Jeddah 21589, Saudi Arabia

Corresponding author: Ondrej Krejcar (ondrej.krejcar@uhk.cz)

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ABSTRACT There are dozens of definitions of smart furniture with meanings that vary greatly. Thus, the aim of this paper is to provide an exact definition of the phrase ‘‘smart furniture’’ based on literature and patent analysis. Why a definition? Because by providing a good definition, we have a statement that captures the meaning, the use, the function, and the essence of a term or a concept and allows the impacts on stakeholders to be described. A literature search was undertaken between 20 July 2018 and 31 August 2018, and the databases searched included SCOPUS, Web of Science, and IEEE Xplore (1998–2017), which were searched by keywords that included the phrase ‘‘smart furniture.’’ Patent searching was performed in the ESPACENET database, where 226 articles from scientific databases and 737 patent applications were examined. After the application of strict criteria, we obtained 23 articles and six patents containing meaningful definitions of smart furniture. Based on the results, smart furniture should be defined as designed, networked furniture that is equipped with an intelligent system or is controller operated with the user's data and energy sources. Smart furniture needs to have the ability to communicate and anticipate a user's needs using a plurality of sensors and actuators inside the user's environment, resulting in user-adapted furniture. The research results and discussion presented in this paper are based on the recognition that the smart furniture research has great policymaking, technological, and economy potential while contributing to the user's wellbeing and Quality of Life (QoL). This paper indicates that the collaboration between the ICT and social-economic research has to be initiated and consolidated in a sustainable way or in an environment that satisfies the needs expressed by the user.

INDEX TERMS Smart furniture, furniture industry, wireless sensor networks, third age, sustainability, market research.

I. INTRODUCTION

The Internet of Things (IoT) [1], [2] and Industry 4.0 [3], [4] provide many opportunities for the use of new technologies.

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The increasing availability of high-quality data collected and transmitted in real time through inexpensive, ubiquitous hardware and connections will undoubtedly lead to scientific, technical, and commercial innovation [5]. Recently, several researchers proposed diverse systems, management

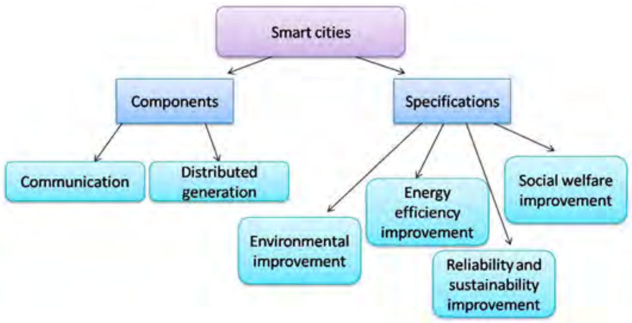

FIGURE 1. The key aspects of Smart Cities [11].

processes, and technologies for managing these data. Some frequently used terms are IoT, intelligent control, home automation, energy management, wearable devices, and smart technologies [6]–[10]. All these elements can also be part of the Smart Cities phenomenon. Papadopoulos et al. 2015 [11] and Tokuda 2003 [12] understand a Smart City to be an intelligence-enabled area connected in a sustainable way that integrates all its infrastructure and services into one compact complex, where intelligent devices are used for monitoring and control to ensure sustainability and efficiency.

Cities/urban spaces cannot be examined in isolation from the context in which they are embedded, be it at the micro, mezzo or macro level [13].

Smart Cities mainly engage in environmental and public services (Fig. 1), but the main building block is represented as a Smart Home, [14] as the Internet of Things (IoT) is now becoming a reality.

Smart Cities are presently becoming a reality for an increasing number of people living in modern cities around the world, where various aspects of the modern city are being automated and integrated with information and communication technologies (ICT) to achieve an improved quality of life (QoL) for the residents [15].

There are 32 different Smart City definitions that can be considered relevant [16]. The term Smart City also covers the following six socioeconomic fields:

- governance
- economics
- environment
- mobility
- people
- living

The research community, however, currently uses an extended number of fields, and 13 fields can certainly be distinguished according to the type of application [17]. The authors stated that smart devices and smart environments are resource-type areas that are required in every type of smart service system. Smart {homes, energy, building transportation, logistics, farming and gardening, security, health care and management, hospitality, and education} are the business system-type areas. Smart City and government systems are defined as an umbrella system for the public administration-type areas [17].

All the aforementioned parts of Smart Cities have been described many times, and their definitions are homogenous. ‘‘Smart Furniture’’, however, is not easily defined. Furniture is one of the main components of our homes, and the role of Smart Furniture is to convert a legacy non-smart space into a smart space where location-based context-aware services, service roaming, personalized services and connectivity to the Internet are ubiquitously provided, as Professor Tokuda mentions [18].

According to the research compiled by Chun in 2015 [19], the global Smart Furniture industry is expected to grow in areas such as North America and the Asian Pacific region. The industry is governed by technological developments, a growing elderly population, and the demand for automation and improved spaces. According to Wallbaum *et al.* [20], the total value of the global Smart Furniture industry was estimated to be USD 111.7 million in 2016, with a projected growth of 22% between 2017 and 2025. The concept of Smart Furniture stems from the IoT, smart things, or intelligent things [21], [22]. According to Li & Wang in 2009 [23], smart things are described as devices that are controlled through control processors and the Internet. The Sonos home music system, Philips colour-changing bulbs, and a revolving Italian Murphy bed and Murphy sofa are examples of devices that are controlled by information technology tools. With the development of such products, concepts such as intelligent furniture and Smart Furniture have been developed. Since the inception of Internet and information technology tools, automated devices such as smart TVs, smart washing machines, smart tables, smart beds, and smart refrigerators have been designed and are already in use [20]–[22].

All of the aforementioned areas are used in the public sector, companies, and households. As these innovations are widely used, and there is also a problem with the exact definitions of these concepts, owing to the differences in meanings. For example, a Smart Home can be described as a house that uses various types of information technology to monitor the environment, control electric appliances, and communicate with the outer world. The Smart Home is a complex type of technology; at the same time, it continues to develop. A Smart Home automation system has been developed to automatically accomplish activities performed frequently in daily life to create a more comfortable and convenient environment [24].

In addition to the well-defined Smart City or Smart Home, another area is the Smart Space Design [25], which allows an optimal design of a user's space according to the user's needs, as well as human computer interaction satisfaction and fulfillment of other aspects of life.

Smart Furniture can be seen as belonging under the umbrella of the Smart Home and Smart City, with an overlap with the furniture sector and the IoT. All of these terms are also connected with the Industry 4.0 phenomenon, where maximum benefits are achieved through the synergies that result in ambient intelligence while creating the ubiquitous home [26]–[28]. Poslad 2009 [29] defined and describes ubiquitous computing as an umbrella term for the following three different directions: smart devices, smart environments, and smart interactions. He states, "the concept smart simply means that the entity is active, digital, networked, can operate to some extent autonomously, is reconfigurable, and has local control of the resources it needs such as energy, data storage". The phrase Smart Furniture is used in various ways regarding connections and meanings in the design of furniture, as it needs to be smart through a connection to a wall-mounted electric socket with an Internet connection. In 2003, Ito *et al.* [30] stated, "Smart Furniture is a platform for systems to realize Smart Hot-spots. By simply placing the Smart Furniture, we can turn legacy spaces into Smart Hotspots. Smart Furniture needs to be equipped with a networked computer, I/O devices and sensors. Coordination with existing network infrastructure or user's devices are also required." Vaida, Gherman et al., in 2014 [31], provided the following definition: "Smart Furniture is the furniture which brings added value, functionality, comfort and elegance to fit every personalized requirement issued by the user". Braun, Majewski et al., in 2016 [32], provided the following definition: "Smart Furniture is able to detect the presence, posture or even physiological parameters of its occupants". According to Technavio's Smart Furniture market research report [33], "Smart furniture is powered by technological advances such as network connectivity via Bluetooth or Wi-Fi and others, which helps users enhance their furniture beyond its basic analogue functions. Smart furniture helps consumers in browsing the Internet for news feeds, weather forecast updates, listen to music. It also offers wireless charging slots for smartphones and has features like distance operation and others". Additionally, the Philips Smart Furniture project explores the ability of furniture to change its appearance by using a transparent futuristic tablet that allows users to manipulate the furniture within a room through augmented reality [34]. Several previous studies have reviewed the Smart Furniture concept and the current trends [31].

However, the given Smart Furniture definitions do not attempt to introduce such an approach as an integral part of Smart Cities and QoL research, despite the fact that Smart Cities and the support of QoL belong to key contemporary phenomena in developed countries.

Furthermore, they have access limitations, such as their availability is only through research database searches and patent applications are rarely taken into account, although the number of patent applications has grown rapidly in the last few years. The keywords are not connected with the term's definitions based on a study of the full texts of scientific articles.

Therefore, the aim of the paper is to provide an exact meaning of the phrase "Smart Furniture" based on a literature and patent analysis in relation to potential users.

A correct definition of "Smart Furniture" is crucial in several areas, where the definition can be seen as a benefit for the following:

1. Users of furniture products: everybody, especially, those vulnerable groups, such as older adults and disabled individuals.
2. Industry: Traditional industries, such as furniture companies, as they would be able to be more competitive and access other market segments, and ITC companies, as their products would have more applications.
3. Society in general: Considering that those vulnerable groups would be more benefitted since these technologies would allow them to live more independently at home and to continue being efficient at work for longer. Smart Furniture would contribute to the future sustainability of pensions, health care and long-care system.

The audience and the beneficiaries can be seen mainly as practitioners, industry members (furniture producers, ICT professionals, electronics manufacturers, architects, designers, construction firms and their relevant professional associations), the general public (especially the elderly, their caregivers, families, friends and any other interested platforms), education institutions, scientists, industry members working in the field, professional organizations, ministries, policy makers (European, national, and regional policy makers involved in health, sustainability, social wellbeing, etc.) and other government organizations, academics, public institutions and communities.

The furniture sector plays an incredibly important role in meeting the challenges that demographic change brings. Not only it is a critical part of the European economy, it can also significantly improve the accessibility of the built environment for older adults by improving its product offering with integrated ICT solutions, ergonomic designs, and more completely taking into account the health and safety needs of the users.

These reasons led the authors of this article to write a review that provides a current scientific and research analysis in the field of Smart Home furniture and to solve the following related problems:

(1) A definition of Smart Furniture does not exist, unlike for a Smart City or a Smart Home, which have been explicitly defined. After examining of a number of relevant database articles, we concluded that there are actually a number of definitions for Smart Furniture [11], [31], [35], [36]. These definitions are often very misleading, with meanings related only to the furniture's design. Characteristics based on functionality, in the sense of an active networked digital element, are often not present within the Smart Home concept.

(2) The customer, for example, may feel that each Smart Furniture product will be able to link to other Smart Home features, as he/she may be misled by results indicating a different purpose. In the scientific community, disunity leads to different interpretations and the

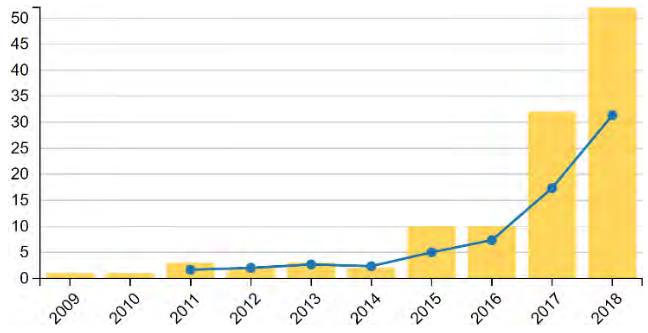

FIGURE 2. Patent activity trend for the topic "smart furniture" within the ESPACENET database, which includes 114 published patent applications worldwide.

creation of inconsistent concepts that deviate from the original idea.

(3) At the beginning of the Industry 4.0 era [37], sensors and actuators were envisioned as unsightly boxes mounted on apartment walls. Currently, we have the ability to buy Smart Home Control devices that connect via our Smart Phones and control a variety of home elements. A refrigerator or washing machine may even already be part of the IoT [38]. Therefore, Smart Home advancements are ongoing, and the next logical step is to incorporate electronic devices into furniture with new added value for the user. The Smart Furniture specifications involve the combination of electronics with designer furniture [33].

(4) The last few years (2015-2018) were significant regarding the increase in patent activity around the world for Smart Furniture, as shown in the figure (Fig. 2). This phenomenon requires investigation using a Systematic Literature Analysis to provide more relevant information and knowledge regarding the current meaning and exact definition of Smart Furniture.

Solving the abovementioned problems leads to answers to questions such as the following: Why does this investigation focus on the definition and specification of Smart Furniture and under what circumstances is this concept misused? How should the gap in the specific domain knowledge in the field of Smart Furniture be bridged?

II. METHODOLOGY

A. SEARCH STRATEGY

Our search of scientific and research sources focused on scientific sources as well as on intellectual property (IP) patents.

The scoping review was performed for research papers based on PRISMA guidelines [39]. The literature search was undertaken between 20 July 2018 and 31 August 2018, to identify published peer-reviewed articles and conference papers in English. The databases searched included SCOPUS, Web of Science, and IEEE Xplore (the first source from 1998 until the last in 2017). The keywords included the exact phrase "Smart Furniture". The keywords were used in the database and journal searches. The references of the retrieved articles were assessed for relevant articles that our searches may have missed; thus, several other results were added.

Patent searching was performed in the ESPACENET database, because it covers most all of the local IP offices' databases. The search strategy was divided into two ways of searching, as we focused on the trends of the Smart Furniture sector as the first result and searched for proper definitions of "Smart Furniture". Because of the importance of the Smart Furniture sector, a search for the words "Smart" AND "Furniture" in the title or abstract of the patent was used. The seven oldest patents, i.e., from 1899 to 1995, were removed from the search results based on a quick screening of these patents. To find proper definitions of "Smart Furniture", a search for the exact phrase was performed, where the range of years was the same as for the scoping review (1998–2017). The general procedure is described in Fig. 3.

B. ANALYSIS

The analysis was performed based on a combination of reviews, original articles, conference papers, (afterwards referred to as articles), and patent applications (as patents). Articles and patents were included in the selection and review based on the following inclusion criteria.

- Ordinary results in a 20-year window: 1998–2017.
- Reviewed full texts of articles or patents in English.
- The aim of this research is to analyze the potential uses of different types of Smart Furniture, innovation research, or perceptions of future potential users.
- The output of the articles included both descriptions of specific Smart Furniture solutions and an analysis of the state of the solution and an effort to define the concept of Smart Furniture.
- Articles where is possible to describe some of the following variables are associated with aim of the paper, i.e., to provide a definition with respect to binding and target groups of users: device types, actuator types, processing type and user identification (personal identification and use-cases).

The results that were gradually eliminated from the analysis were done so for the following reasons:

- Written in a language other than English.
- Results that were focused only on the description of the concrete technological / technical solutions of the selected Smart Furniture elements; even in the theoretical background, there was no meanings given for these concepts.
- Results that were closely related (only included a description of the technical solution) to the technological solution.
- Results addressing the area of sustainability of development and the impacts of these elements on the environment.
- Results in which "Smart Furniture" was only mentioned but not further defined.

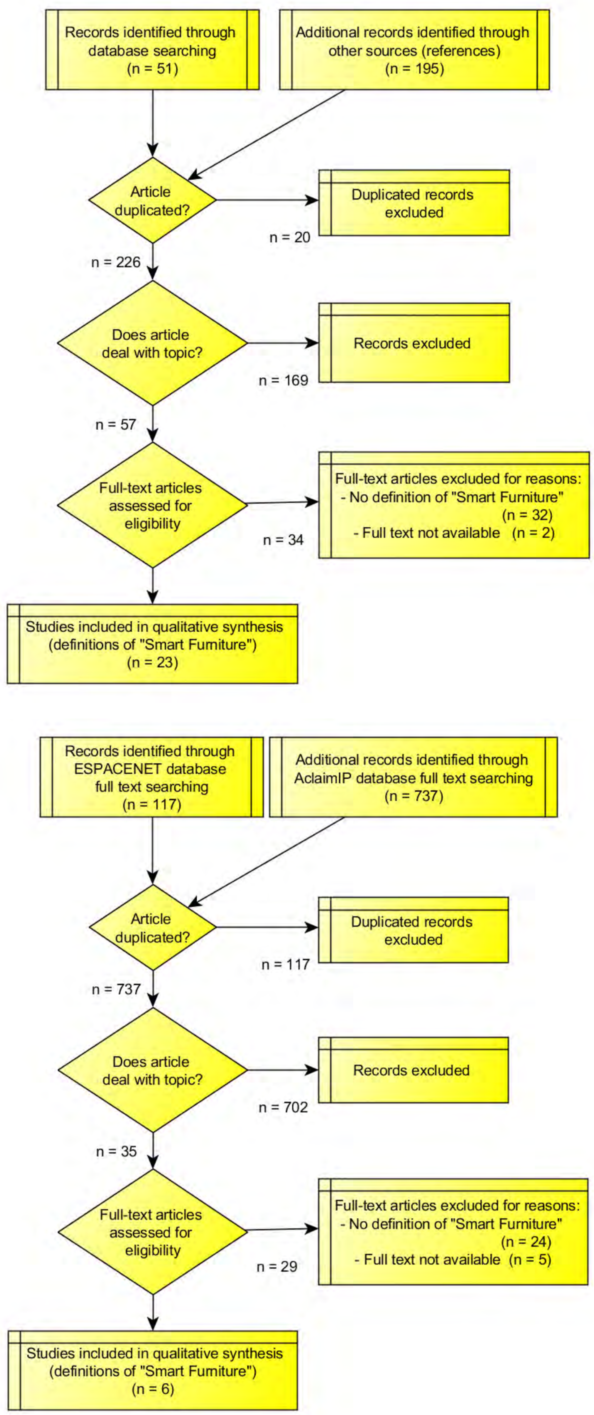

FIGURE 3. Diagrammatic representation of the study-selection flow for the systematic literature review (SLR) (upper) and systematic patent review (SPR) (lower).

III. RESULTS

A. SMART FURNITURE – TERM SPECIFICATION, SPECIFICATION, AND CHARACTERISTICS IN THE LITERATURE

The most active main authors for the topic "Smart Furniture" in the ISI WOK database are Tokuda H. (6×), Brooks J.O. (4×), Papadopoulos I. (4×), and Braun A. (4×).

TABLE 1. Frequency and top words for analyzed literature.

Word	Occurrences	Frequency	Rank
smart	77	5.9%	1
furniture	68	5.2%	2
user(s)	22	1.5%	3
space / environment	21	1.4%	4
control(ler) / automated	18	1.4%	5
data / information	18	1.3%	6
system(s)	17	1.3%	7
sensor(s)	16	1.3%	8
design	16	1.2%	9
Intelligent(ce)	16	1.1%	10
according	14	1.1%	11
technology	12	0.9%	12
things / objects	12	0.9%	13
wireless networks	10	0.4%	14
table(s)	10	0.9%	15
functionality	9	0.4%	16
devices	9	0.4%	17
computer	8	0.4%	18
Internet	8	0.4%	19
interaction	5	0.2%	20

The authors focus on how to define the term and how to specify the properties of Smart Furniture. Table 2 contains 12 frequently used keywords from the area of IT; the keyword for the design area is the only one used 16 times. Table 1 shows that the frequency of occurrence is based on 23 studies that were screened based on the exclusion and inclusion criteria (Fig. 2).

Based on these keywords, the authors propose a definition of Smart Furniture and, to a greater extent, describe the characteristics of Smart Furniture.

1) TERM SPECIFICATION FOR SMART FURNITURE

In 2004, Tokuda [18] stated that Smart Furniture is a product that has the ability to change the residential space into an intelligent space through the use of information technology. Additionally, in 2004, Tokuda [18] further defined the concept of Smart Furniture as a platform that uses smart hot-spots, which use sensors, computing devices, and computer networking facilities to transform the private space into an intelligent space. On the other hand, in 2015, Panda and Goel [40] asserted that Smart Furniture is based on informational technology devices, such as sensors and computing networks, that aim at providing comfort to the users within the human environment. The core concept of Smart Furniture is that objects can be equipped with information technology capabilities, which can allow them to communicate with the devices through the use of sensors and

TABLE 2. Applicant countries in the patent databases ESPACENET and AcclaimIP for the phrase smart furniture ("SF").

Country (applicant)	ESPACENET "SF" in topic	AcclaimIP "SF" in topic	ESPACENET "SF" anywhere	AcclaimIP "SF" anywhere
United States	6	6	60	95
China	17	61	24	819
World	4	4	10	22
Taiwan	1	1	1	13
Korea, Republic of	2	3	2	8
Romania			7	6
EU			6	5
India				4
Canada			3	2
Japan	1	1	1	1
Mexico	1	1	1	1
United Kingdom			1	1
Australia			1	
Total	32	77	117	977

computer networks through the Internet [19], [34], [36], [41]. Consequently, this allows the integration of real-life data with the virtual environment's information. According to Collins English Dictionary, ''Furniture consists of large objects such as tables, chairs, or beds that are used in a room for sitting or lying on or for putting things on or in''. Oxford Dictionaries defines furniture as ''The movable articles that are used to make a room or building suitable for living or working in, such as tables, chairs, or desks''. The meaning of this word is well known, as there is no difference between the different meanings. The Oxford dictionary provides different meanings for the adjective, verb, and noun. Collins English Dictionary provides the definition of Smart Home as ''a dwelling equipped with systems and appliances that can be operated remotely using a computer or mobile phone'', but for the simple word smart, it provides ten examples of its usage and many synonyms. As asserted by Li and Wang [23], intelligent furniture consists of conventional furniture and information technology, which emphasizes creating a ''dialogue between the human being and the furniture''. The literature suggests that the term Smart Furniture is a relatively new term [20]–[22], [42]. However, a previous work by Maskeliunas & Raudonis (2013) [43] also reveals that the term intelligent furniture is used to describe automated furniture, which has the ability to collect data through sensors, which transmit it to the controller [43]. The controller is responsible for processing the information according to the encoded procedures to automate the furniture's control process. Another term used in the literature is smart things, which is used to describe objects with sensing, processing, and networking capabilities and are autonomous in nature [21]. Tang, He & Wu in 2013 [42] asserts that smart things have the ability to connect the virtual and real environments for automation and monitoring; they operate from networks through the use of web services. Technologies such as sensors, Bluetooth technology, ambient intelligence, Web 3.0, Wi-Fi, and ZigBee are used to connect the physical and virtual environment [42].

2) SPECIFICATION OF SMART FURNITURE

In 2014, Vaida *et al.* [31] provided 14 Smart Furniture characteristics; based on a survey, they determined that five of them can be considered more valuable than the others, with an overall importance of almost 50%. The most important criteria for customers are design, functionality, safety in use, customization, and structural design [44]. In 2014, Probst *et al.* [45] stated that functional furniture aims at improving its users comfort through the use of intelligent systems. In 2018, Pan *et al.* [46] stated that Smart Furniture is based on an intelligent system that aims at increasing the value, comfort, and functionality of the furniture for the user. As asserted by Panda & Goel in 2015 [40], Smart Furniture is characterized by its ability to execute several applications at the same time, their ability to support customization and mobility, and the capability to connect the remote service and operate as per user input. According to the work of Papadopoulos, Karagouni & Trigkas in 2016 [11], the characteristics of Smart Furniture vary according to individual needs and requirements. These are discussed as follows.

(1) Style: Smart Furniture design is accommodated according to individual requirements. It can be novel, traditional, or extravagant [11].
(2) Space: Space has been identified as an important factor that affects the design of the Smart Furniture. Space requirements can include ample open space, some space, or restricted space [41].
(3) Functionality: According to the work of Papadopoulos et al. in 2015 [38], Smart Furniture design is highly dependent on functionality. Smart Furniture can be designed to act as a space saver or to have a multipurpose function.

Smart Furniture has several capabilities. In 2013, Maskeliunas and Raudonis [43] asserted that smart furniture is designed for user detection and establishing social connections between users. Chun, in 2015 [19], stated that Smart Furniture's main capabilities are to retrieve user data and analyze the user network's topology, settings, and characteristics. According to Jianping & Haibin's work in 2012 [34], the Smart Furniture's capabilities are characterized by their ability to collect user data, coordinate the data to the control unit, and provide the output based on the data collected. The Smart Furniture architecture requires hardware and software platforms that must connect the physical environment, the virtual environment, and the wireless network [36]. The architecture needs to support customization, perception, and physical output based on the artefact type; therefore, it needs an adaptable configuration system, control unit, and support for sensor modalities, based on user requirements [34], [41]. In 2004, Tokuda [18] stated that the Smart

Furniture design was based on previous designs proposed by Tokuda in 2003 and 2004 [12], [30], which proposed a Smart Furniture model. The proposed design was based on human-computer interaction through the use of hardware and software technologies. The term smart hot-spot services was proposed by researchers, which acted as a computer network to offer functionality to the end-user. The hardware requirements of the Smart Furniture include a controller, actuator, sensor, and hardware circuit. The software requirements serve as the main operating system that is responsible for collecting data [14, p. 2], [18]. The intelligent behavior of the Smart Furniture is used by the consumers through user interaction with the computer interface. Through the interface circuit, the control commands are transmitted to all parts of the furniture. The application programme is responsible for the collection of data, which can achieved either through speech recognition, touch-screen technology, or somatosensory technology [36]. The data are then moved to the sensor. The sensor is responsible for creating awareness in the physical environment, which requires the communication of objects to create the virtual presence that make it a part of the network. The communication requirements essential to establishing a connection include local transmission support of information to the objects that are nearby and quick response to network changes without the need for user interaction [23]. Consequently, the objects need to be highly efficient, compact, and lightweight. Once the data are retrieved by the sensor, they are processed and analyzed by the cloud technology database.

B. SMART FURNITURE IN PATENT DATABASES

The first patent containing the words Smart Furniture is from 1998, when inventor W.D. Gilbert of the Powerdesk company mentioned that a card can be a smart card and the computer and card-reader can be integrated into an item of furniture, e.g., a desk or writing table [47]. The next invention by Kevin [48] described intelligent furniture equipped with a set of sensors and an intelligent processor. The Smart Furniture patenting activity trend for these years was increasing. The first patent containing the exact phrase "Smart Furniture" in the body is a patent application from Nokia Corporation from 30 April 2002, granted 27 March 2007 [49]. Unfortunately, this patent only used "Smart Furniture" as one of the many references in the text, while the application theme is not connected to the searched topic. The first relevant patent application in history dealing with the phrase "Smart Furniture" is the "RFID smart office chair" by Hagale et al., from the IBM Corporation in an application on 5 August 2004 [50], granted on 15 November 2005. This patent application contains the phrase "Smart Furniture" 71 times (4 times in the Abstract, 40 times in the Claims, and 27 times in the Description). This patent is also the most cited patent (71 times by other patents) for all patents covered by a search in the ESPACENET database for the phrase "Smart Furniture". The total distribution by country is shown in Table 2.

TABLE 3. Frequency and top words for patents.

Word	Occurrences	Frequency	Rank
Control (ler) (ing) / monitoring / processing / Automatic (ally)	139	3.9%	1
Smart	122	3.8%	2
Furniture	93	3.2%	3
plate / table / lamp / bed / light / equipment / television	90	2.5%	4
Device(s) / terminal / machine	83	2.2%	5
module	58	2%	6
data / information	51	1.4%	7
user / body	50	1.0%	8
Remote / mobile / central	43	0.9%	9
Home / indoor	35	0.7%	10
Connected (ion) (ing)	32	0.6%	11
wireless network	32	0.6%	12
arranged	30	0.5%	13
system	27	0.5%	14
Surface / material	27	0.5%	15
signal	16	0.3%	16
installed	13	0.3%	17
recognition	12	0.2%	18
connector / sensors	12	0.2%	19
Electric / power	12	0.2%	20

There are seven companies around the world whose name contains "Smart Furniture", and they have 20 active patent applications. These patents do not contain information related to the definition of "Smart Furniture", but they are also taken into account due to the company name.

The most used keywords that were included in the patent databases for Smart Furniture are specified in Table 3.

Based on the available options from the analytical solutions presented in patents, we selected the two most relevant circle graphs based on the most frequently used nouns in the results from the ESPACENET database (Fig. 4) and the most frequently used assignees from AcclaimIP (Fig. 4). The most used nouns highlighted several parameters that define Smart Furniture, as follows.

- several types of furniture
- current state of furniture
- hardware solution which is embedded in Smart Furniture
- identification of user by plurality of parameters
- use of a personal profile by secure communication

A summary of selected patent applications performed by Hagale *et al.* [50] resulted in the most frequent nouns and assignees (Fig. 4). It is evident from the most used words that Smart Furniture must be designed as furniture with some connection to user data for suitable adjustment of Smart Furniture items to fit to a user's needs.

1) TERM SPECIFICATION FOR SMART FURNITURE BASED ON PATENT DATABASES

Inventors [50] also stated that "Smart Furniture can include a reader for the identification device to identify a person

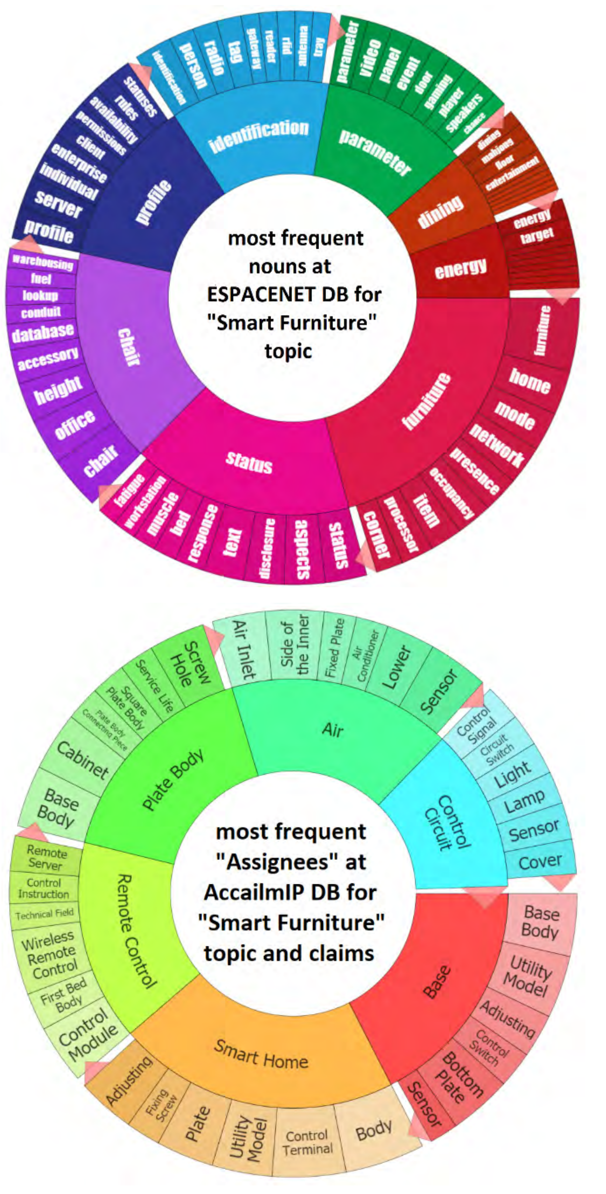

FIGURE 4. Most frequent "nouns" and "Assignees" found in the patent applications in the ESPACENET (upper) and AcclaimIP databases (lower) for the phrase "Smart Furniture" in the topic (117 patents and 217 patents, respectively).

using the piece of furniture. The Smart Furniture may also include storage in which settings profiles of users are stored. The Smart Furniture may then receive a profile that matches the person using the furniture and set adjustable features according to the profile. Settings profiles may be uploaded to or downloaded from a remote storage using a wireless communication interface, such as a wireless network interface". Such a network is described as an Internet connection to provide even worldwide connections as well as propagation to any other Smart Furniture capable of communicating and applying these settings. The last-named ability is very important because it confirms the need to reconfigure the functionality of the Smart Furniture to fit the user's needs or preferences. As the last parameter, the priority of each Smart Furniture item is declared to be equipped. The next interesting patent application dealing with some definition of Smart Furniture in connection with a Smart Home router was from China in 2016 [51]. The inventors provided a description of "Smart Furniture" that is almost up to date. The invention discloses "a Smart Home router which is capable of achieving self-adaptation of the IoT" [51]. They also state that "different Smart Furniture devices are controlled through various apps installed in the router in advance to be connected into the network in a wired or wireless mode". They are also controlled by users using a "connection according to the protocol and encryption authenticated hardware in intelligent furniture", which indicates the security level for this home equipment. Smart Furniture, according to this patent application, is also part of the IoT, as they declare that "Various kinds of Smart Furniture can be connected into the IoT through a cloud tool or a desktop end and mobile terminal APPs, and the user does not need to conduct complex configuration; meanwhile, due to the fact that an encryption and decryption hardware chip is arranged internally, the home network is safer and not likely to be attacked" [51]. The emphasis given to the security level of this invention is significant, as they plan to use a HW crypto solution.

The use of Smart Furniture for one of the original purposes defined by Tokuda [12] is declared by another patent application, "Wireless network distribution method applicable to smart furniture device" by Chuan [52], where the inventors stated that "The invention belongs to the field of smart furniture, and provides a wireless network distribution method applicable to a smart furniture device".

The next invention, named "Smart Furniture" by Yang, 2017, is based on the use of standard home equipment, such as a bed, sofa, or chair, with detection sensors to measure the health data of the user [53]. They described Smart Furniture as "a furniture article designed for being used by a user and a smart system which includes a detection module built-in with the furniture article for detecting health data of the user when the furniture article is used". They suggest the use of a plurality of sensors, which need to be "located at a user supporting surface of the furniture article for collecting health data of the user" [53]. The measured user health data are then analyzed to ensure that the user is using the article of furniture properly [53].

C. SPECIFICATION OF TYPES AND USES OF SMART FURNITURE IN THE LITERATURE AND PATENT DATABASES

Wide-ranging studies have discussed the design and possible uses of Smart Furniture to improve living standards, promote user safety, promote energy efficiency, and save operational and maintenance costs [11], [36], [40], [41], [46].

As previously mentioned, the first patent with the phrase "Smart Furniture" was filed by Hagale et al. of the IBM Corporation in August 2004 [50]. They used several possible descriptions of what Smart Furniture is and what role it can play. They first stated the following: ''Smart furniture is provided that automatically adjusts to a person's preferences based on an identification of the person. A person may be equipped with an identification device, such as a radio frequency identification device'' [50]. This definition is still valid and up to date. Smart Furniture needs to adjust to user preferences once the user is identified by the device. At that time, a radio frequency identification device (RFID) [54] was one of the common possible options; now, any personal mobile smart device, such as a Smartphone, can easily be used for this purpose; however, they cannot use them exclusively thanks to their start-of-market penetration beginning in 2005. In 2012, Bleda *et al.* [35] asserted that the use of Smart Furniture aided by sensors and ambience intelligence systems offers several benefits. Ambience intelligence systems with sensors can be integrated into the furniture and, because they are small and lightweight, the user cannot feel them. The potential use of ambience technology allows a ubiquitous computing environment. Another potential advantage of this technology is that it can help elderly people execute daily operations [20], [22]. In 2003, Ito *et al.* [30] suggested that users can use Smart Furniture as a gateway to the cyber world, as a service operator, or as a service receiver. As asserted by Tokuda in 2004 [14, p. 2], mirror-type Smart Furniture could be used ''as a personal reminder or a controller for various appliances at home''. In 2011, Brooks *et al.* [41] conducted a study to present the concept of Smart Furniture. Their study emphasizes using nightstands based on intelligent systems. The nightstands had embedded sensors and smart features and were primarily used by senior citizens. The researchers focused primarily on the design and function of the nightstand. The capabilities of the nightstands included the ability to move up and down and the interactions were voice-activated [41]. The nightstand design was based on a contemporary design with additional storage facilities. Furthermore, the researchers proposed another Assistive Robotic Table [41]. Its capabilities included smart storage and a smart table surface. The smart table surface could fold and extend through automated control. Furthermore, the modified robotic nightstand had an automated headboard with interactive functionality [41].

In countries such as China and Japan, Smart Furniture is being used in commercial buildings and public spaces to improve user comfort, improve functionality, and save space. The use of smart office furniture in commercial offices includes office controlling systems and intelligent file cabinet systems [22]. In healthcare, the Smart Furniture pieces developed by researchers include a smart medicine cabinet that has the ability to identify expired medication, automated smart tables whose height can be adjusted based on user requirements to relieve exhaustion [20]. For residential units, the types of Smart Furniture are wide ranging. Tables with built-in light systems have been developed. These tables have the ability to detect the luminosity based on user's requirement and can provide the required amount of light within a short time to reduce visual exhaustion. Furthermore, these tables have light sensation controls, on/off lighting capabilities, and time-switching capabilities [42]. Magnetic induction installations in the tables offer temperature regulation, which ensures a constant room temperature.

Study furniture for children has been designed with smart capabilities. According to Pan et al. in 2018 [46], study-type furniture has been designed to adjust the study-table height according to the user's requirements. A project by Maskeliunas & Raudonis in 2013 [43] developed a human–computer interaction sofa with the following three technologies: gaze tracking, hand touch, and speech recognition. The proposed design demonstrates the efficiency of the three technologies combined. An intelligent sofa has been designed with welcoming speech capabilities [19]. Another recently developed Smart Furniture design is smart bookcases that signal the user if the load of books on it exceeds its limit. A smart chest has been designed with disinfection and dehumidification functionalities. The design of Smart Furniture is not limited to living room and bedroom furniture. According to Papadopoulos *et al.* [11], smart kitchen cabinets and stations have been designed to regulate the temperature, the fire intensity of the cooking range, and recreational facilities, such as watching videos and listening to music.

1) KEY TECHNOLOGIES OF SMART FURNITURE

Since the year 2003, when the phrase ''Smart Furniture'' was initially coined by Ito *et al.* [30], a number of technologies have been described within this domain. A summary table (Table 4) was prepared to provide a list of technologies used in the Smart Furniture phenomenon as well as the advancements in recent years in the given domain.

In 2004, Tokuda [18] proposed a Smart Furniture design with Internet accessibility through the use of a smart hot-spot that has access to the Internet. The design principle of this Smart Furniture based on a smart hotspot was to improve the user's functionality and comfort. The researchers used computer networks, sensors, and devices that allowed the user to use the Smart Furniture to access a virtual environment by acting as service operators. Based on the proposed system, they designed a cylindrical lamp and a mirror-type Smart Furniture product that contained an iPAQ and Linux operating system. The cylindrical lamp had six LED lights that operated alternatively. The mirror-type Smart Furniture product had an iPAQ with a wireless LAN and a Linux operating system.

In 2012, Bleda *et al.* [35] reviewed the existing wireless communication standards in the automation and control field that were suitable for a larger network of communication nodes. Among the main standards were X10, LonWorks, and KNX, and the ZigBee, a standard of IEEE 802.15.4, was found to be the most suitable standard for Smart Furniture [35]. They also reviewed low power microcontrollers, which are needed to provide sensor nodes with low power consumption. The main microcontrollers are MICA/MizaZ, Tyndall, Telos/TelosB, and Movital/Jennic. The microcontrollers resolve the problem of the quality loss of the communication link when a sensor network is deployed

TABLE 4. Smart Furniture characteristics according to sensor/device types, actuator types, processing types, personal identification and use-cases.

		Sensor/device types			Actuator types		Processing types		Person detection and recognition			Use-cases	
Authors	Title of study	Wearables/ phones/ tablets	Ambient sensors (embedded)	Wireless Network	Wi-Fi Access Point	Electrical / mechanical	Processing on local computer or ad hoc	Cloud based processing / online service / server	Identification by device/tag	Identification by ambient recognition	Anonymous person identification	Monitoring	Experimental study
Ito et al. in 2003 [30]	Smart furniture: improvising ubiquitous hot-spot environment	X	touch, voice	RFID, Wi-Fi, IrDA	X	X, display, speaker, light, LCD, lamp	X		X	X			
Tokuda in 2004 [14]	Sf2: Smart furniture for creating ubiquitous applications	X	touch	RFID, Wi-Fi, IrDA	X	X, display, speaker, light, LCD, lamp			X	X		X	
Hagale et al. 2004 [50]	RFID smart office chair	X	X	RFID, Wi-Fi	X	X		X	X				
Brooks et al. in 2011 [41]	Toward a "Smart" Nightstand Prototype: An Examination of Nightstand Table Contents and Preferences		X, voice			X				X		AL, rehabilitation	28 participants (adult patients), 36 students & 36 older people
Bleda et al. in 2012 [35]	Evaluation of the Impact of Furniture on Communications Performance for Ubiquitous Deployment of Wireless Sensor Networks in Smart Homes	X, WSN, IoT, WoT	X, temp, humidity, luminosity	ZigBee, 6LoWPAN, GLoWBAL			X	X		X		AAL	
Tang, He & Wu in 2013 [42]	Design and Implementation of the System Based on the Mechanical Topology Smart Furniture		X	RF		X, ATmega16L, on/off windows & gas tank	X, ATmega16L	X			X	X, PIR	
Maskeliunas & Raudonis in 2013 [43]	ROBOSOFA-Low cost multimodal I/O fusion for smart furniture		voice, touch, gaze, camera, accelerometer				X		X	X			10 participants (adult)
Wallbaum et al. 2016 [20]	RemoTable: Sharing Daily Activities and Moods Using Smart Furniture		proximity	RFID, Wi-Fi		X, Arduino Mega, LED	X, Raspberry Pi				X		14 participants (adults)
Papadopoulos, Karagouni & Trigkas in 2015 [11]	Techno-economic Analysis of Furniture Innovation: Developing a Green and Smart Furniture for Mass Production	X	camera	X		X, mirror	X, tablet, PLC			X			

in the furniture of a house with respect to signals at 2.4 Ghz, which are used in ZigBee, for example. Therefore, the higher power consumption that results in decreased battery life is also a common problem. The materials tested, starting with those that introduce lower power losses (plastics, PVC, bamboo) and ending with materials with greater power losses (cardboard, aluminium and steel), have been reviewed [35].

The design of Smart Furniture was also investigated by Tang, He & Wu in 2013 [42]. The researchers emphasize the benefits of using wireless networking for a Smart Home's control system [42]. The key features of the system included motor driven windows and an on/off control system for the gas tank.

There is an emerging trend of using new technologies for sensor nodes and end point HW controllers as well as using the new standards in wireless communication covering the well-established WiFi and RFID or ZigBee standards. The new standards also covered Bleda et al. in 2012 [35] and their use of the Internet of Things (IoT), Web of Things (WoT) and Wireless Sensor Networks (WSNs) as the umbrella system.

Vaida et al. 2014 [31] contributed to the Smart Furniture topic with a study covering 30 participants, where they determined that 5 of the most valuable Smart Furniture characteristics of the 14 available are as follows:

(1) Design
(2) Functionality
(3) Safety in Use
(4) Customization
(5) Structural Design

The design of the Smart Furniture is its most important feature, as every user needs to use the furniture for its primary purpose. The second and fourth characteristics, ''Functionality'' and ''Customization'', however, require more specific information, which characterizes the ability of the user to satisfy his/her declared and nondeclared needs. The user's needs should be transferred to the Smart Furniture by HW equipment, which allows the detection of identified or anonymous users. A number of possibilities are available to enable a user identification system, as shown in Table 4.

Identification is mostly performed by the user's smart device, a RFID in earlier years, or by a proximity sensor if anonymous users are allowed. Using a camera for identification is also a new trend because, with the increasing processing power of node controllers, it is possible to detect the face of a user for identification.

Thus, the definition of Smart Furniture is now more focused on furniture with interfaces for entering commands rather than furniture with interfaces that actively transform the furniture.

With the goal of providing a correct ''Smart Furniture'' definition, the key technologies have to be studied in detail [55], [56]. The key technologies needed to exploit Smart Furniture can be summarized as a network of physically connected devices, such as vehicles or home appliances, that enable these 'things' to connect and exchange data. This connectivity, in turn, creates never-before-seen opportunities to converge the physical and the digital – via data analytics – to improve efficiency (both in the public and private sectors), drive economic benefits and improve livelihoods.

The most used and, therefore, the key technology for Smart Furniture, as described by research articles and patents (Table 4), includes any type of ambient (embedded) sensor (9 studies). The second most used technology includes any type of actuator, where visualization is most often used, but the trend is towards using a microprocessor unit with a high-level programming language (7 studies). Some studies (7 studies) include Wireless Network communication, which is needed to connect all types of Smart Furniture with the nodes and main stations, such as Raspberry, Arduino or a microprocessor unit in the case of a final commercial product. Smart Furniture nodes interconnected by any type of wireless technology require a processing unit, as presented in the literature six times. The processing speed of the unit depends on the purpose of the Smart Furniture, and the current trend is to use an embedded PC type tablet.

Another interesting phenomenon is the presence of Ambient Assisted Living (AAL) [57] or monitoring (4 studies) due to the connection of the Smart Furniture to a Smart Home system with some level of (artificial) intelligence. Studies have also covered the ethical issues regarding monitoring (either with active or passive (PIR sensors)) or personal identification (6 studies).

Based on the analyzed research projects, studies and patent applications, Smart Furniture can be described in the context of Smart Homes, Smart Devices, Smart Environments and Users, as well as with the basic building blocks of the Smart Furniture concept which are as follows: furniture, sensors, connectivity, embedded systems, energy sources and actuators (Fig. 5). The role of the user is also important, and it needs to be stated that users can interact with other components of the Smart Home, not only with the Smart Furniture.

D. A SUGGESTED DEFINITION OF SMART FURNITURE BASED ON THE LITERATURE AND PATENT ANALYSES

Based on the frequency of keywords used in the literature and patent databases and based on the examination of the content of the studies and patents included in the selection based on the exclusion and inclusion criteria, the authors suggest the following definition of Smart Furniture.

Smart Furniture is designed, networked furniture that is equipped with an intelligent system or controller operated with the user's data and energy sources. Smart Furniture is able to communicate and anticipate the user's needs using a plurality of sensors and actuators inside the user's environment, resulting in a form of user-adapted furniture or an environment that satisfies the user-declared needs and non-declared needs for the purpose of improving their quality of life in a smart world.

Smart Furniture must be put into the context of other related consequences and used concepts. As the user lives in the real environment (lower level at Fig. 6), which is equipped with a number of sensors and actuators, a unique ubiquitous environment [58] surrounds the user (Fig. 6, 7). The physical environment is used to provide the actual presence of the user for the digital–ubiquitous environment of which a Smart Home as well as Smart Furniture is a part. Smart homes need to analyze (in real time) the presence of a digital user to provide a relevant decision about which action needs to be taken in the physical environment. Most important, the action needs to be determined based on personalized settings, which need to be delivered to the Smart Furniture as well as the whole Smart Environment, which is used by a recognized user (Fig. 6).

The visualization presented in the figure (Fig. 6) shows a user entering a Ubiquitous Environment [29] (upper level at Fig. 6). The user is detected via a Smart Device, while the digital representation of the user is updated to the Smart Home system. Based on predefined settings stored in or generated by the Smart Home system, the Smart Chair (as an

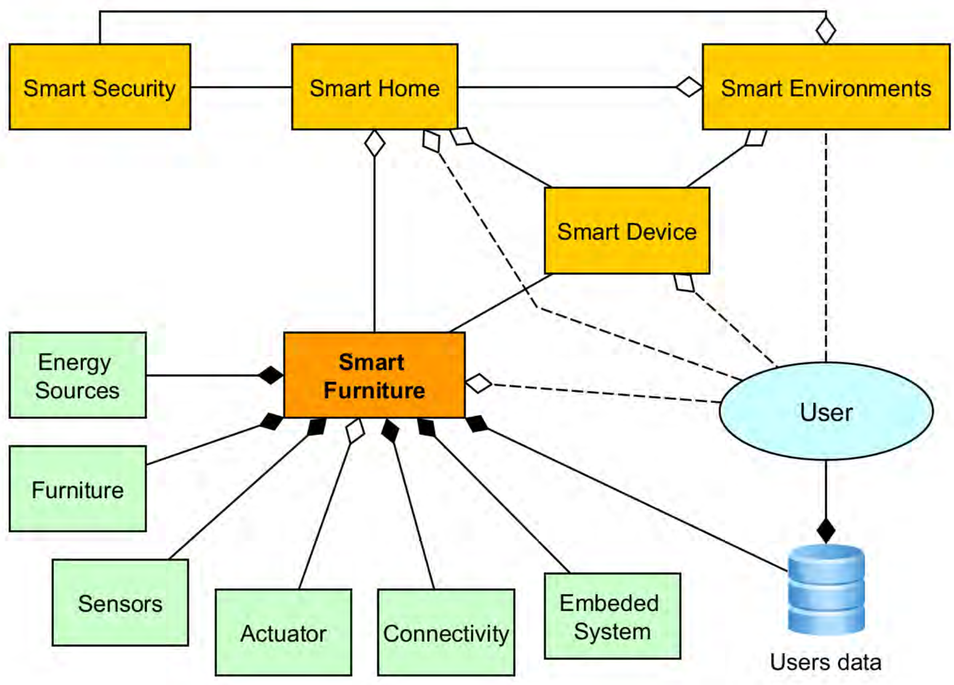

FIGURE 5. Role and position of Smart Furniture within the Smart City umbrella according to the UML design.

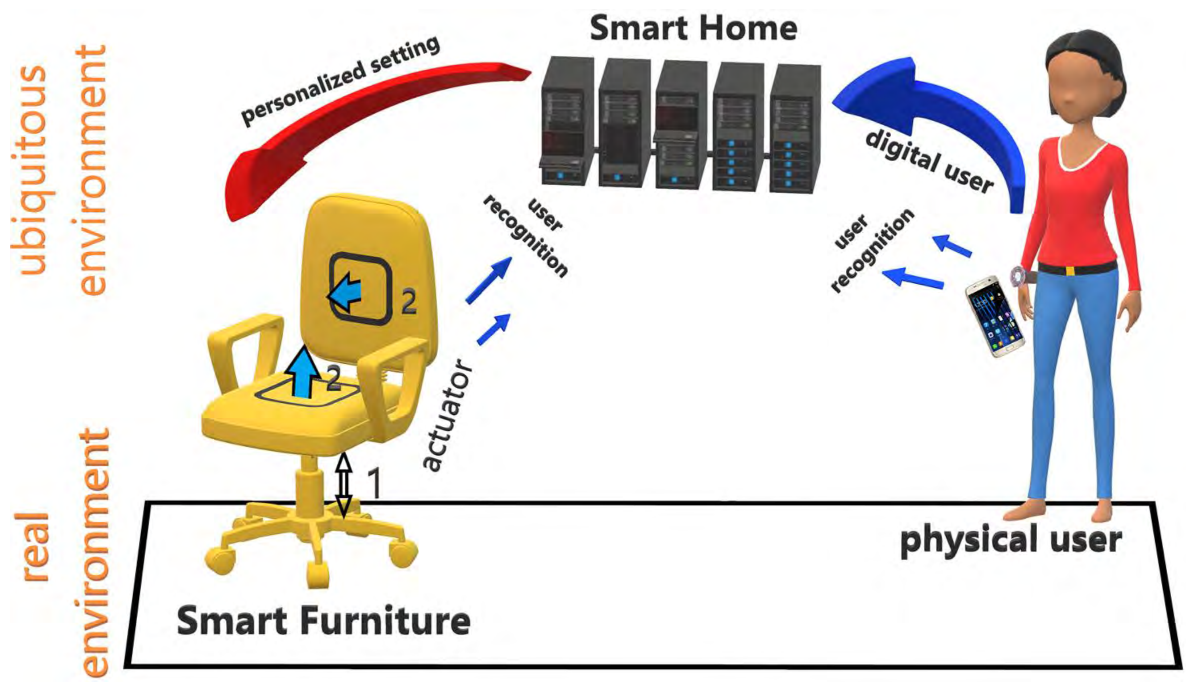

FIGURE 6. Smart Furniture in the context of a Ubiquitous Environment (Smart Home, Ambient Assisted Living [57]).

example of Smart Furniture) updates its setting to fit to the identified user. The personal settings of the Smart Chair can be pre-set by the user or updated based on experience from sensors embedded within the Smart Chair [50] (Fig. 6). The digital user representation as well as the historical trends of real user behavior can be shared from the Smart Home system to the Smart City environment where they can be used, e.g., for energy consumption predictions.

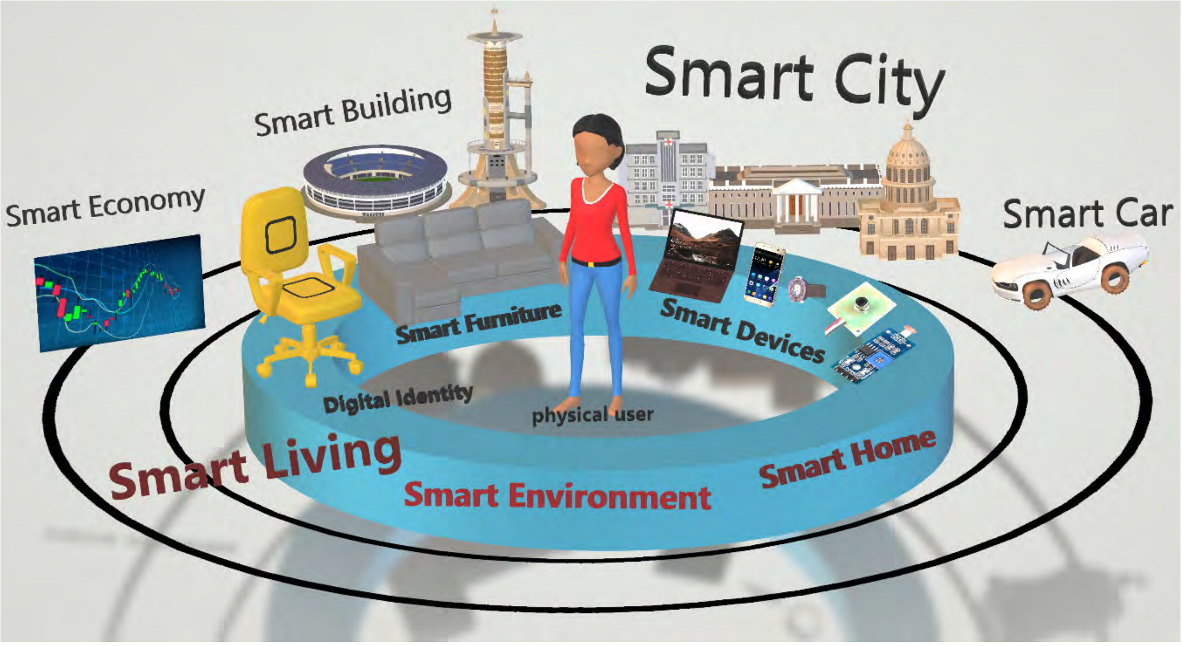

FIGURE 7. A user in a digital world of smart concepts (living, furniture, devices, home, environment, car, building, city, economy, etc.).

User life is becoming increasingly digital; the connection to the digital world is ubiquitous. The internet accompanies the user all day through the use of smart devices, while the digital ID exists even if the physical user is sleeping. The smart world is full of smart concepts in various areas (Fig. 7).

Future trends of smart concepts, however, need to be oriented towards the non-obtrusive behavior of a ubiquitous environment to target the real need for help by the user [58].

IV. DISCUSSION

A. RESEARCH MOTIVATION

The given definition opens the Smart Furniture concept to a new generation of ICT-enabled Smart solutions in the context of a Smart City. Its content suggests that more organized and result-oriented discussion among a variety of stakeholders is required, which will lead to global and sustainable polices for research on Smart Furniture. It also highlights that this discussion should be enriched by means of the collaboration with users to improve their wellbeing and QoL. By emphasizing the variety of research to Smart Furniture's policymaking, the given definition represents a starting point to discuss technological and policymaking research issues existing on the micro, mezzo, and macro level, as proposed in [59].

The integration of technological, policymaking and user's requirements indicates the need for a new approach at all levels. The given Smart Furniture definition is one of the first attempts to introduce such an approach as an integral part of the Smart Cities and QoL research [59]. While many research organizations and business partnerships compete to develop smart city applications, the given definition of Smart Furniture encourages a scientific discussion about the convergence of technological, economic and user requirements within this context. Having in mind the final vision of Smart Furniture, this definition indicates that a holistic approach is required to integrate the Smart Furniture research into the advanced theories of technological innovation and socially inclusive economic growth. Defining Smart Furniture will aid the adjustment and adaptation of our environment to the future extended working older population surroundings and thereby contribute to economies worldwide, given that there is an increased worry over the ageing population trend and its impact on economies. However, this requires a joint effort of all stakeholders included in the technological and social-economic development of Smart Furniture.

Since the given definition of Smart Furniture follows the nested-cluster model [13], it allow us to argue that sustainability depends on strategic alignment and integration of the five clusters (i.e., policymaking; services; industry; resources; research, education, innovation). The research, education, innovation cluster has a central role in drawing the research agenda and vision of the user-oriented and personalized development of Smart Furniture that opens communication among its stakeholders, which is beneficial for all them.

Smart furniture is also associated with significant concepts, such as IoT and artificial intelligence (AI).

IoT is defined as the extension of Internet connectivity into physical devices and objects of daily use [60]. IoT also play a role involving active objects with some type of adaptation to user needs. Such a specific form of the IoT vision is in close connection with the Smart Furniture definition and specification, which can be seen as an IoT object represented visually as a piece of furniture. To reach the Smart Furniture concept, some type of real-time analytics or machine learning as a part of Artificial Intelligence (AI) needs to be embedded into the solution. Considering the first and the most cited patent application of a Smart Chair [50] and the current trend in using IoT as well as cutting prices for any sensors and actuators from the IoT family, the most room to improve can be seen, for example, in office chairs and Smart Working Spaces, in general. Wider penetration of the IoT and AI into Smart furniture can improve the home and working environment and quality of life.

The result of this work is a precise definition for Smart Furniture. Why define Smart Furniture? A definition is a statement that captures the meaning, the use, the function and the essence of a term or a concept. Good definitions are a valuable asset and allow us to assess a situation better to make better decisions. A truly good definition is generative and creates value beyond its intended purpose of effectively describing something. By defining Smart Furniture, we are participating in the debate regarding its role in a Smart City.

The Smart City has the potential to improve the QoL and provide convenience at work, safety protection, among many other possible uses, as Deng et al. 2019 and Islam et al. 2017 stated [61], [62]. Namely, Smart Cities focus on ICT as a key enabler to fulfill the objectives of wellbeing and sustainability. Smart Furniture is an integral part of the Smart City concept, as recently proposed by Visvizi and Lytras [13], [59], [63] and in accordance with our definition; it relies on ICT solutions and is intended to improve wellbeing.

From an economics point of view, Smart Furniture is conditioned by the operation of five clusters (i.e., policymaking, services, industry, resources, and research, education, and innovation), which are described in the nested clusters model proposed by Visvizi and Lytras [13], [59], [63]. Each of these clusters is embedded in Smart Furniture as an integral part of Smart Cities, where ICT solutions advance the performance of these clusters. Their strategic alignment and functional connections define the sustainability of Smart Furniture because the inclusion of strategy and policymaking considerations makes the smart context holistic, scalable, and human-centered. The nested clusters model, which was introduced in the Smart Cities research, encourages a more structured discussion focused on the sustainable development of Smart Furniture. Additionally, highlighting the policies and strategies suitable for providing users with the ability to profit from and contribute to Smart Furniture development makes a case for pragmatic and demand-driven research dedicated to improving QoL.

B. RESEARCH CHALLENGES

Smart Furniture has entered a new stage of development that is distinguished by an inter- and a multi-disciplinary approach. There are many open technological and policymaking research issues, which should be discussed on the micro, mezzo, and macro levels and are in line with the conclusions provided by the abovementioned authors that all the spaces in the Smart City concept (Smart Furniture is one of them) cannot be examined outside of the context in which they are embedded, i.e., micro, mezzo, or macro. Additionally, Smart Furniture is a part of all the considered cases of the proposed framework, i.e., data aggregation, analytics, cloud blockchain, innovation and socially inclusive economic growth and sustainability, in all three layers.

However, most of the ***technological issues*** in the Smart Furniture research can be identified at the micro level. These issues are mainly directed at user profiling, taking into the account the semantic annotation of Smart Furniture services, interoperability between distributed Smart Furniture services, integration with single-point-of-access Smart Furniture services, and location- and geospatial-aware Smart Furniture. A crucial requirement is the establishment of advanced networking technologies and the implementation of an integrated-data warehouse. The unified approach to data management demands, on the one hand, enables novel analytics of Smart Furniture efficiency, and on the other hand, enables artificial intelligence for real-time processing of big data for any purpose. To promote the new approach to financial stream management, blockchain technologies should be utilized in this smart context. Last, but not of least importance, is the awareness and training of users in Smart Furniture skills; their competence will contribute to improving overall wellbeing and QoL.

The technological issues in the Smart Furniture research at the mezzo and macro levels are related to issues in the Smart Cities research. At the mezzo level, these issues refer to the adaptive design of data crawlers, which will be exploited for data, services and decision-making. Different business intelligence and analytic applications will be explored along with approaches to increase the flexibility of the establishment and management of Smart Furniture services. At the macro level, technological issues are associated with data management, which utilizes intelligent, interoperable agents for real-time data extraction. Advanced analytics should be exploited to monitor and predict indicators related to innovation, socially inclusive economic growth, and sustainability.

Beyond the technological issues in Smart Furniture research, ***strategies and socially aware policymaking*** should be covered by future research activities. Smart Furniture strategies should consider research into sustainable innovations, case studies of smart furniture research, caring communities and integration. Social awareness issues should be discussed in terms of smart communities, linked data for Smart Furniture as an integral part of Smart Cities, and security and privacy issues in smart service provision. These strategies and policymaking considerations will create connections between the normative and the empirical in Smart Furniture as an integral part of the Smart Cities research, with the ultimate goal to achieve better wellbeing and QoL.

In relation to the Smart Solution concept, the most frequently mentioned ***risks are privacy and data protection***. In this respect, public attitudes, opinions and behaviors will be critical as far as privacy and data protection are concerned [73]. Privacy and obtrusiveness issues appear to be the most important factors that affect the adoption of Smart

Home technology [74]. A multicenter smart-home project indicated that privacy and choice were the major areas of ***ethical focus in the design*** and implementation of Smart Home health technologies. While actual respect is clearly ethically important, favorable end-user perceptions are essential for public acceptability of new technologies and ensuring that their benefits are spread equitably. Even where researchers were able to ensure adequate data privacy, the lack of a commonly agreed concept of privacy could mean that, even with sustained attention, privacy is limited in its ability to be solved as an ethical problem [75].

C. RESEARCH RECOMMENDATIONS

As mentioned above, the definition of Smart Furniture is connected with technological, risk and privacy, ethical, and economic issues. In future research, the key functionalities of Smart Furniture need to be outlined to determine the main characteristics of the furniture of the future and which design aspects should be satisfied and addressed (multi-functionality [63], ecology [64], security [65], education [66], health [67], [68], leisure [69], social interactions [70], governance [71], [72], etc.).

Second, these main characteristics and functionalities should contribute to, and improve, at least one dimension of QoL so that the Smart City concept will be meaningful.

The third direction involves synchronization and synergy with other smart world concepts, such as Smart Homes, Smart Ageing and so on, which means that Smart Furniture should sometimes provide input to other smart concepts. Sometimes, these aspects should rely equally on each other to progress, while in other situations, other smart concepts should support Smart Furniture.

A combination of these factors should result in a framework and synergy for shaping future Smart Furniture solutions.

V. CONCLUSION

In the context of current changes and trends, such as the IoT phenomenon, rapid technological developments, when different technology solutions are being made available to wider groups of users, or within the increasingly high quality of life in developed countries, it has been explored how and for whom the smart furniture solution can benefit, and what solutions exist in relation to selected target groups (as mentioned in the inclusion criterion section of the method). At the same time, we wanted to identify and distinguish between sensor / device types, actuator types, processing types, personal identification and use cases.

The research results and discussion presented in this article are based on the recognition that the Smart Furniture research has great policymaking, technological, and economy potential while also contributing to user's wellbeing and QoL. This paper indicates that the collaboration between the ICT and social-economic research has to be initiated and consolidated in sustainable way. This is motivated by the conceptual work that queried the interdisciplinary nature of the Smart Cities research [63], which may include the specificity of furniture to start a discussion into the Smart Furniture research. Similar to the wider research agenda proposed in [59], this paper implicitly highlights the importance of integrating the Smart Furniture research with policymaking designed for innovation, socially inclusive economic growth, and sustainability. Finally, the future research should place the scalability of the Smart Furniture research and policymaking considerations in the wider context of the inter-disciplinary discussion.

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ONDREJ KREJCAR is currently a Full Professor of systems engineering and informatics with the University of Hradec Kralove, Czech Republic. He is also the Vice-Dean for science and research at the Faculty of Informatics and Management, UHK. He is also the Director of the Center for Basic and Applied Research, University of Hradec Kralove. At the University of Hradec Kralove, he is a Guarantee of the Doctoral Study Programme in Applied Informatics, where he is focusing on lecturing on smart approaches to the development of information systems and applications in ubiquitous computing environments. His h-index is 16, with more than 850 citations received in the Web of Science. He has published more than 40 IF research papers. He has a number of collaborations throughout the world (e.g., Malaysia, Spain, U.K., Ireland, Ethiopia, Latvia, and Brazil). His research interests include control systems, smart sensors, ubiquitous computing, manufacturing, wireless technology, portable devices, biomedicine, image segmentation and recognition, biometrics, technical cybernetics, and ubiquitous computing. His second area of interest is in biomedicine (image analysis), as well as biotelemetric system architecture (portable device architecture and wireless biosensors), and the development of applications for mobile devices with use of remote or embedded biomedical sensors.

Dr. Krejcar has also been a Management Committee Member substitute of the project COST CA16226, since 2017. In 2018, he was the 14th Top-Peer Reviewer in Multidisciplinary in the World according to Publons. He is on the Editorial Board of *Sensors* (MDPI) with JCR Index and several other ESCI indexed journals. He has been the Vice-Leader and a Management Committee Member at WG4 of the project COST CA17136, since 2018. Since 2019, he has been the Chairman of the Program Committee of the KAPPA Program, Technological Agency of the Czech Republic, as a Regulator of the EEA/Norwegian Financial Mechanism in the Czech Republic (2019–2024). Since 2014, he has been the Deputy Chairman of the Panel 7 (Processing Industry, Robotics and Electrical Engineering) of the Epsilon Program, Technological Agency of the Czech Republic.

PETRA MARESOVA has been the Head of the Department of Economics, Faculty of Informatics and Management (FIM), since 2016, where she has been a member, since 2008. In 2015, she was awarded the title of Associate Professor at the Faculty of Business and Economics, Mendel University, Brno. Her h-index is 11 with more than 460 citations received in the Web of Science. She is also a Principal Investigator of several running projects, including the Czech Science Foundation, Technology Agency in the Czech Republic, project LTC COST Action Inter Excellence in connection of the EU Action COST ''Indoor Living Space Improvement: Smart Habitat for the Elderly.'' Her work is focused on the evaluation of qualitative costs and benefits in various fields (modern technology, knowledge management, and biomedicine), public expenditure in healthcare, and costs analysis in healthcare. She has authored approximately 20 IF articles with a focus on healthcare expenditure that has been published. She has a number of collaborations throughout the world (e.g., Malaysia, Spain, Latvia, Switzerland, Bosnia, Macedonia, and Brazil).

ALI SELAMAT is currently a Full Professor with Universiti Teknologi Malaysia (UTM), Malaysia. He has also been the Dean of the Malaysia Japan International Institute of Technology (MJIIT), UTM, since 2018. An academic institution established under the cooperation of the Japanese International Cooperation Agency (JICA) and the Ministry of Education Malaysia (MOE) to provide the Japanese style of education in Malaysia. He is also a Professor with the Software Engineering Department, Faculty of Computing, UTM. He has published more than 60 IF research papers. His h-index is 16, and his number of citations in WoS is over 800. His research interests include software engineering, software process improvement, software agents, web engineering, information retrievals, pattern recognition, genetic algorithms, neural networks, soft computing, computational collective intelligence, strategic management, key performance indicator, and knowledge management. He is on the Editorial Board of the journal *Knowledge-Based Systems* (Elsevier). He has been serving as the Vice Chair of the IEEE Computer Society Malaysia, since 2014.

FRANCISCO JOSÉ MELERO has been a Chemical Engineer with CETEM, since 2007. He has experience in coordinating national and international initiatives from different Research and Innovation programmes, such as FP7, H2020, Erasmus+, and Interreg, arranging dissemination planning and reaching the target users of those projects that he has been dealing with, sharing concrete results, and ensuring the availability and use of the project results. He is currently coordinating the Sector Skills Alliance In4WOOD: Industry 4.0 for Furniture manufacturers and holds the Chair position at the SHELD-ON COST Action. Since 2008, he has taught the learning pillar on ''Management Systems: Quality and Environment'' in the University Master's Degree in Design and Business Management programme for the Furniture and Woodworking Sectors in CETEM (3ECTS).

SABINA BARAKOVIC is currently an Assistant Professor with the University of Sarajevo and the American University in Bosnia and Herzegovina. She is a Co-Founder of the research laboratory Little Mama Labs and an Expert Adviser at the Ministry of Security of Bosnia and Herzegovina. She has a Principal Investigator of many national and international projects (Horizon2020, NATO, ITU, Erasmus+, and so on) and has collaborations throughout the world (e.g., EU member countries, SEE region countries, and Qatar). She participates in the following COST actions: IC1003, IC1304, IC1303, and CA16226. Her research interests include multidimensional QoE modeling of multimedia, mobile web-based applications, and unified communications, QoS/QoE/QoL management, cybersecurity in smart environments, and the IoT/WoT.

JASMINA BARAKOVIC HUSIC is currently an Associate Professor with the Faculty of Electrical Engineering, University of Sarajevo. She is also a Specialist with the Department for Planning and Development of Technologies and Services, BH Telecom, a joint stock company, Sarajevo. She is also a Co-Founder of the research laboratory Little Mama Labs. She has been a Principal Investigator of many national and international projects (NATO, Erasmus+, Ministry of Education, RAI, and so on) and has collaborations throughout the world (e.g., EU member countries and SEE region countries). She participates in the following COST actions: IC1304, IC1303, and CA16226. Her research interests include a variety of topics in networked multimedia services, QoS/QoE/QoL management, and the 5G-IoT communications.

ENRIQUE HERRERA-VIEDMA received the M.Sc. and Ph.D. degrees in computer science from the University of Granada, Granada, Spain, in 1993 and 1996, respectively.

He is currently a Professor of computer science and A.I and the Vice-President for Research and Knowledge Transfer at the University of Granada. His h-index is 69, with more than 17 000 citations received in the Web of Science and 85 in Google Scholar, with more than 29 000 cites received. He has been identified as one of the world's most influential researchers by the Shanghai Centre and Thomson Reuters/Clarivate Analytics in both the scientific categories of computer science and engineering, from 2014 to 2018. His current research interests include group decision making, consensus models, linguistic modeling, aggregation of information, information retrieval, bibliometric, digital libraries, web quality evaluation, recommender systems, block chain, smart cities, and social media.

Dr. Herrera-Viedma is the Vice-President of Publications of the SMC Society and an Associate Editor for several JCR journals, such as IEEE Transactions on Fuzzy Systems, IEEE Transactions on Systems, Man, and Cybernetics: Systems, *Information Sciences*, *Applied Soft Computing*, *Soft Computing*, *Fuzzy Optimization and Decision Making*, *Journal of Intelligent Fuzzy Systems*, *International Journal of Fuzzy Systems*, *Engineering Applications of Artificial Intelligence*, *Journal of Ambient Intelligence and Humanized Computing*, *International Journal of Machine Learning and Cybernetics*, and *Knowledge-Based Systems*. He is also the EiC of the journal *Frontiers in Artificial Intelligence* (Section Fuzzy Systems).

ROBERT FRISCHER is currently an Associate Professor with the University of Hradec Kralove (UHK), Czech Republic. He is also an Associate Professor with the Technical University of Ostrava (VSB), Czech Republic. He has published more than 20 IF research papers. His h-index is 9, with over 250 citations in WoS. His research interests include automation and computing, industrial applications, artificial intelligence in digital image processing, biomedicine, technical cybernetics, artificial neural networks, pattern recognition, advanced sensors, printed circuit board development, and low-power electronics.

KAMIL KUCA is currently a Full Professor with the University of Hradec Kralove, Czech Republic. Within the last ten years, he has worked for several academic institutes in the Czech Republic (the Faculty of Military Health Sciences, University of Defence, the Faculty of Science, University of Hradec Kralove, the University Hospital Hradec Kralove, and the National Institute of Mental Health) as a Senior Researcher and the Head Group Leader. He has been an Invited Professor with Florida International University, Miami, USA, the Institute of Military Engineering, Rio de Janeiro, Brazil, Yangtze University, Jingzhou, China, and the University Technical Malaysia, Kuala Lumpur, Malaysia. He is currently the President of the University of Hradec Kralove. He has published more than 500 IF research papers. He has been a Scientific Advisor with several companies. He has many collaborations throughout the world (e.g., South Korea, Croatia, United Arab Emirates, USA, France, Turkey, China, Singapore, Sweden, and Brazil). His h-index is 47, with over 9000 citation in WoS. In 2015, he was the seventh most cited European author (2005–2011) in pharmacology and toxicology, according to the list published by Lab Times. He has been a Principal Investigator on numerous national and international projects (EU, NATO, GACR, IGA MZ, MSMT, and so on). His research interests include drug development and toxicology, pharmacoeconomy, chemical and biological threats, and ICT in biomedicine.

3.2. Artículo 2: Aging at Work: A Review of Recent Trends and Future Directions

El punto de partida de este trabajo es el planteamiento de las siguientes preguntas: ¿Cuáles son las motivaciones que impulsan la investigación sobre el envejecimiento de la población activa?, y ¿Cuáles son las soluciones más comunes para abordar las cuestiones relacionadas con el envejecimiento en el trabajo?, con el fin de reconocer y resumir los trabajos de la literatura científica relacionados con el envejecimiento de la población activa en términos de tendencias recientes y direcciones futuras, y extraer los principales problemas de motivación y soluciones para apoyar el concepto de envejecimiento en el trabajo.

Para responder estas preguntas, se examinaron estudios sobre el envejecimiento de la población activa publicados entre enero de 2008 y agosto de 2019, siguiendo la metodología PRISMA de elementos de información preferidos para las revisiones sistemáticas y los metaanálisis para revisar la literatura sobre políticas de envejecimiento en el trabajo. La búsqueda de artículos se llevó a cabo a través de una herramienta de procesamiento de lenguaje natural (NLP) diseñada para automatizar la búsqueda de literatura a través de distintas frases, escaneo y evaluación de la elegibilidad a través del marco PRISMA [57]. El proceso de revisión a través de la herramienta NLP se centró en publicaciones indexadas en distintas librerías digitales.

En el trabajo se usó el razonamiento inductivo para la revisión y análisis de los artículos considerados adecuados. Los artículos seleccionados se organizaron en dos grupos: artículos que se centran en factores de motivación y artículos que se centran en alguno de los pilares de la solución. Se generó un resumen detallado para cada artículo incluyendo los siguientes elementos: objetivo, métodos, principales hallazgos, limitaciones y palabras clave. Dichos elementos se utilizaron como inputs para la discusión y las conclusiones.

Los artículos seleccionados, tanto para el análisis de las motivaciones como para el análisis de las soluciones, fueron organizados en grupos focales de acuerdo con los términos considerados para cada una de las dos propiedades. El trabajo presenta dos tablas que resumen, para cada artículo, los objetivos, métodos, principales hallazgos, limitaciones y palabras clave de éste.

Dicho análisis permitió tanto identificar implicaciones políticas como exponer conclusiones sobre la investigación científica desarrollada en la temática de envejecimiento de la población activa, tendencias recientes y direcciones futuras, etc. permitiendo extraer conclusiones en cuanto a los principales problemas de motivación y soluciones para apoyar el concepto de envejecimiento en el trabajo.

Los trabajos más destacados sugieren políticas y prácticas que apoyan el aprendizaje a lo largo de toda la vida, una mano de obra que comprende tanto a trabajadores jóvenes como a trabajadores de avanzada edad, y una jubilación gradual. Enfoques como éstos pueden ser la mejor respuesta a los problemas de la globalización, la reducción de la mano de obra, el mantenimiento de la independencia financiera de trabajadores de edad avanzada y otros beneficios sociales.

Como líneas futuras a este trabajo se propone continuar la investigación sobre la normalización de los enfoques de este problema en distintos países, con el apoyo de autoridades en el ámbito laboral. El objetivo no debería ser implementar los mismos enfoques en diferentes entornos, ya que no abarcaría todos los factores culturales, sociológicos y económicos. En cambio, en este trabajo se considera que unos enfoques sistemáticamente documentados y bien enfocados facilitarán la medición de los resultados y el análisis causal al investigar los beneficios y los inconvenientes.

Durante el desarrollo del presente trabajo, el doctorando participó activamente en la selección de parámetros de entrada para la realizar la búsqueda de estudios a través de la herramienta NLP, la evaluación del título y contenido de los trabajos seleccionados como elegibles por la herramienta de acuerdo con los requisitos de inclusión o exclusión y en el resumen de los artículos seleccionados que se centraban en factores de motivación y en alguno de los pilares de la solución. Además, colaboró en la escritura y revisión de las distintas versiones del documento.

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Review

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Promotion of Healthy Work

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Review

Aging at Work: A Review of Recent Trends and Future Directions

Jasmina Barakovic Husic [1,2,*], Francisco José Melero [3,4], Sabina Barakovic [2,5], Petre Lameski [6], Eftim Zdravevski [6], Petra Maresova [7], Ondrej Krejcar [7], Ivan Chorbev [6], Nuno M. Garcia [8] and Vladimir Trajkovik [6]

1. Department of Telecommunications, Faculty of Electrical Engineering, University of Sarajevo, 71000 Sarajevo, Bosnia and Herzegovina
2. Little Mama Labs, Gradacacka 29, 71000 Sarajevo, Bosnia and Herzegovina; barakovic.sabina@gmail.com
3. Technological Centre of Furniture and Wood of the Region of Murcia (CETEM), C/Perales S/N, 30510 Yecla, Spain; fj.melero@cetem.es
4. Telecommunication Networks Engineering Group, Technical University of Cartagena, 30202 Cartagena, Spain
5. Faculty of Transport and Communications, University of Sarajevo, 71000 Sarajevo, Bosnia and Herzegovina
6. Faculty of Computer Science and Engineering, Ss Cyril and Methodius University in Skopje, 1000 Skopje, North Macedonia; petre.lameski@finki.ukim.mk (P.L.); eftim.zdravevski@finki.ukim.mk (E.Z.); ivan.chorbev@finki.ukim.mk (I.C.); vladimir.trajkovik@finki.ukim.mk (V.T.)
7. Faculty of Informatics and Management, University of Hradec Kralove, 500 03 Hradec Kralove, Czech Republic; petra.maresova@uhk.cz (P.M.); ondrej.krejcar@uhk.cz (O.K.)
8. Instituto de Telecomunicações, Universidade da Beira Interior, 6201-001 Covilhã, Portugal; ngarcia@di.ubi.pt

* Correspondence: jbarakovic@etf.unsa.ba

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Abstract: Demographic data suggest a rapid aging trend in the active workforce. The concept of aging at work comes from the urgent requirement to help the aging workforce of the contemporary industries to maintain productivity while achieving a work and private life balance. While there is plenty of research focusing on the aging population, current research activities on policies covering the concept of aging at work are limited and conceptually different. This paper aims to review publications on aging at work, which could lead to the creation of a framework that targets governmental decision-makers, the non-governmental sector, the private sector, and all of those who are responsible for the formulation of policies on aging at work. In August 2019 we searched for peer-reviewed articles in English that were indexed in PubMed, IEEE Xplore, and Springer and published between 2008 and 2019. The keywords included the following phrases: “successful aging at work”, “active aging at work”, “healthy aging at work”, “productive aging at work”, and “older adults at work”. A total of 47,330 publications were found through database searching, and 25,187 publications were screened. Afterwards, 7756 screened publications were excluded from the further analysis, and a total of 17,431 article abstracts were evaluated for inclusion. Finally, further qualitative analysis included 1375 articles, of which about 24 are discussed in this article. The most prominent works suggest policies that encourage life-long learning, and a workforce that comprises both younger and older workers, as well as gradual retirement.

Keywords: aging at work; discrimination; growth; deficit; assistance; policy; legislation

1. Introduction

The older population is growing rapidly. In 2019, approximately 700 million people were aged 65 years or more in the world population. It is anticipated that this number will be doubled to 1.5 billion in 2050 [1]. During the next three decades, the size of the aging population in the European Union (EU) will have the same rising trend resulting in 149 million people in 2050 [2].

The growth of the older population is an effect of a reduced fertility rate and an increased life span [3]. Various factors influence the population aging, such as improved conditions in life and work, healthy lifestyles, and enhanced healthcare [4]. They lead to the growth of the aging population, which in turn, poses a broad range of economic challenges, including labour supply reduction and higher social costs. The aging population will continue to grow leading to a labor force reduction. This will lead to changes in the retirement age, an increased burden on government finances, and lower levels of pension provision [5].

Societies need to take a smart and multidimensional view of aging since these individuals may provide vast economic and social opportunities [6]. Rather than disrupting economic and social growth, the aging population may instead stimulate the social transformation of the 21st century, which can affect all sectors of society, including labour markets, the need for goods and services, as well as family structures and connections that affect several generations [2]. This process is focused on the transformation of the labour market by recognizing the aging population and its needs and capabilities. Older workers cannot perform certain jobs as a result of physical changes that progress with age [7]. Therefore, it is necessary to assess their current capabilities, modify their work positions, or employ them in a different position after appropriate training [8].

Not employing older people in certain work positions does not have to be a symptom of age-based discrimination, which is the most common form of discrimination, with one in five workers having witnessed it or personally experienced it [9]. It comes from a negative image of aging, preconceptions, and the overall perceptiveness of older workers themselves [10]. For example, there are stereotypes regarding the gender [11] or productivity of older people [12,13], the correlation between old age and illness [14], etc. Those stereotypes are sufficient motivation to look for a potential solution in policies and legislation that aim to inhibit discrimination, as well as promote an affirmative image of the aging labour force.

Sustainable growth at work means reaching the living and working conditions that support older people in their involvement in and continuance of work for a longer duration in their lifetime [15]. To achieve this, work has to be transformed to eliminate the factors that demotivate older workers to stay in or enter the labor market [16,17]. Concerns about the work sustainability, including the economic growth, pensions, and labour supply, have motivated a policy response as a potential solution to address the issues of longer working lives and later retirement [18,19].

Furthermore, an employment deficit calls for an effective response that should balance economic and regulatory needs with an influence on the jobs, working conditions, skills demands, and social protection [20]. Despite the many measures to cope with this issue [21,22], such as the unemployment benefits, social protection, and public employment services, activation of new policies is required as a potential solution to facilitate transitions to new jobs and decrease the risk of long-term unemployment and inactivity. Policies and legislation that encourage life-long learning seem to be an effective solution for preparing employees to change jobs if they cannot continue their current work due to decreasing opportunities [23].

In response to the aforementioned issues, the aging labour force has been studied over the last decade to contribute to the understanding of different motivations and solutions in the given context. However, there is a lack of systematic review of these motivations and solutions to support the aging labour force. Therefore, the aim of this paper is twofold. The first goal is to recognize and summarize the articles related to the aging labour force in terms of recent trends and future directions. The second objective is to capture the main motivation issues and solutions to support the concept of aging at work, i.e., the aging labour force.

The following research questions were posed:

1. What are the motivations that drive the research on the aging labour force?
2. What are the most common solutions for addressing the issues related to aging at work?

2. Methodology

2.1. Article Search Strategy

In order to answer the research questions, we examined studies on the aging labour force that were published between January 2008 and August 2019, to recognize the trends in the literature written in English with respect to motivation issues and potential solutions. We focused on the trends starting from the recession in 2008, when, although the economic growth slowed, the employment rate of older people remained strong, thus basically changing the position of older workers [24]. An additional motivation for focusing on this time period was because in the last decade, many assistive technologies have emerged that can aid older adults in different environments. At the same time, many jobs are transforming and can be successfully performed from home, which has recently become evident with the COVID-19 pandemic. Considering these two observations, the goal of this research is to investigate whether there is an underlying trend that reveals opportunities for aging at work.

We adopted the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) methodology [25] to review the literature on aging at work policies. The PRISMA flow distinguishes separate stages of systematic reviews. These stages are the collection of papers, scanning of papers' text, evaluation of eligibility of papers, and meta-analysis.

The collected papers on aging at work policies exceeded the capacity that would allow articles to be searched manually. Thus, we used natural language processing (NLP) algorithms to perform an efficient search of the identified literature. The NLP toolkit [26] was designed to automate the literature search by using different search phrases, scanning, and evaluating eligibility within the PRISMA framework while generating visualizations of aggregate results. The NLP toolkit provides increased efficiency of the review process by screening the title and abstract while using the predetermined properties and their synonyms to determine the literature search phrases. It should be noted that the NLP toolkit does not understand the context and, therefore, categorizes more articles as relevant than a human reader would. However, it is a valuable resource that increases the efficiency of the review process, as demonstrated in a scoping review [27] that focused on wearable technology for connected health. The adopted PRISMA information flow is shown in Figure 1. Since the NLP toolkit automates the review process of publications that are indexed in only three digital libraries and because we have not taken into account the nonindexed publishers, some relevant publications (e.g., reference [28]) have been omitted from the analysis. This one and a few other papers were manually identified, and those publications originated from different digital libraries. They were used to confirm the findings of this review. However, we did not use these papers from other digital libraries to identify trends because the size of the searched digital libraries is sufficient for the purpose of the analysis.

The NLP search strategy was applied in order to automatically screen irrelevant articles that have a low correlation with the topics of interest in the study. Additionally, it helped in consolidating the collected articles by automatically merging results from multiple digital libraries as well as removing duplicate entries. Moreover, it allowed us to iteratively fine-tune and modify the search phrases in the hope of identifying more relevant articles. Finally, the NLP toolkit automatically generated charts (such as Figures 2–5) that highlight the trends of publications for certain topics. For more details about the inner workings of the NLP-based toolkit, we refer interested readers to [26], and also to [27], which applied it to review wearable technology for connected health.

By using yearly graphs, we were able to analyze and report the potential trends in data by investigating articles in each property group (i.e., theme) separately.

The NLP toolkit input parameters are a collection of phrases. Keywords, together with their synonyms, are applied as search terms for the digital libraries used in the literature search. The input can be further expanded by NLP toolkit properties. Properties are phrases that are being searched within the title, abstract, or keywords section of the articles identified from the previous keywords search. Property groups are sets of properties that can be used for a more comprehensive presentation of search results.

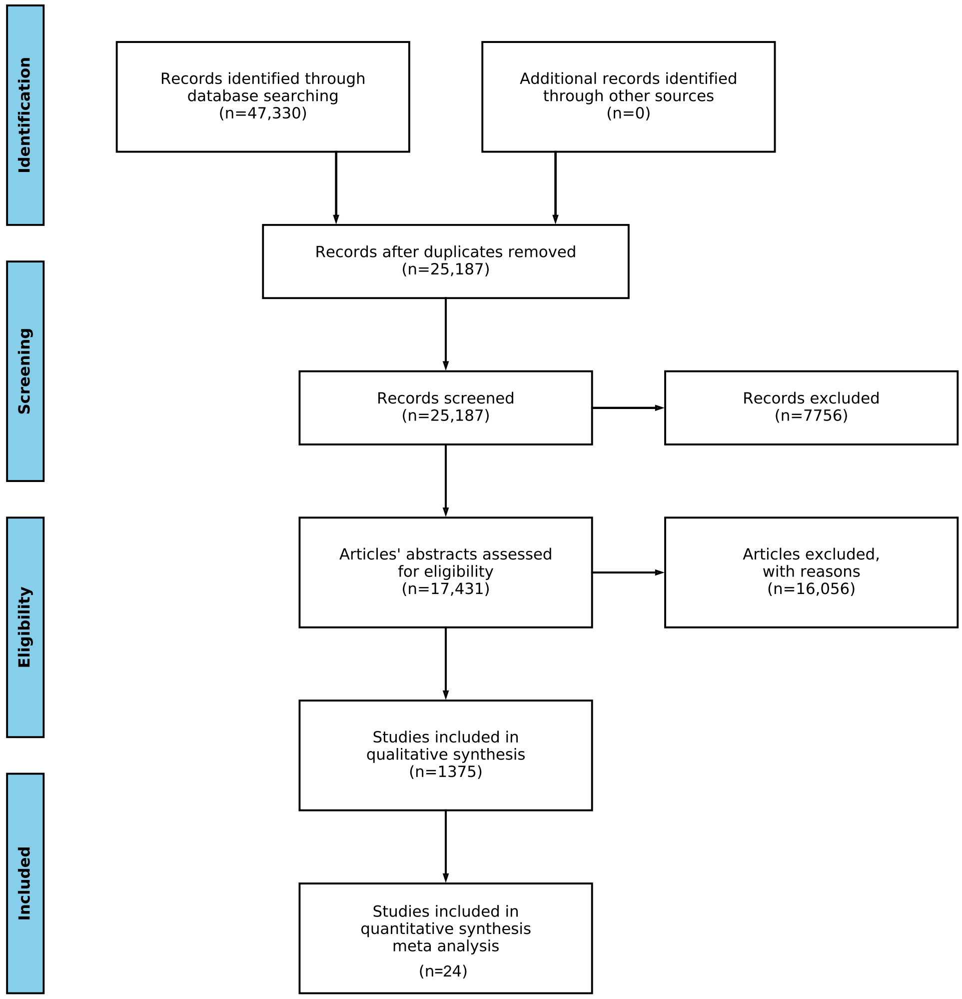

Figure 1. The PRISMA review workflow reflecting the number of articles identified, screened, processed and removed in each step.

The input parameters used in this study are shown in Table 1. These keywords, property groups and properties are the final versions after an iterative process in which all authors participated and considered different alternatives of keywords and properties, and analyzed the preliminary results. In the process of selecting articles to be included in the quantitative synthesis, four authors participated, of which at least two had to be in agreement.

Table 1. The NLP toolkit input parameters: keywords, property groups and properties.

Keywords	"active aging at work", "older adults at work", "successful aging at work", "healthy aging at work", "productive aging at work"
Property Groups	Properties
Motivations	"deficit", "discrimination", "growth"
Solutions	"EU policy", "assistance schemes", "eligibility criteria", "legislation", "national policy"

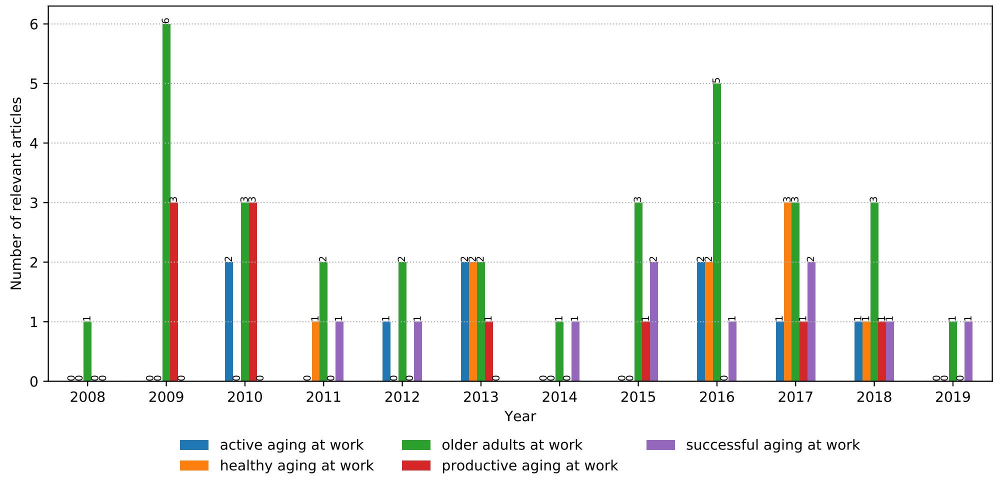

Figure 2. The number of identified relevant articles per year from January 2008 to August 2019.

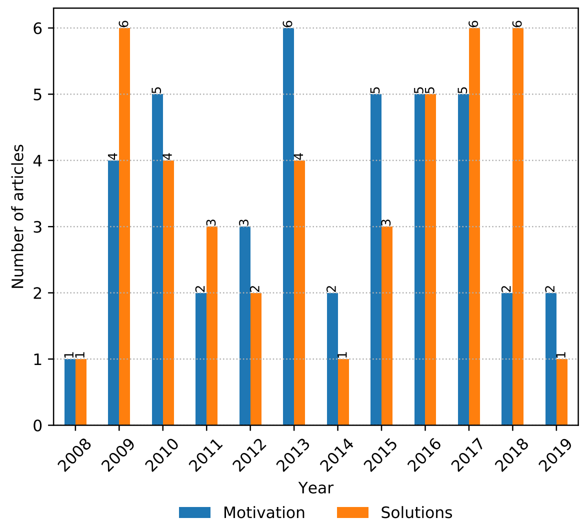

Figure 3. The number of relevant articles per property group and year within the period of interest.

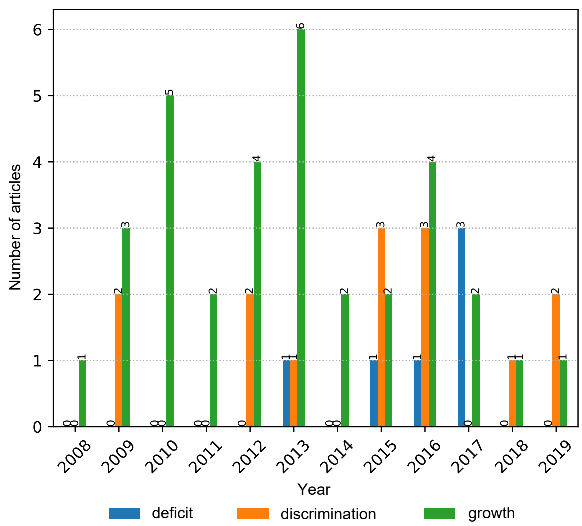

Figure 4. The number of relevant articles related to motivations property group categorized by "deficit", "discrimination", and "growth" properties from 2008 to 2019.

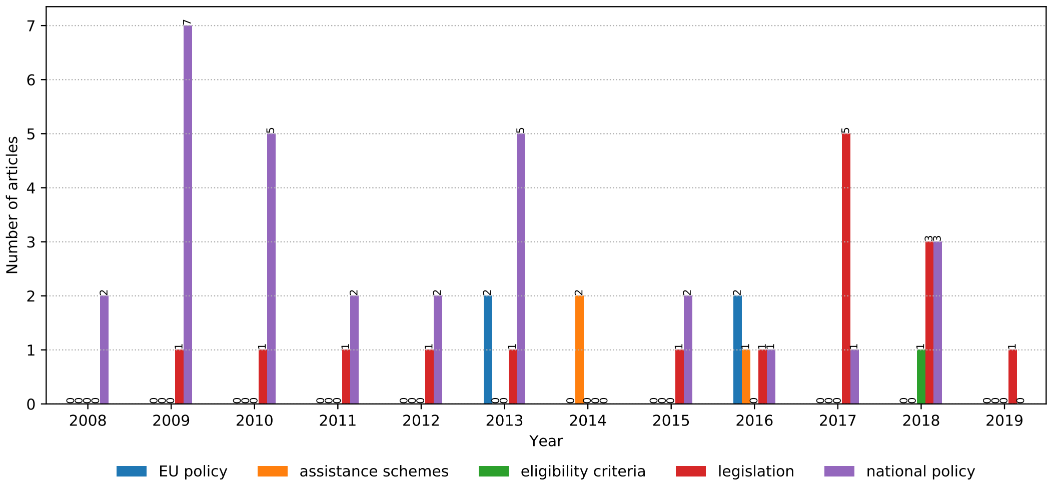

Figure 5. Solutions-related properties: "EU policy", "assistance schemes", "eligibility criteria", "legislation", and "national policy". The trends apply to the period from 2008 to 2019.

2.2. Article Selection Process

The titles and abstracts retrieved by the NLP-based search strategy were evaluated by two independent researchers. They compared their opinions in order to select articles that satisfied the inclusion and exclusion criteria.

The inclusion criteria were as follows:

1. Articles that consider the concept of aging at work, i.e., the aging labour force.
   (a) Articles that discuss any of three motivation factors, i.e., discrimination, growth, and deficit;
   (b) Articles that support any of three solution pillars, i.e., assistance, policies, and legislation.
2. Articles that use research methodology with any results.

The exclusion criteria were as follows:

1. Articles that are about aging and older people in general that do not consider the concept of aging at work;
2. Articles that cover any of three motivation factors, i.e., discrimination, growth, and deficit, in a context other than the aging labour force;
3. Articles that cover any of three solution pillars, i.e., assistance, policies, and legislation, in the context other than the aging labour force;
4. Articles that do not provide sufficient information for classification.

When researchers differed in their opinions about an article's suitability, the article was selected for further consideration. This resulted in an initial selection of 70 articles. Furthermore, the full texts of the chosen articles were reviewed in order to determine their suitability for further discussion. After the data abstraction of the final selected articles, two additional researchers separately reviewed 20% of randomly chosen articles. In the case of any disagreement on the suitability of articles, a third researcher was consulted for recommendation and assessment of the given article. This researcher was a specialist who drew a final conclusion regarding the article selection process.

For the selection of the final 24 articles, two of three authors needed to be in agreement, considering the completeness of the methods, relevance to the study goal, details about the population, and impact of the study.

2.3. Article Review and Analysis

We used the inductive approach for the article review and analysis. The selected articles were systematically organized into two groups:

1. Articles that focused on motivation factors (i.e., discrimination, growth, and deficit);
2. Articles that focused on solution pillars (i.e., assistance, policies, and legislation).

We generated a detailed summary of each article and extracted the following items: objective, methods, main findings, limitations, and keywords. The extracted items provided the input data for discussion and conclusions.

3. Results

After searching PubMed, IEEE Xplore, and Springer, we identified 47,330 potentially articles. After performing the PRISMA steps shown in Figure 1, the number of articles was reduced. Specifically, the removal of duplicates reduced the number to 25,187 studies. The first screening process eliminated an additional 7756 studies with an out-of-scope publication year, or other parsing issues (no title, abstract, etc.). Then, 17,431 papers were subject to the eligibility estimate using the automated NLP toolkit, which removed articles without any of the required properties. Eventually, 1375 papers remained as potentially relevant and eligible for further manual inspection. A total of 70 articles were initially selected to analyze the trends on the aging labour force, while 24 articles were used to explore the motivation issues and solutions in the given context.

3.1. Trends

The selected keywords aimed to show different aspects on the literature corpus on aging at work. Figure 2 presents the number of potentially relevant papers that contained the defined keywords and that were additionally filtered manually based on their relevance to the defined properties per year. A relatively similar number of identified articles can be observed in the evaluated time period. "Active aging at work" is the keyword with the smallest number of occurrences. The most frequent keyword phrase in the identified publications is "older adults at work". The number of research articles did not grow in the period of interest, but articles that address the associated keywords seem to be distributed more evenly over time.

Findings related to property groups show that the number of papers related to "motivation" of the adult workforce is relatively constant, with a small decline in the last two years, while the papers focused on the "solutions" property group seems to be slightly more predominant in the last few years (Figure 3).

A more granular analysis was carried out on the property groups data at the properties level, and the chart reveals that "growth" is the primary topic within the motivation group of papers, followed by "discrimination". The papers related to the topic of "deficit" appeared only in recent years (Figure 4).

The focus of papers within the "solutions" property group (Figure 5) seems to move from "national policy" based to "legislation", while "assistant schemes" and "EU policies" seem to be of smaller interest for the scientific community. There was only one paper that addressed "eligibility criteria", which makes this topic interesting for further research.

3.2. Motivations

A total of 12 articles out of 24 were selected for the further analysis of motivations that drive the research on the aging labour force. The selected articles were organized into three focus groups according to the considered terms related to motivation, i.e., "discrimination", "growth", and "deficit". A more detailed analysis of these articles is presented in Table 2.

3.3. Solutions

The remaining 12 articles out of 24 were used for a more detailed analysis of solutions for the aging labour force. The selected articles were organized into three focus groups according to the considered solutions, i.e., assistance, policy, and legislation. Table 3 shows results of the analysis.

4. Discussion

4.1. Study Implications and Recommendations

The ageing labour force could represent a risk both for society and economy unless it is well managed. Therefore, the attention that researchers, governments and other stakeholders have devoted to this issue has grown over the time. According to analysis of motivations (Table 2) and solutions (Table 3) for ageing at work, possible policy implications have been identified and split into five parts:

Extend the length of work ability. Different organizations implement changes by creating common policies and strategies, but they are not oriented toward the older workforce. Intentionally interrupting the existing age-graded logic and its replacement with age-neutral logic are proposed in [16]. The authors in [29] found that the expected decline in employment could be partially offset by public policies that encourage the employment of older people. This causes problems for public finances due to expenditures on health, long-term care, pensions, etc. [3]. In order to encourage policies to maintain work ability at an old age, it is necessary to invest in decreasing of both work stress and social inequalities in health care [30]. However, extending the length of work ability does not just pose issues, but provides social and economic opportunities.

Avoid the age-based discrimination. The labour market will have to adapt working positions and eliminate the attitude of age-based discrimination, since it will have to fight for a working force older than 65 because it is lacking. When facing age-based discrimination at work, the organizational help and friends and family support were found to be significant in achieving better health and adaptability [31]. On the other hand, older workers with high job satisfaction without age-based discrimination remained longer in the labour market [32]. Finally, the authors in [10] found that experiences of discrimination were rare and reduced with age among men, whereas almost no age differences were noticed among women. This indicates that age-based discrimination is possibly overstated, and age-related obstacles could have been miscomprehended. Therefore, the flexibility of older workers can be seen as an opportunity for the active global aging trend [33].

Table 2. Detailed analysis of articles that focus on motivation factors.

Focus	Study	Objective	Methods	Main Findings	Limitations	Key Words
Discrimination	[32]	To recognize psychosocial work condition factors of interest to keep older workers by assessing the connection between the psychosocial work conditions and early voluntary pension.	Longitudinal study (survey). Study sample—general sample (N = 9913) aged 18-60 years, senior sample (N = 4477) aged 50 years, company sample (N = 3823) aged 18–80 years. Cox regression. Holm-Sidak correlation test.	Older workers with high job satisfaction, development possibilities, affirmative relations to management, and no age discrimination stayed longer in the work market. Positive relations with colleagues did not affect older workers decisions on early pension.	The measures were self-evaluated. The psychosocial factors were measured at single time point. Successive changes in the psychosocial work conditions could cause early pension that would be missed by the study.	Early pension, work conditions, management quality, job satisfaction
	[31]	To examine the relation between successful aging and stress sources at work among older workers in China	Questionnaire study. Study sample—242 workers aged >40 years. Method variance. Harman's one-factor test. Factor analysis.	Perception of institutional support and social help from family and friends significantly corresponds to efficient aging at work.	Participants were surveyed at a single time point. The study relied on participants self-reports.	Successful aging, work stressor, social help, institutional support
	[10]	To improve comprehension of the discrimination at work, with a focus on age and gender challenges.	Survey study. Study sample—3203 workers with mean age 43 years. Computer-aided telephone interview. Binary logistic regression.	Daily discrimination was unusual. It appears with age among men, and not among women. The nature of work market age obstacles is not understood correctly, and the degree of aging discrimination is overstated.	There was a small number of workers who faced daily discrimination. The degree of daily discrimination has to be further investigated.	Ageism, employment discrimination, gender, work
	[33]	To investigate the age-related connection between job stress, extreme tiredness, prosperity, and associated personal, institutional, and community factors.	Survey study. Study sample—1298 participants aged 18 years or older. Descriptive statistics. Linear Regression. One-way analysis of variance.	Job stress was associated with several types of extreme tiredness and prosperity. Personal work style, institutional and community factors were associated with prosperity. Old age was connected to a poor perception of health.	The study did not compare work differences. The data were cross-sectional and the causal relation of the work conditions and style with job stress, extreme tiredness, and prosperity could not be confirmed.	Age difference, exhaustion, prosperity, work stress, work condition
Growth	[30]	To investigate the connection of social, demographic, economic and job related factors with disability.	Survey study. Study sample—2665 men, 2209 women aged 50–54 years. Principal component analysis. Confirmatory factor analysis. Poisson regression. Maximum likelihood estimation.	A decrease in job stress and sociable disproportion in healthcare is appropriate for the development of policies that support aging at work.	The disability indices were not formulated based on functional testing. The evaluation of stressful work was performed by abbreviated scales.	Socioeconomic position, aging workforce, work stress, work ability, social disproportion
	[16]	To examine organizational work disrupting age-graded policies.	Interview study. Study sample—23 organizations with employees aged 50–69 years. Qualitative content analysis.	Organizations implement changes by creating common policies and strategies, but not those oriented toward an aging workforce. They propose to intentionally interrupt the existing age-graded logic and replace it with age-neutral logic.	Creative, high-tech, or communications organizations were not studied. Sample size was small, so broader claims about Minnesota or U.S. workers cannot be made.	Organizational logic, older workers, pension, flexibility
	[29]	To examine the influence of demographic trends on the economic growth and employment level that Japan is expected to face in the next 20 years	NUPRI Macro Simulation model of the economy in Japan	The expected decline in employment could be partially offset by public policies that encourage the employment of older people.	Not reported.	Low fertility, population decline, population aging
	[3]	To provide a literature review on the need for the senior workforce and recognize main directions for research on this topic.	Systematic literature review. Empirical evidence.	There is a negative association between salary and employment outcomes for the senior workforce. The connection between efficiency and salary is defined by governmental conditions and motivation to take early pension.	The variations in micro-, macro-, and meso-level factors were not captured, simultaneously. There is a need for improvements in the analysis of the impact of age-based discrimination on the employing of older workers.	Work market, employment protection, regulation, legislation
Deficit	[17]	To examine the influence of organizational factors on work ability.	Cross-sectional study (online survey). Study sample—306 employees. Path analysis modeling. Maximum likelihood estimation.	Organizational culture and professional effort indirectly enabled the prediction of work ability, with job satisfaction mediating these relations.	The sample included mostly younger and female workers. The cross-sectional design of the study did not provide the possibility to understand causes and effects related to work ability.	Work ability, organizational culture
	[34]	To recognize professions prevailed by an older workforce and evaluate their vulnerability to hazards in these professions.	Survey study (interviews). Study sample—6502 workers aged 55 or more. Chi-squared test.	Work-related hazards should be decreased to inhibit professional disturbance in professions prevailed by an older workforce.	Self-informed data were included in the study.	Health issues, hazards, profession, musculoskeletal disorders
	[35]	To investigate job discrimination related to age and disability.	Equal Employment Opportunity Commission Integrated Mission System data from 1993 to 2007. Descriptive statistics.	Job discrimination of aged or disabled workers is focused on challenges involving seating, revenge, and cancellation.	Data do not contain supplemental information regarding a secondary cause for each filed allegation.	Job/age/disability discrimination
	[36]	To investigate the relation between psychosocial factors and pension intention of older employees, while considering healthiness and work ability.	Survey study. Study sample—3122 workers aged 50 years or older. Pearson correlation. Ordinal logistic regression.	Ageism and the absence of acknowledgement and growth opportunities are connected to older male workers' pension intention. Work ability is strongly related to the pension intention of both genders.	The pension age could depend on unfamiliar alternations in the worker's environment or health status.	Psychosocial factors, pension intention, healthiness, work ability

Table 3. Detailed analysis of articles that focus on solutions.

Focus	Study	Objective	Methods	Main Findings	Limitations	Key Words
Assistance	[37]	To critically review the literature on older farmers in Canada and the USA and describe how musculoskeletal disorders influence their ability to work.	Literature review. Twelve articles analyzed in detail.	Musculoskeletal disturbance can lead to trauma or loss of ability to farm. It is necessary to develop safer work practices and encourage healthiness, efficiency, and professional longevity.	Some related articles may have been excluded from the study due to the specificity of the search strings.	Older farmers, work-related musculoskeletal disorders, pension age
	[8]	To investigate the action plans that workers use to acquire skills in software and complete assignments	Exploratory study (interviews, surveys). Study sample—10 administrative assistants. Grounded Theory. Non-parametric statistics.	Administrative assistants are regularly communicating and sharing knowledge.	Exclusion of workers from different organizations, lack of extensive investigation on behavior at work, and creation of software tool design instructions.	Workplace, generations, collaboration
	[38]	To collect information to direct the preparation of programs for returning older adults to work	Survey study (questionnaires). Study sample—37 jobless participants aged 51–76 years. ANOVA. Chi-square test.	Participants who felt discriminated indicated the preference to acquire technological skills and get classroom-based education.	Work obstacles could not be generalized.	Older workers, absence of technological skills, work conditions, work experiences
Policy	[39]	To investigate factors related to perceived work ability in a sample of Brazilians sample aged 50 years and more	Longitudinal study (surveys). Study sample—8903 workers aged 50 years and over. Multivariate analysis. Poisson regression.	Work ability in old age depends on the life course, i.e., academic level, health conditions in younger and older age, minimum working age, etc. Policies aiming to extend longevity in the work market must consider these factors.	The collection of self-reported data associated with past experiences might have been affected by the preference to demonstrate an acceptable image, causing information bias. Establishment of temporal relations for the variable related to current conditions is limited.	Work ability, health, socioeconomic factors
	[40]	To review the documentation about the influence of psychological health on staying at work after pension and discuss consequences of public health policies.	Systematic literature review. Ten articles analyzed in detail.	Staying at work after pension can be positive for psychological health. Pension action plans are required to provide national policies that will increase the pension age and not exacerbate any disproportion in the older population.	Only cross-sectional and longitudinal studies investigating the impact of unexpected variables on psychological health were involved in the review.	Pension, job status, psychological health, social policy
	[7]	To analyze the literature on workplace health promotion (WHP) aimed at older workers	Systematic literature review. Eighteen articles analyzed in detail.	Existing documentation does not demonstrate that WHP enhance work ability, retention, efficiency, lifestyle, health, or prosperity of the senior workforce.	The heterogeneity and low quality of the studies makes it difficult to synthesize the literature and draw the conclusions.	Workplace health promotion, senior workforce, health, lifestyle
	[41]	To investigate the results of unfulfilled expectations of staying at work after age 62 on life satisfaction.	Longitudinal survey. Study sample—1684 workers aged 51 and over. Growth mixture modeling. Descriptive statistics. Linear regression. Multi-nominal logistic regression.	Majority of men and almost no women expected to stay at work after age 62. The subjective prosperity of older adults is affected by unmet expectations of staying longer at work .	The significance of different job options before full pension was not assessed.	Work expectations, pension, life satisfaction, subjective prosperity
	[42]	To find out whether the workers' ages determine the evaluation of their work–life balance.	Survey study. Study sample—500 workers aged from 21 to 70 years. Kruskal-Wallis test. Spearman's R correlation analysis.	The maintenance of work–life balance will be indicated by older workers. All employees do not have the same possibilities to take advantage of solutions that provide the support of work-life balance.	The diversity of the answers given by the participants according to the type and state of particpants affiliation was not analyzed.	Work-life balance, workers'assessment, aging workforce
Legislation	[13]	To estimate the impact on the efficiency of the reduction of assortment mechanisms among senior employees.	Italian National Institute of Statistics data from 2009 to 2013. Descriptive statistics. Multivariate regression analysis.	The growth of pension age, as well as limitations on early pension intention, kept older workers at the work without a positive influence on efficiency. More efficient older employees are mroe likely to stay at work in comparison with those who are not as efficient.	The number of employees kept at the work was underestimated. The reform's influence on the employees' structure is an additional issue.	aging workforce, pension reforms, labor productivity
	[43]	To investigate the workforce participation and absence among older adults in Sweden.	Data from the Swedish population register. Study sample—workers aged 55–64 years. Descriptive statistics.	The alternation in regulations affected the share of workers associated with illness and disability pension programs. Simultaneously, the share of workers going to early pension has grown.	This study noticed no alternation related to the difference in working-life exit patterns associated with hierarchical and academic positions in the organization.	Workforce participation, older worker, pension, illness benefits
	[20]	To review the expert way of thinking in relation to policies influencing the employment of older adults.	Survey study. Study sample—89 participants aged 50 years or older. Descriptive statistics.	A broad range of policies recommend possibilities for innovation.	There is a sampling bias related to the language and review method. There were no participants from South America, while a few participants from Africa demonstrated about limited Internet access.	Aging workforce, older workers, employment policy, mandatory pension, government answers
	[44]	To investigate whether age and mental capabilities mitigate the connection between job stress and negative affect	Survey study. Study sample—139 workers aged 25–69 years. Descriptive statistics. Correlation and regression analysis. Johnson–Neyman technique.	Cognition mitigated the connection between job stress and negative affect. Crystallized cognition had a large influence on the connection between job stress and negative affect for senior workers. The mitigating influence of fluid cognition was unchanging.	The study did not permit a setup of directionality among variables. Better evaluation of professional features and job requirements is needed.	Job stress, negative affect, older workers

Improve the well-being of older workers. Difficulties that older people experience at work indicates a need for healthcare strategies to adjust the work conditions so that they are suitable for older workforce with decreased physical ability. The authors in [34] identified professions that are dominated by older workers and suggested that work-related hazards (e.g., noise, vibrations, etc.) should be reduced to prevent health problems. Older workers and workers with disabilities can be used as the sources of required skills. Such unutilized workers need to be recruited and well-managed to ensure that their skills are retained [35]. In order to improve the well-being of older workers, the authors in [17] considered the influence of organizational factors, whereas those in [36] examined psychosocial factors at workplace. Unfulfilled prospects for work in old age influenced the prosperity of older workers [41]. Therefore, it is necessary to perform workplace health promotion activities [7].

Promote the lifelong learning. The growth of the aging labour force and emerging technologies change the work environment, generating a need to train older workers to improve their skills. Older workers gain benefits when well-designed training approaches are used. Therefore, the authors in [38] studied the training requirements and work experience, as well as the perception of ideal job features. To encourage technology adoption in the work environment, there is a need to understand how workers study software tools and complete assignments [8]. Therefore, further research should concentrate on developing safer work practices and supporting worker's productivity and professional longevity [37].

Encourage the late retirement. In order to achieve more successful inclusion of older people into labour market, there is a need for more comprehensive policies and harmonized all-age legislation. This is indicated by the fact that the overall decrease in the share of individuals in pension and disability programs is caused by changes in regulations [43]. In this regard, the authors in [20] studied the factors that affect the aging labour force and the range of current policies that suggest the possible opportunities for innovation. The implications for older workers are related to lifespan earnings, job retention, retirement savings, the possibility of changing jobs, or employment assurance [13,44]. Increasing the pension age should not exacerbate social and health disproportion in the older workers [40]. This is important since many older workers report unequal options to take advantage of solutions for supporting the balance between work and private life [42].

The abovementioned policy implications may be useful from policy making perspective. They could lead to the creation of framework that targets government, the non-governmental sector, private sectors and other stakeholders. However, the creation of such policy framework should take into account many other contributing factors [28] that can be the subject for future research activities. Furthermore, a future research agenda should consider the concept of ageing at work at national level and intensify collaboration at international level. Nevertheless, the following recommendations for governments and other stakeholders can be drawn from this research study:

1. Encourage incentives to extend the working ability in old age;
2. Eliminate age-based discrimination at work along with promotion of gender equality;
3. Invest in education, lifelong learning, health and well-being while increasing the productivity;
4. Improve the working conditions to increase the safety at work and health of workers;
5. Support late retirement along with the increase of life expectancy;
6. Reduce the use of early retirement if workers' health and work ability are satisfactory.

4.2. Study Strengths and Limitations

This study provides a systematic review of articles related to the aging labour force in terms of recent trends and future directions. Additionally, it identifies and evaluates the motivations that drive research on the aging labour force and potential solutions that address the issues related to the aging at work. Sustainable growth and age-based discrimination are recognized as the main motivations to perform the research activities in the given context. On the other hand, policies that stimulate life-long learning are identified as a potential solution for the aging labour force. The additional value of this study lies in its identification of policy implications and recommendations for governments and other stakeholders.

Furthermore, along with this paper, we also provide a Supplementary Materials of all identified relevant articles that can be filtered in terms of different fields to recognize articles for further analysis in a particular subfield. This initial search for a systematic review design may provide useful results on the relevance, practicability, and time needed to carry out a systematic review.

Despite the valuable insights in this study, it suffers from several limitations as well. First, this study took into consideration only three digital libraries, so some relevant articles could be unintentionally omitted from the study because of the specificity of the search strings and the fact that we have not taken into account the non-indexed publishers. However, the size of the searched digital libraries is sufficient, so the obtained results are suitable for the purpose of the study. Additionally, the articles obtained for this study are the results of a search query sent to different search engines with different retrieving and formatting rules from those that are used in the considered libraries. However, we are convinced that the specificities of the publishers' search engines had no influence on the findings of this study, taking into the account the number of analyzed articles.

Finally, the articles are categorized to provide the quantitative results that show the recent trends and future directions of aging at work, whereas the qualitative results are manually covered to a limited extent to describe the motivation issues and solutions for the aging labour force.

5. Conclusions

The aging of the population raises many issues and provides many opportunities. It intensifies the requirement for long-term care, healthcare, and a better-skilled workforce, and increases the demand for age-friendly environments. On the other hand, it enables the contributions of older people to their family, local community, or broader society.

In order to review articles related to the ageing at work in terms of recent trends and future directions, we performed a scoping literature review using an NLP-based framework to automate some of the steps in the PRISMA methodology and quickly identify potentially relevant articles. As a result, starting from over 70 thousand potentially relevant articles, we analyzed in detail about 70 of the most relevant approaches and discussed 24 of them.

We identified that the most prominent works suggest policies and practices that support life-long learning, a workforce that comprises both younger and older workers, and gradual retirement. Approaches like these could be the best response to the globalization issues, reduction of workforce, maintenance of financial independence of the aging workforce, and other social benefits.

Future work could be focused on standardizing approaches to this problem across different countries, supported by different policymakers. The goal should not be to end up with the same approaches in different environments, as this would hardly encompass all cultural, sociological, and economic factors. Instead, we believe that systematically documented and well-thought-out approaches will facilitate the measurement of the results and analysis of causality when investigating benefits and drawbacks.

Supplementary Materials: Supplementary Materials can be found at http://www.mdpi.com/1660-4601/17/20/7659/s1. Table S1: Supplementary list—Data.

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3.3. Artículo 3: Rural Healthcare IoT Architecture Based on Low-Energy LoRa

En este tercer artículo se identifican cuatro casos de uso como punto de partida para el diseño de la arquitectura que representan retos reales a la hora de monitorizar el bienestar de una persona, así como las principales limitaciones que hay en los entornos rurales y los retos para el despliegue de arquitecturas IoT, en los que se basa la arquitectura propuesta en cuanto al protocolo de comunicaciones inalámbrico a utilizar, la transmisión, el almacenamiento y procesamiento de datos, dispositivos y el consumo de energía. También se incluyen ejemplos de conectividad de los componentes de la arquitectura, de transmisión y almacenamiento de datos con la arquitectura propuesta, así como los elementos que componen un eHealth Gateway, y los dispositivos IoT.

El artículo aborda las posibles vías en las que el sistema pueda gestionar notificaciones tipo *push* de eventos que pueden suceder en cualquier momento (p.ej., que un cuidador quiera comprobar si el usuario está en la cama o el estado del dispensador de medicina). Más allá de las comunicaciones planificadas tipo *pull*, lo que requiere es: o bien realizar mediciones de manera continua, o usar un dispositivo que emita una señal de alarma que “despierte” a uno o varios sensores en concreto de su modo standby una vez que dicho evento ocurra. En el trabajo se analizan cuatro tipos de señales de alarma: (1) de radio frecuencia (RF), en el que se detalla el mecanismo de ahorro de energía WuRx, (2) de luz, descartado por los autores debido a que se limitaría solo a nodos IoT que se encuentren en una misma estancia, (3) de sonido, que pueden identificar un accidente o activar un dispositivo IoT por voz, aunque tienen como inconvenientes que son sistemas muy complejos y de alto coste para su implementación en módulos sensores sencillos, o (4) mecánicos, capaces de detectar vibraciones, movimientos, presión, y que pueden colocarse en colchones, mobiliario tapizado, marcos de puerta, suelos, etc., para detectar si el usuario está en la cama o ha entrado o salido de una estancia, lo que indicará si los nodos IoT tienen que entrar o salir de su estado de letargo.

En este trabajo se proponen distintas opciones para la conservación de la energía, y se demuestra que los temporizadores de potencia ultrabaja ULP externos pueden utilizarse para extender la vida de las baterías, dependiendo del perfil de uso del nodo IoT. Mientras que los temporizadores ULP pueden prolongar la vida de las baterías durante años, es necesario que el sistema sea capaz de responder cuando sea necesario, por lo que se proponen sistemas de activación para los microcontroladores y los sensores. Ciertos eventos pueden actuar como activadores generando una carga eléctrica o cerrando un circuito abierto, lo que permitiría contar con sensores de energía cero. Los sensores que identifican cambios son capaces de detectar y activar un evento. Las señales de activación de muy bajo consumo se utilizan para reanudar el funcionamiento de un microcontrolador en reposo. Estos activadores incluyen señales de activación por radiofrecuencia y señales de activación por luz, sonido y mecánicos.

Durante el desarrollo del presente trabajo, el doctorando participó activamente en la definición de los casos de uso, las limitaciones en entornos rurales que las arquitecturas de sistemas IoT de monitorización y seguimiento de salud deben de cumplir, en el diseño de la propia arquitectura y la definición de limitaciones, así como en la escritura y revisión de las distintas versiones del documento.

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Rural Healthcare IoT Architecture Based on Low-Energy LoRa

Ace Dimitrievski [1,*,†], Sonja Filiposka [1,†], Francisco José Melero [2,3,†], Eftim Zdravevski [1,†], Petre Lameski [1,†], Ivan Miguel Pires [4,5,6,†], Nuno M. Garcia [4,†], José Paulo Lousado [7,†] and Vladimir Trajkovik [1,*,†]

1 Faculty of Computer Science and Engineering, Ss. Cyril and Methodius University, 1000 Skopje, Macedonia; sonja.filiposka@finki.ukim.mk (S.F.); eftim.zdravevski@finki.ukim.mk (E.Z.); petre.lameski@finki.ukim.mk (P.L.)
2 Technological Centre of Furniture and Wood of the Region of Murcia (CETEM), 30510 Murcia, Spain; fj.melero@cetem.es
3 Telecommunication Networks Engineering Group, Technical University of Cartagena, 30202 Cartagena, Spain
4 Instituto de Telecomunicações, Universidade da Beira Interior, 6200-001 Covilhã, Portugal; impires@it.ubi.pt (I.M.P.); ngarcia@di.ubi.pt (N.M.G.)
5 Computer Science Department, Polytechnic Institute of Viseu, 3504-510 Viseu, Portugal
6 UICISA:E Research Centre, School of Health, Polytechnic Institute of Viseu, 3504-510 Viseu, Portugal
7 CISeD Research Centre in Digital Services, Polytechnic Institute of Viseu, 3504-510 Viseu, Portugal; jlousado@estgl.ipv.pt
* Correspondence: ace.dimitrievski@gmail.com (A.D.); trvlado@finki.ukim.mk (V.T.)
† These authors contributed equally to this work.

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Abstract: Connected health is expected to introduce an improvement in providing healthcare and doctor-patient communication while at the same time reducing cost. Connected health would introduce an even more significant gap between healthcare quality for urban areas with physical proximity and better communication to providers and the portion of rural areas with numerous connectivity issues. We identify these challenges using user scenarios and propose LoRa based architecture for addressing these challenges. We focus on the energy management of battery-powered, affordable IoT devices for long-term operation, providing important information about the care receivers' well-being. Using an external ultra-low-power timer, we extended the battery life in the order of tens of times, compared to relying on low power modes of the microcontroller.

Keywords: connected health; LoRa; IoT

1. Introduction

Medical advances and access to healthcare available in developing countries have improved the quality of life for older adults. On the other hand, the economic growth in many developing nations has resulted in a reduction in multi-generation households [1]. In countries with fast-paced urbanization, the young people increasingly migrate for economic reasons, while the retired population remains in their rural homes during this initial migration phase. This trend has left an increasing number of old age population alone or in some areas they take the additional role for caring for their grandchildren [2]. Often this aging population can lead independent and productive lives in their advanced age, and many choose to remain in their home as long as they can [3]. Moreover, with the aging population in rural areas absent government regulations to promote rural investing, there is less incentive for technology and telecommunication providers to invest in bringing stable electricity and network connections to these areas [4].

In addition to telecommunication and electrical infrastructure, rural environments pose other challenges, including sparse population, road conditions, distance to urban areas, and lack of local skilled labor. While these aspects vary from location to location, designing such critical systems as Active Assisted Living (AAL) should holistically consider all constraints.

For the independent living of older adults in rural areas, providing cost-effective, low-maintenance solutions is essential. This paper proposes an architecture that would meet these requirements based on recent advancements in the Long Range (LoRa) network, fog computing, and low Earth orbit (LEO) satellite connectivity, using state-of-the-art energy efficiency. Such proof of concept for supporting older people using the LoRaWAN network, the Things Network, and ESP-32 microcontroller was already presented in [5] focused on providing real-time data, and in this paper, the concept is extended.

LoRa falls under the low-power wide-area network (LPWAN) type of communication technology. LoRa is a proprietary physical layer protocol that transmits in unlicensed frequency bands reserved for industrial, scientific, and medical (ISM) use. The data-link layer, most commonly used in Internet of Things (IoT) devices, is called LoRaWAN and is an open standard. LoRa and LoRaWAN only define the communication protocol and often come in a combined hardware package with microcontrollers. LoRa is designed for low-energy sleep mode, and many IoT microcontrollers also have low-energy states.

Fog computing extends the cloud services to the edge of the network. It makes computation, communication, and storage closer to edge devices and end-users, which aims to enhance low-latency, mobility, network bandwidth, security, and privacy [6]. Fog computing introduces another layer between the cloud and the end devices, called the fog layer. The end devices also referred to as IoT nodes, are located in the terminal layer. IoT nodes, by definition, must be connected to a network, and they usually include various sensors or actuators that interact with the physical world [7]. Specifically, in fog computing for medical applications, they connect to a device called e-healthcare gateway that provides services and offers cloud connectivity.

The IoT nodes are usually battery-powered. Due to multiple constraints in rural areas, it is essential to implement efficient battery-saving protocols using sleep modes when the node is idle. To accomplish long battery life ultra-low-power (ULP) modes, that are built-in with modern microcontrollers and external ULP timers are used. However, for the application to be practical, the device would need to wake up either after a specific time interval or via an external interrupt to conduct the required tasks.

2. User Stories

To design a more functional architecture, we identify four user stories that present different challenges in a realistic scenario when monitoring a person's wellness.

2.1. Story: Finding a Lost Person

Seniors with deteriorating mental health, including dementia, can wander away from their residence and get lost. A holistic approach for identifying when the person left their residence and identify the current location is needed for timely intervention by rescue teams or search groups from other residents in the area. In a rural area, people might live alone and have infrequent visitations from other community residents, and they might not be identified as missing for many days. Chances of finding the person can be increased by equipping everyday used clothing items such as a winter jacket, outdoor shoes, a belt, or a personal item with a battery device. This device will send a signal that can be triangulated or obtain and transmit GPS coordinates. Such a signal should be received by any other healthcare gateways in the area. A healthcare gateway used by the person's residence should have an algorithm for detecting and raising the alarm when certain events occur that indicate the house resident is expected to be at home but is not present and should be considered lost [8]. For privacy reasons, the healthcare gateway should not transmit such data if the person was away due to normal daily activities depending on the time of day and has returned within the expected time.

A wireless healthcare service system for seniors with dementia is proposed in [9]. The authors suggest using various wireless solutions and rely on the availability of a GSM network to send emergency signals. In a rural environment, a GSM network might not be available. However, any proposed system should support all necessary technology to locate the person.

2.2. Story: Detecting Abnormal Changes in Daily Living

Older people tend to establish daily routines that help them organize their lives and create a comfortable environment. Having repetitive days is often a good sign for the care providers. On the other hand, sudden disturbances can indicate possible underlying problems with their health or well-being. One of the most important routines for a healthy life is healthy sleep. Health issues or emotional stress can project onto a person's sleep patterns. Care providers would benefit from a non-invasive system present in the sleeping area to monitor the person's sleep. The monitoring will include the time of day when they go to bed and wake up, the time it takes them to reach a sleep state, and potential disturbances in their sleep. Such a system should be a part of the environment and not require direct interaction like attaching wearable sensors and prompts.

Based on previous research [8,10], we have learned that passive-infrared (PIR) sensors positioned above a person's bed could identify these sleep parameters and also do it in a non-invasive and privacy-preserving way [11].

In cases where the health care receiver's actions can improve the condition, a recommendation system such as the COllaborative HEalthcare SYstem model (COHESY), described in [12–14], can be used to recommend activities. For example, if evening walks are determined to improve sleep in a specific group of people, such activities could be automatically recommended to persons with similar health or demographic characteristics.

2.3. Story: Environmental Safety Monitoring

Relatives and care providers would benefit from knowing that seniors live in a safe environment, including reduced risks. While notifying relatives or care providers in case of emergencies is essential, false alarms cause other sets of challenges [15], causing a need for a balance in the accuracy and frequency of notifications. Due to the lack of infrastructure in rural areas, common defects can have severe and even dangerous consequences. Having standalone, easy to install sensors to monitor electricity and water usage, detect water leaks or fire hazards can significantly improve the inhabitants' safety. There is great potential to equip everyday items with inexpensive sensors that will, in turn, communicate with the in-house or remote gateway. The following are some examples:

- A compressed canister with gas used for the cooking stove can be equipped with a hall sensor to detect when it is being turned on and even have a safety shutoff valve triggered by a timer if left on beyond the expected time.
- An inductive coil placed around an electrical lead wire can induce a signal for a sensor to monitor electrical usage. Multiple devices can be monitored by monitoring the consumption of common power lead.
- A water sensor can be placed on the floor to detect any water leaking in the house, either from running water or rain.
- Magnetic sensors on the doors and pressure sensors on floor mats can detect when a person enters or leaves the house.

2.4. Story: Medicine Dispenser

A patient with prescribed medication would benefit from having a medicine dispenser device to remind them and keep track of when the medicine needs to be taken. Depending on the type of medicine, the system would prevent doubling the dosage when the care receiver does not notice or ignores the alerts and does not take the previously dispensed dose on time. A healthcare provider would benefit from a centralized system that would track compliance with the prescribed treatment. The doctor would use the same system to adjust the prescribed frequency of the medicine already in the dispenser. Thus, it is required for the dispenser to be connected to the system via the healthcare gateway. The pharmacy and the distributor would have a complete inventory. They will refill all the medicine dispensers in the area with minimal trips while ensuring that all medicine will be taken before the expiry date.

3. Architectural Challenges

With the push to increase connectivity in developing and under-developed countries, regions with a dense population such as cities, towns, and suburban areas are increasingly interconnecting. This trend would accelerate soon, especially with the push towards 5G networks. On the other hand, rural areas are shrinking in size, and the average age of the population is increasing [16], thus providing connectivity is not a priority for network providers. Solutions such as mobile and satellite internet, for direct connectivity to the cloud, are prohibitively expensive. Furthermore, by the nature of rural areas and farmlands, the houses are sparsely positioned, cable and Wi-Fi links are technologically not viable due to signal deterioration. Thus, we identify the following constraints that the architecture must meet:

- Internet connectivity is of low quality, expensive, or nonexistent.
- Houses are mostly spaced out at a distance of at least 100 m.
- Electricity is not reliable, and blackouts are to be expected.
- The care receivers are unable to troubleshoot or repair IoT devices.
- Servicing can be done from once in few months to once in a few years.
- The systems must be affordable, even for a few participants, and scaling up reduces cost.
- When storage is limited, the most valuable data has a higher priority over the most recent data.

The lack of persistent Internet connectivity implies a self-sustained network that relies on one or few links for connecting to the cloud. The limitation for Internet connectivity requires an architecture that would support local processing as the data cannot be fully or immediately uploaded to the cloud. The sparse distribution of the houses and the need to minimize cost require long-range wireless network links.

The lack of reliability of electrical power is one factor that would require a battery backup for the devices. However, difficulties and expenses related to the installation of powered devices, especially in older houses that might not have electrical installations in all rooms, increase the preference for battery-powered devices. The battery capacity should be maximized so that the active time of the devices is sufficiently longer than the maintenance window when the operator could service or replace batteries. To extend the lifetime of the battery-powered devices, it is crucial to have low power and sleep states such that the device would minimize the time needed to remain in a higher power consummation state.

3.1. Communication Synchronization

A big challenge for devices that remain in sleep states for prolonged periods of time is communication synchronization. The energy constraints prohibit a device from having a complete picture of the state of the environment, the network, and other devices.

Communication in the network is inherently sparse based on the assumption that energy is not reliable. Each IoT node and healthcare gateway should have a built-in real-time clock and calendar chip and a battery-powered circuit. If power is lost due to power grid blackout or bad conditions for renewable energy harvest, a timer-based battery switch starts the gateways at the predetermined communication time slot. A real-time clock or internal timer will also wake up IoT devices with buffered data to transmit to the network.

3.2. Energy Conservation

In multiple papers, energy conservation in LoRa networks has been studied, most of which address the LoRa and LoRaWAN parameters and the tradeoff between energy consumption, reliability, and distance [17–20]. Minimizing data transmission is a practical energy-saving approach, especially in our proposed architecture that relies on slow data links. Techniques to achieve this includes compression and data pre-processing, and filtering. This paper proposes using external ULP timers to replace the modern microcontrollers' built-in ULP modes, as presented in Section 4.7. This approach enables nano-Ampere sleep currents for the IoT device.

Energy efficiency in LoRa based networks, especially when using the LoRaWAN protocol, is a well-researched topic. An energy consumption model based on LoRa and LoRaWAN is described in [17]. The authors study the impact of LoRaWAN parameters such as acknowledged transmission, spreading factor, coding rate, payload size, and communication range on the sensor node consumption. Their model is based on LoRaWAN Class A. The optimization study showed a tradeoff between the LoRaWAN communication range, the spreading factor, and the transmission power. This optimization study is very interesting to choose and configure LoRa/LoRaWAN parameters [17]. Energy efficiency optimization of LoRaWAN using an open-source simulator is presented in [18].

Optimization strategy in LoRa networks can be done by transmission parameter selection. There are 7620 possible parameter combinations [19]. It is possible to use different network parameters, which result in acceptable link quality but with energy consumption that differs 100 times [19]. The LoRaWAN specification does not provide configuration selection mechanisms; thus, most implementations use static parameters. For high communication ranges (greater than 10 km), the transmission power must be fixed to 20 dBm with Spreading Factor (SF) set to 12 [17].

Energy efficiency for multihop LoRa networks was studied in [20]. The authors used an adaptation of the TSCH MAC protocol for a long-range operation which addresses most of the challenges created in multihop LoRa communications. A time division mechanism synchronizes nodes' wake-ups for constrained nodes. They also implement a channel hopping mechanism to diversify transmissions over different channels in a power-efficient manner.

4. System Architecture

To address the lack of internet connectivity and the distance between connected devices, and the inability to establish an Ethernet connection, we propose a flexible fog network architecture where the primary communication channel for long-distance traffic is based on LoRaWAN. In Figure 1, we present a sample connectivity scheme. IoT devices in a home, including sensors, can have two modes of connectivity. They could either be connected to an in-house healthcare gateway or have embedded LoRa transceiver radio and communicate to the neighboring gateway. Wearable devices with LoRa radio transmit can communicate with any healthcare gateway in the network. The process for sending data is shown in Figure 2.

Unreliable electricity and difficulty to set up charging outlets and the risk of them being unplugged by the house occupants is addressed by relying only on battery-powered IoT devices. The healthcare gateways also require reliable battery operations with recharging the batteries either via the power grid when electricity is available or using renewable energy sources such as solar panels. The need for battery operation and the long servicing time poses energy conservation as the primary challenge in our design, and we address this in the following sections.

To ensure cost efficiency from small implementation to scaling up, we propose inexpensive off-the-shelf components integrated into sensor enclosures for small quantity deployments. Then, when a need arises for larger deployments, some components can be reduced or combined to save material costs. An example of such cost saving through consolidation is creating custom boards with multiple sensors used by an IoT device, built-in sleep timers and clock chips, and a single power supply circuit.

The proposed architecture has several built-in constraints resulting from batteries as the primary energy source and LoRa as the dominant protocol for distant communication. LoRa is designed to be energy efficient; however, that comes at the cost of very low bandwidth. With the requirement of a long-lasting battery, energy conservation is the primary challenge. Ensuring maximal energy conservation is accomplished by reducing higher power consumption events and extending sleep states' ability. IoT devices should be awake only long enough to collect and transmit data. The challenges introduced by power cycling devices and long sleep periods are the following:

- No internal real-time clock/calendar for time-stamping events.
- Communication is unreliable, and data transmission is not always possible.

Figure 1. System architecture for rural area network for healthcare IoT.

Figure 2. Data transmission decision process workflow.

4.1. LoRa and LoRaWAN

LoRa is a proprietary radio modulation technology licensed by Semtech Corporation. LoRa uses unlicensed ISM bands: 868 MHz in Europe, 915 MHz in North America, and 433 MHz in Asia [5]. The Bidirectional communication is done using Chirp Spread Spectrum (CSS) modulation, or as defined by [21] a Frequency Shift Chirp Modulation (FSCM), where each symbol is sent using a wide frequency band. The advertised communication range of LoRa is more than 15 km for suburban environments [22]. The long-range and low-power nature of LoRa makes it a likely candidate for smart sensing technology for health monitoring and environment monitoring [23].

There are three classes of end-devices (Class A, Class B, and Class C) which differ in the timings of the receive windows [24]. Class A has receiving windows after the send windows. Class B has received windows at timed intervals. Class C has continuous listening.

There are five configuration parameters for LoRa radio: Transmission Power (TP), Carrier Frequency (CF), SF, Bandwidth (BW) and Coding Rate (CR) [22]. The rate at which the data is transmitted depends on three physical layers parameters: SF, BW, CR [24]. SF indicated how the signal is distributed in time. The more time it takes to send the packet, the lower the minimum RSSI. A higher coding rate increases redundant bits, thus making the transmission more reliable. However, it increases time and energy consumption. A higher bandwidth reduces the transmission time but at the cost of lowering the noise floor.

On top of the physical layer, the MAC layer protocol defines the topology of the network. An analysis for the creation of ad-hoc MAC layers is presented in [25]. A synchronous-based, medium access control (MAC) protocol, MAC on Time (MoT) was studied with the potential to have reduced energy footprint [26]. An alternative MAC layer protocol named LoRaBlink was discussed in [27]. However, in this paper, we review only LoRaWAN, which uses a star topology and is most often used in LoRa deployments. The LoRa modulation is proprietary; however, the LoRaWAN is an open standard being developed by the LoRa Alliance. It is designed mainly for sensor networks, where sensors send data to the server infrequently (one transmission per hour or even days) [23]. LoRaWAN is based on the ALOHA protocol. The end devices communicate directly to an always-on gateway when they have data ready to send [28]. The downsides of this star topology include: cost of the base station(s); the need for more frequent battery replacement for remote nodes; and need for high SF and a higher chance of collisions for remote nodes [20].

The analysis conducted in [29] shows that the long-range transmissions of LoRa are vulnerable to multiple security attacks. The possible attacks include compromising nodes to obtain network keys, jamming, replay, and wormhole attacks. The security measures in the LoRaWAN protocol are left to be implemented by developers and manufacturers, thus providing room for bad implementation in some devices to introduce risk for the network.

4.2. Fog Computing and E-Healthcare Gateway

With the evolution of healthcare, Fog Computing is one of the possible solutions for the improvement of healthcare treatments in rural environments for the performance of all treatments remotely [30]. Fog computing is a paradigm that addresses connectivity constraints. Our architecture focuses on moving computation closer to the edge. All IoT devices have sensors and microcontrollers to conduct data processing and only transmit the minimal amount of data needed to reach the cloud. The primary constraint in the proposed fog topology is the limited bandwidth of the LoRa network. The gateway has bi-directional communication with the IoT devices and the communication hub for the area, typically a village. Communication with nearby devices located in the same house can be established with other protocols such as ZigBee [31], or Bluetooth 5, which can have up to 200 m range [32].

In the proposed architecture, the healthcare gateway collects raw medical signals from sensors, conducts data pre-processing, and feature extraction [33]. Depending on the type of data, the system could utilize different Machine Learning (ML) models to extract meaningful information from the raw data. When ML is used for decision-making, the gateway determines actions based on the most recent ML model. Such decisions considering the identified user stories and include determining alarm activation for a missing person or abnormal changes in daily activities, environmental controls, and health monitoring.

The main constraints for applying ML in the edge nodes are related to the limited computing and battery power. Therefore, the ML model training is conducted in the cloud, and the model is deployed on the e-healthcare gateway. The fog network is used to transmit up-to-date models from the cloud to the e-healthcare gateways [34]. When selecting the algorithm, considerations should be made that updates are done via low bandwidth links and that the data has a low sample rate due to energy constraints. In addition, the pre-trained ML models that would be used on the edge nodes should be as lightweight as possible, for example, by using data structures with lower precision and, consequently, lower memory footprint. The specific selection of the ML algorithm and implementation details would depend on the use case, the sensor types, and the data quantity. However, the proposed architecture would apply to any algorithm that could meet the said constraints.

In Figure 3, we present the workflow for data transmission and data processing in the proposed architecture. The IoT nodes pass the data to the e-healthcare gateway, shown in the blue/left block, where the local model is run. If a significant event is detected, a communication channel is established with the communication hub, which can communicate to the cloud or care providers if the alert is triggered. Additionally, in cases of low confidence classification or when ambiguous classification occurs, the data is sent for further processing and labeling in the cloud. This means that all outliers and classifications made by the lightweight ML models on the edge nodes would eventually be validated by more performant ML models on the cloud side. On the communication hub, shown in green/middle block, the results are validated, and if a significant discrepancy is found, the hub will set a flag to download the latest cloud model and update edge ML models. All data received by the communication hub is stored and transmitted to the cloud either by network link, such as LEO satellite, or via offline data collection during the service period. The cloud, shown in red/right block, is responsible for generating the ML model and providing an interface for labeling data. In addition, the cloud gathers data from external sources such as medical databases and patient records. Therefore, all services offered to care providers are centralized in the cloud.

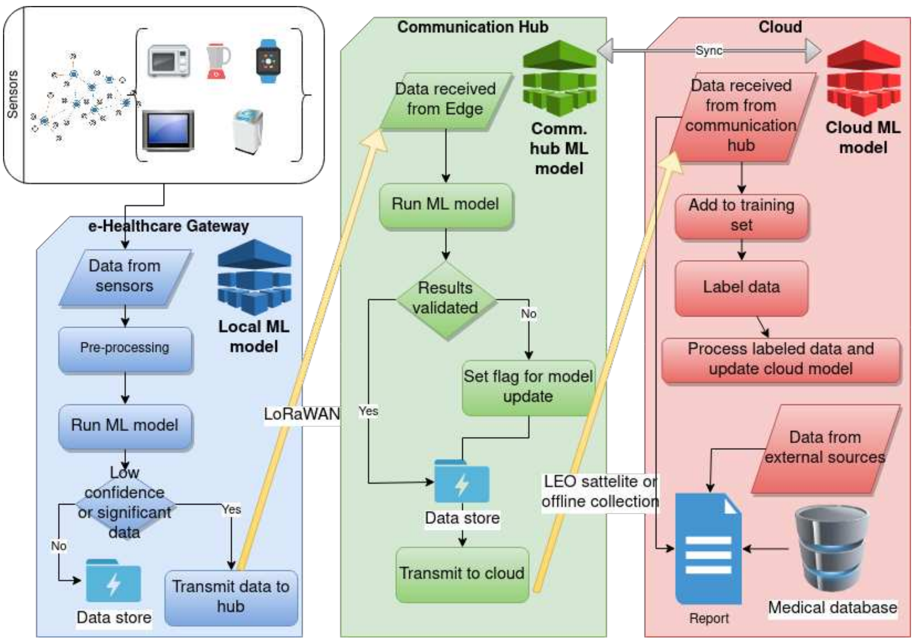

Figure 3. Machine learning workflow using Fog based architecture.

To illustrate the ML process within the proposed architecture and to state the challenges given the architecture constraints, we will use a scenario that falls under the user story "Detecting Abnormal Changes in Daily Living", described in Section 2.2. More precisely, we consider how sleep monitoring of a person can be used to indicate underlying health conditions. In our previous work, we have elaborated that a combination of piezoelectric and PIR sensors that measure different physical properties, thus minimizing the possibility of noise signal contamination, show a strong correlation, and can be used to detect the person's movement in bed during sleep [35]. For the data collection, the microcontroller can operate in the ESP32 Deep Sleep state. This sleep pattern of the microcontroller is known as ULP sensor-monitored pattern and the stated current usage is 10 µA [36], while higher when it is part of a microcontroller. Additionally, the sensors should be modified to minimize elements that dissipate energy in the form of heat, such as the linear voltage regulators.

The data collected from the sensors is stored in the real time clock (RTC) memory, which, based on the hardware revision, is 8MB or 16MB. When the RTC memory is full, the microcontroller wakes up, compresses the data, and begins transmission to the e-healthcare gateway. The e-healthcare gateway must first filter the data to determine its validity and filter for possible noise by correlating data from multiple sensors. Then, using its pretrained ML model, the gateway detects events of interest about the care receiver's sleep. The challenge presented in this case is transmitting the sensor data and labeling it for reinforcement learning in the cloud. The LoRaWAN bandwidth limitation implies that not all data can be continuously transmitted to the communication hub and from there to the cloud. Thus, the system should contain thresholds either by the number of non-zero readings from the sensor or by the number of low confidence classifications. The data can then be analyzed by a medical specialist who can label the data by the patient's current diagnosis. This may include if the patient is known to have developed respiratory symptoms or has been diagnosed with sleep apnea. More granular labeling can be made if the care receiver, in addition to non-invasive sensors, was using body area sensors such as a wristband to detect pulse and oxygen saturation. Thus, data from patients that use such sensors should be prioritized for transmission and, upon reaching the cloud, is added to the reinforcement training set.

To minimize the energy dissipation of dropped packages from the IoT sensor nodes, the gateway should maximize the receive slots to capture data from the nodes. Furthermore, sleep times for the healthcare gateway should overlap with all potential sending nodes' sleep times. However, the dependency of the IoT cloud analytics or storage facility must be minimized for the exploitation of the proposed solution [37].

For ease of operation and maintenance, the gateway will feature functionality for auto-update, and remote reboot [38]. A block diagram of the e-healthcare gateway is shown in Figure 4.

Figure 4. E-healthcare gateway components.

The healthcare gateway should manage user interfacing with the system either as a built-in interface or via a separate user interface (UI) module. Smartphone interface could be used as an extension but should not be mandated as it will introduce additional complexity. A consideration for accessibility should be part of the UI design.

4.3. IoT Devices

In the proposed architecture, the IoT devices collect data. In the topological sense, they are part of the fog network as they connect to the healthcare gateways through a network link. These nodes consist of a microcontroller, optional communication chips and timers, and sensors. A diagram of the IoT node components is presented in Figure 5. The sensors are part of the device's enclosure, or in some cases, are connected by wire, depending on the type of measurement conducted. To reduce cost, the number of sensors on a node is maximized. However, each sensor could independently be turned on or off to facilitate energy-saving schemes. While data processing is primarily done on the gateways, the IoT nodes also reprocess data. Decision-making for simple logic that can be programmed on the microcontroller is also done directly on the node. For example, in the environmental safety user story, a water shutoff is automatically initiated by a node that monitors water usage if certain limits are reached. Such actions should always be reported to the healthcare gateways, with the possibility to receive overrides. The UI on IoT nodes should be limited to only servicing interfaces and alerting the care receivers, such as with the medicine dispenser.

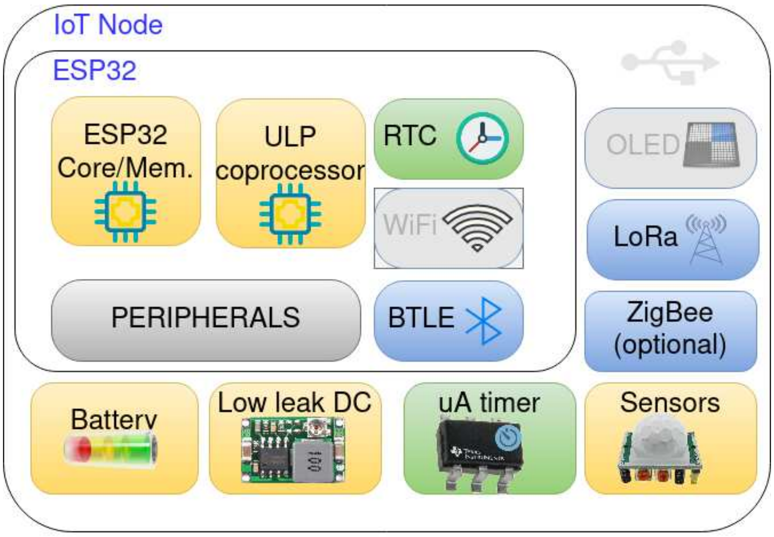

Figure 5. IoT node components.

IoT devices in healthcare might not have predetermined patterns for energy usage, especially when they measure events related to the person who receives the care. For example, devices that measure sleep-related parameters will consume energy proportional to the number and duration of monitored activities. The same applies to other aspects of activities of daily living (ADL). Thus, different behavior in ADL could lead to a different energy profile of the devices. Proper battery management is needed to estimate and adjust the activity periods to extend the battery life to the expected period. A battery level measurement could be conducted to receive feedback of battery consumption, and battery usage could be estimated from the duration and energy profile of different stages of the IoT device, such as boot-up, data collection, data processing, and communication. The energy consumption should be measured for each IoT device and a detailed energy profile created. This energy profile will then be stored in the persistent memory of the device itself. The battery capacity profile should also be established [39]. Different device profiles should be created depending on the speed of battery depletion to compensate and extend the battery life. Techniques must be customized depending on the device function but could reduce sensor sampling frequency, reduce communication windows, and increase the threshold for data collection. For example, the ML models such as decision trees should be pre-programmed or received from the network. They should be structured to use minimal computing and battery power, for example, by using data structures with lower precision and, consequently, lower memory implications.

4.4. Rural Healthcare Data and Communication Hub

The fog layer needs to be connected to the Internet (TCP/IP network) to allow access to the cloud services, including data storage and analysis. Due to network delays and bandwidth limitations, a simple internet connectivity link is insufficient as any down-times would introduce congestion if the data is buffered on the e-healthcare gateways. Thus, we propose a centralized communication hub that can serve one or several adjacent rural communities depending on geography. This communication hub would have data storage and additional data processing capabilities. Such a centralized hub could benefit from having more expensive technologies to implement on the e-healthcare gateways, such as satellite telephones for emergency communication, dedicated microwave links, and high gain antennas for GSM where a signal too weak to be picked up by mobile phones exists.

The connectivity must be made by one of the available options (cable, microwave, 3G/4G) or by another network access technology that may become available in the future, namely 5G, TVWS or LEO Satellites. In addition, several devices available on the market can work as a Gateway, with WIFI or 3G/4G connection. For example, the Dragino Gateway LG308, an open-source source LoRaWAN Pico Gateway allows bridging LoRa wireless network to an IP network via WiFi, Ethernet, Or 3G/4G cellular via optional Long Term Evolution (LTE) module that results from an application of the WiMAX (Worldwide Interoperability for Microwave Access) spectrum [40].

With the emergence of 5G mobile telecommunications, we will see the development of devices supporting this technology, allowing a range of differentiated and possibly low-cost use, combined with a very efficient coverage. However, we will always be conditioned to mobile network coverage, which will not always be economically viable in remote and rural regions, making this not a technology of the first choice in some contexts, like other mobile communications based on 2G, 3G, and 4G.

The future will involve using the Internet supported by LEO satellites, which is increasingly close to reality. The mass delivery of LEO satellites is intended to provide coverage of high-speed Internet services to all regions of the world [41]. Recently, major technology companies such as Google and SpaceX have entered into agreements to provide data, cloud services, and applications to domestic and business customers all over the world soon. Likewise, it was reported that SpaceX will also install ground stations within Google's data centers that will connect to Starlink satellites, allowing Internet services through the Google Cloud platform. Starlink's satellites are over 60 times closer to earth than geostationary satellites, resulting in lower latency and the ability to support Internet services typically not possible with traditional satellite [42]. This will undoubtedly be an unprecedented revolution that will democratize access to the Internet anywhere in the world.

4.5. Bandwidth Limitations

A requirement for remote devices that would have to operate during long periods between servicing is receiving remote updates, including software updates and updates to ML models. The LoRa alliance provides a specification for remote firmware updates called Firmware Updates Over the Air (FUOTA) [43]. However, updating the firmware over the air is complex, difficult to execute, and requires a series of technical requirements. It usually involves several steps to ensure that the update is successful, namely:

1. Identify the devices that need to be updated and place them in multi-cast groups;
2. Generate a binary firmware update file specific to the platform of the device to be updated;
3. Sign the binary file with a private key to ensure the integrity and authenticity of the update file;
4. Send the binary file to the device group to be updated;
5. Each device will have to verify the signature to authenticate the file as well as the authenticity of the origin;
6. Each device will need to install the firmware update;
7. Each device must report the status of the update operation (success or failure).

This information is collected by an integrated device management platform that monitors its status. Some of these steps (2, 3, 5, and 6) are very specific, depending on the devices, mainly conditioned by the following characteristics:

- Device microcontroller architecture (ARM, X86, etc.);
- Device memory capacity;
- Whether the device uses an operating system;
- Whether the device uses a secure boot-loader;
- Whether the device's firmware is designed for partial updates;
- Whether the device has a cryptographic hardware accelerator;

These restrictions make it impossible to standardize a FUOTA process that works for all devices on all LoRaWAN networks, in addition to the low bit rate (50 Kbps) intrinsic to LoRaWAN networks [44]. To address this issue, the LoRa Alliance, the industry body behind the LoRaWAN standard, created the FUOTA working group to define the basic needs to enable an efficient FUOTA over LoRaWAN. This has resulted in new specifications to cover multi-cast, fragmentation, and time synchronization topics, which are essential resources for an efficient FUOTA. In [45], the authors describe these new LoRaWAN specifications and examine how the new features can enable a fast and efficient firmware update, using a simulator developed for this purpose.

The use of higher bandwidth networks such as WiMAX (802.16), wireless communication network, currently using microwaves with frequencies between 2 and 11 GHz (the initial version used frequencies between 10 and 66 GHz) with communication rate up to 70 Mb/s and range up to 50 km, is an alternative to establish the connection between LoRa Gateways and the Internet, in areas of difficult access, such as remote, mountainous and rural regions where fiber and wireless communications cable are not possible to install. Although very promising, this technology ended up being overshadowed by 4G in mobile communications, particularly in the use of LTE, which took away market space for WiMAX. However, the latest version of WiMAX is a strong bet for wireless communications, working at rates of 1 Gb/s. However, its use is severely restricted, being used in particular situations [46].

Another viable alternative to allowing data communication between the e-healthcare gateways and communication hub is the TVWS technology, as presented in [5], which is inspired by WiFi networks and is considered the most robust and economical solution in rural environment scenarios. With the transition from analog TV to digital transmission, the use of TVWS, which are the underutilized portions of terrestrial TV bands, for data communication purposes is becoming increasingly evident worldwide. It uses the spaces between television channels that are not used by the frequency range of television broadcasts (between 300 MHz and 3 GHz). These frequencies can be used to communicate over long distances (up to 200 km). Several pilot projects have already been successfully tested. The essence of the unlicensed spectrum is that any certified device can operate within it, with only minimal restrictions on the uses that can be made. The unlicensed spectrum encourages manufacturers to collaborate in the development of open standards and compete to deliver low-cost components and user equipment. However, there are limitations in the use of this spectrum, namely due to the difficulty in finding a common universal standard [47]. Having an updatable database online on the routers is the main obstacle since each country has its free frequencies. Within each country, the frequency ranges available may vary from region to region, which significantly complicates implementing a standard system using TVWS. However, it is still a good alternative for wireless long-distance communications as its broadcast nature could allow for transmitting software updates and ML models to the entire network.

More recently, a new model for wireless communications has emerged that appears to complement existing technologies to solve the limitation of coverage of the terrestrial network. This satellite network has been considered in the construction of IoT systems to provide global and uninterrupted IoT services. Considering the limited energy consumption of the IoT device, the LEO satellite is a good candidate for providing IoT services due to its low propagation loss. Meanwhile, the LEO satellite also has advantages in the low propagation delay and in provisioning continuous global coverage, which satisfies the requirements of a global IoT network. The LEO satellite generally acts as an access point in a satellite communication network, making a network like LoRaWAN in the topology domain. Therefore, when combining LoRaWAN with the LEO satellite system, LEO satellites mainly play the role of LoRaWAN gateway, which is used to acquire data from devices, operate and control access [41].

In order to meet the needs of IoT by satellite systems, in [48] the authors introduced LEO satellite constellation technology to support IoT telecommunications systems. These have unique advantages compared to geostationary satellite communication systems since they orbit closer to the earth. The constellation of LEO satellites (usually less than 2000 km) is more efficient in terms of time. In terms of propagation delay, quantified by a round trip time (RTT), the LEO satellite constellation has an RTT of less than 100 ms. In comparison, the RTT of geostationary systems is greater than 600 ms. Thus, the constellations of LEO satellites are presented as a good bet for the future to make Internet access available in remote regions, rural areas, among others, where terrestrial technologies, by cable or fiber, are not possible to be installed.

4.6. Memory Persistence in Sleep Modes

As transmitting data via LoRaWAN has energy implications, an application that aims to reduce consumption could buffer the data gathered by the sensors and transmit more infrequently depending on the data size and the LoRaWAN packet size.

Let p_l be the power used for sending the LoRaWAN packet and t_l be the time needed to send the packet. Let n_p be the byte-size of the packet and n_s be the sample size of data collected in one sampling interval. Let p_s is the power consumed during sleep. We will assume that this value is much lower than p_l and would not consider it. The energy savings when using data buffers is E, shown in Equation (1).

$$E = \left(\left\lfloor \frac{n_p}{n_s} \right\rfloor - 1 \right) * p_l t_l \quad (\text{if } p_s \ll p_l) \tag{1}$$

It is illustrated in Figure 6, where the blue/dotted line indicates a normal scenario where data is sent after each sample and the red/solid line is the energy saving mode where a message is composed of multiple data readings to form a single data frame. $\left\lfloor \frac{n_p}{n_s} \right\rfloor$ is equal to four. This indicates that the data from each sensor sample is less than or equal to 1/4 of the message size. The '−1' in the Equation indicated that we could not avoid the final transmission once the packet size is reached. In the case of a noisy channel with a high probability of collisions, this approach further reduces the probability of collision by reducing the number of transmissions.

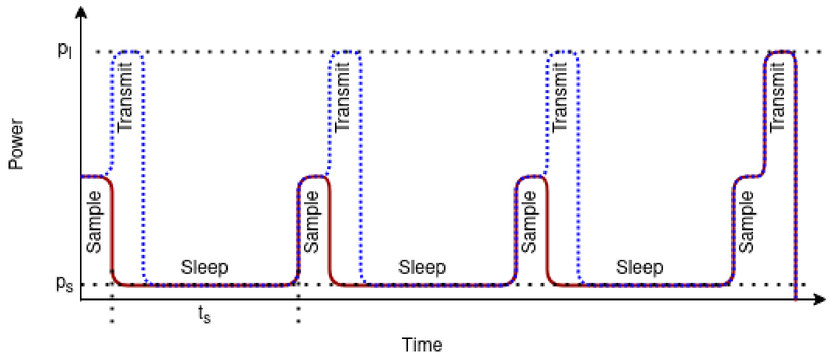

Figure 6. Energy savings by combining data in a single data frame.

Another option is using persistent memory, such as a micro SD card, to preserve the data. In this use case, additional energy is used to read and write data on the SD card each time the sensor reading is performed. We must read data every time the sensor measurement is done to determine if the buffer is full and ready to transmit. Let energy used for the write and read data step E_{rw}. Since the data is written to permanent memory, the microcontroller could be placed in a power-off state to be awaken by external ULP timer. If we consider that the external interrupt uses power much lower than the microcontroller ($p_{ext} \ll p_s$), in the sleep state, the energy is saved for the entire sleep interval t_s. The average power used during boot-up is p_b, and the total energy used for the boot-up step is E_b. The energy-saving E is calculated using Equation (2).

$$E = \left(\left\lfloor \frac{n_p}{n_s} \right\rfloor - 1 \right) * (p_l t_l + p_s t_s) - \left\lfloor \frac{n_p}{n_s} \right\rfloor * (E_{rw} + E_b) \quad (\text{if } p_{ext} \ll p_s; \, p_s \ll p_l) \qquad (2)$$

This is illustrated in Figure 7, where the blue/dotted line indicates the transmit-for-each-sample scenario and the red/solid line is the energy savings by combining data in a single data frame and writing to persistent storage. The time axis is presented to include all states but is not to scale. In reality the sleep state lasts much longer than the other events such as read-write t_{rw} and boot-up t_b ($t_s \gg [t_{rw}, t_b, t_l]$).

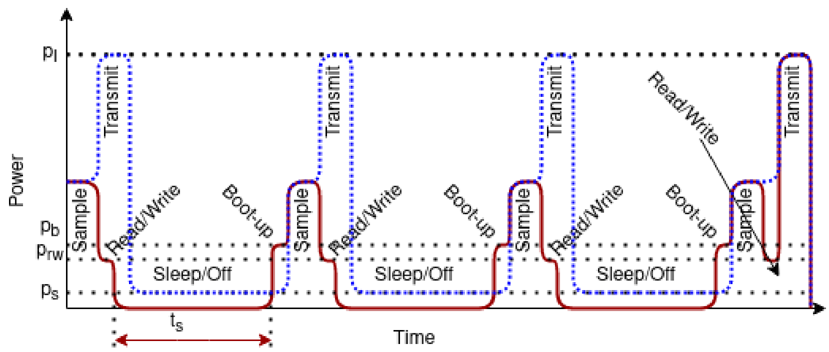

Figure 7. Energy savings by combining data and writing to persistent storage.

4.7. Utilizing ULP Timer

ULP timers consume electric current measured in nano-Ampere. Unlike timers that use quartz crystals, these chips have an error rate of around 1%. We proposed the use of ULP timers for IoT devices. We have measured the possibility of up to 45 times battery extension when using TPL5111 [49] chip, compared to microcontroller's built-in ULP, for IoT nodes that are active up to 1 min per day [50]. Such nodes are primarily used to monitor environmental conditions that need infrequent measurements. The TPL5111 chip was used in combination with a DC-DC (buck) converter as a voltage regulator. The ULP timers control the power supply tough the chip enable pin on the DC-DC converter. Thus the microcontroller is completely shut off during the sleep cycle, and a separate wake-up circuit is needed to start the node before the timer expired. The TPL5111 has a DONE pin that the microcontroller can use to send a shutdown signal when it wants to start the next sleep cycle.

Ultra-low-energy timers do not use quartz crystals for measuring time due to the energy conservation goals. In the case of TPL5111 [49], the time is proportional to an external resistance. Knowing that resistance components are usually sensitive to environmental conditions, such as temperature, we can assume that such timers cannot have a precision comparable to the quartz crystal-based circuits. In many cases, we do not need such precision. For example, activating sleep monitoring sensors should be done some time in the evening and does not require second or minute precision.

Due to the imprecision of the timer, when the sensor measures a physical parameter, timestamping should be relative to the start of the microcontroller's internal clock. When transmitting the data to the healthcare gateway, device up-time should also be sent to allow the gateway to correct the timestamp to the absolute time of the network.

While the ESP32 microprocessor has multiple low-energy states offering a balance between available resources and power efficiency, the expected energy efficiency is often not fully utilized by the microcontroller manufacturer. Not all peripherals take advantage of all the available power management. In reality, microcontrollers come with peripherals that either do not have low-power states or do not fully take advantage of those states when the microprocessor cannot use them. The most obvious example of energy waste is voltage regulators that rely on heat dissipation to provide the required voltage. Even when the microprocessor uses ultra-low power, the voltage regulator could waste energy orders of magnitude greater. This is evident from our experimental measurements shown in Table 1, conducted on Helteh's Wireless Stick microcontroller. When the wireless stick has entered low-power mode, when the power is provided using switching converter on 3.3 V, the native voltage of the electronic components, with the input voltage to the converter of 5.00 V, the current is 2.27 mA, and the power consumption is 11.35 mW. However, when the device is powered using 5 V via the 5 V pin or the USB power, the power consumption is much higher, 81.04 mW and 65.13 mW respectively. The lowest current we were able to measure on the Wireless Stick was 2.27 mA; however, the expected current, if we take only the microprocessor ESP32, on which this microcontroller is based, in the hibernation mode, is 2.5 µA [36].

Table 1. Power consumption based on Vdd input pin [50].

State	Voltage	Current	Power
Using micro USB connector			
Wireless Stick ON	5.01 V	51 mA	255.51 mW
Wireless Stick low power	5.01 V	13 mA	65.13 mW
Using 5 V pin			
Wireless Stick ON	7.01 V	44.15 mA	309.49 mW
Wireless Stick low power	7.09 V	11.43 mA	81.04 mW
Power OFF by TPL5111	7.11 V	37 µA	0.26 mW
Using 3.3 V pin			
Wireless Stick ON	4.91 V	32.95 mA	161.78 mW
Wireless Stick low power	5.00 V	2.27 mA	11.35 mW
Power OFF by TPL5111	5.00 V	26 µA	0.13 mW

Let C is the battery capacity, I_{ON} is the average current used during the active state of the microcontroller, and I_{ULP} is the current consumed in sleep state, and x is the number of minutes in a day that the device is active. The battery lifetime in days T is expressed in Equation (3). We add the 24 h in the denominator to obtain a result in days. As the collection is infrequent and the data packet transmitted via LoRa is small, we expect most applications to have a very low duty cycle of under ten minutes per day.

$$T = \frac{(C)\text{mA h}}{24\,\text{h} \cdot (I_{ON}\frac{x}{1440} + I_{ULP}\frac{1440-x}{1440})\text{mA}} \tag{3}$$

If we take for example a 2000 mA h battery, and we replace the measured values in Equation (3), the resulting is shown in Equation (4). We can then plot this result as shown in Figure 8, where we draw both the ratio for battery life extension using TPL5111 and the built-in ULP state of the microcontroller.

$$T_{TPL5111} = \frac{2000\,\text{mA h}}{24\,\text{h} \cdot (I_{ON}\frac{x}{1440} + 0.026\frac{1440-x}{1440})\text{mA}} \tag{4}$$

From Figure 8, we notice that sensors that operate for 10 min per day can last one year on a charge of 2000 mA h battery when using an external ULP timer. While this is the best-case scenario for this microcontroller, if we account for radio communication and other energy-intensive tasks, the energy consumption will increase.

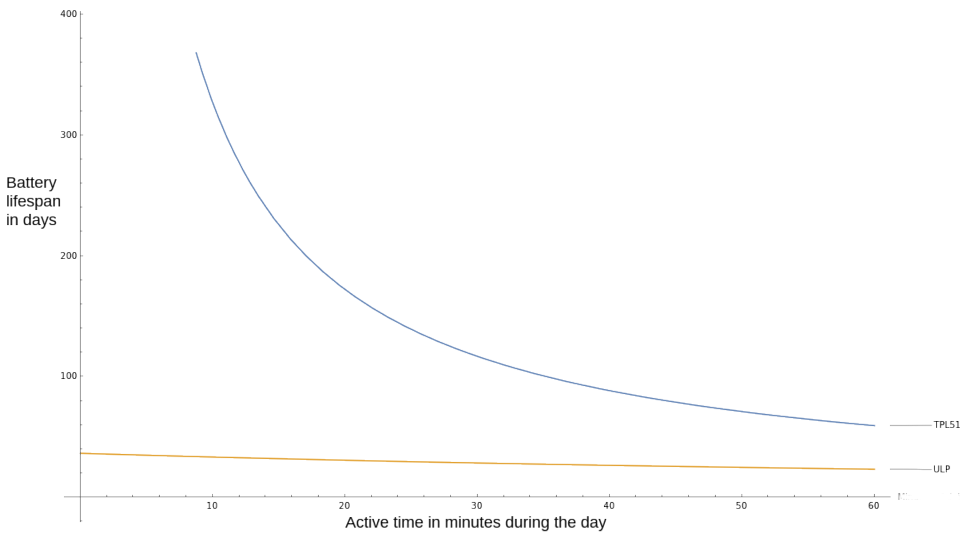

Figure 8. 2000 mAh battery lifetime when using TPL5111 and ULP in sleep mode, based on node active period.

In Figure 9 we also include the variable of average current during the active period from the minimal value od 33 mA to 100 mA graphed on the y-axes, while the z-axes indicate the number of days the battery charge is expected to last. The top chart in orange indicates the battery lifespan when the TPL5111 timer is used, while the bottom chart in blue indicates the usage of the onboard sleep state. The maximum shown in the plot is 200 days, and the area in gray indicates a lifespan of at least 200 days. Thus, we see that the ratio drastically increases when the active state is short and energy-efficient. For sensors that require a longer active state, the energy efficiency should further be improved by using microcontrollers capable of using the multiple ESP32 power modes [36].

Figure 9. 2000 mAh battery lifetime depending on active time and active average current I_{ON}.

5. Remote and Environment Triggering

The low power constraints of the architecture result in information pulling as means for the battery-powered devices to communicate in the network. This is sufficient to complete some goals, such as scheduled communication and sending data when needed. However, push notifications are necessary for specific situations, such as when a command is sent from the care providers. To allow for push notifications, we propose utilizing wake-up signals to trigger the devices to exit the sleep state and prepare to receive network communication.

In an ideal case, a sensor IoT module will not consume any energy until the act of measurement. When measuring parameters on time intervals, this can be accomplished by ULP timers. However, when monitoring for an event that might happen at any time, we either have to conduct measurement the entire time or construct a device that will wake the node upon such event occurs.

A care receiver might want to obtain sensor information at a specific time. For example, they might want to check if the person is in bed, if there is electricity in the house, or if the medicine disposal device is empty. A remote trigger mechanism is needed to send a wake-up signal to those sensors that are identified as needing these ad-hoc probes. Such a signal must be routed through the communication gateway for the system. The standby energy usage must be low enough not to affect the devices' expected battery life significantly.

When utilizing the external switch to cut the power supply to the microcontroller, we need a way to send a wake-up signal to start the microcontroller. Fortunately, the ULP timer can receive interruptions. A wake-up signal can be used to trigger this interrupt. To "wake up" the TPPL5111, the DELAY/M_DRV pin should be set to high, which can be accomplished by a short connection to V_{DD} pin.

In this paper, we consider the following types of wake up signals:

- Radio frequency (RF) signal;
- Light signal;
- Sound signal;
- Mechanical signal.

5.1. RF Wake-Up

The primary mode for data communication in LoRaWAN is to send data while avoiding collision and then pulling from the gateway. While it is possible to set up LoRaWAN always to receive packets from the gateway, such a setup would have energy consumption implications. Furthermore, it would prevent the deep sleep states we want to achieve.

Instead, we can implement a low standby energy radio receiver as an interrupt for waking up the microcontroller and activating LoRaWAN to receive the intended packet.

Developments in CMOS power consumption have led to the birth of a new design paradigm to reduce power consumption and, in combination with energy harvesting, reach the goal of the perpetual operation [51]. This energy-saving mechanism is known as the wake-up radio (WuRx). WuRx is a very low-power secondary radio that allows the main radio to remain powered off. As soon as some information should be transmitted, the WuRx receives a wake-up signal from the device initiating the communication and then decides to switch on the main radio receiver [52]. As a result, WuRx consumes power orders of magnitude lower than the radio hardware utilized by the wireless sensor [28]. A comprehensive research review of the progress in WuRx, both for hardware and software aspects, is presented in [51].

On power management, three techniques are used: always-ON, duty cycling the WuR, or energy harvesting [51]. As the name implies, the always-ON is in a perpetual listening state, and then the wake-up signal can be detected at any time, thus minimizing latency. In contrast, the duty cycle mode periodically activates the radio receiver, requiring the wake-up signal to be at least active for the receiver's entire power cycle duration. When the communication is sporadic, this method is inefficient for energy consumption and latency, and it cannot be used for critical applications that require high-reliability [52]. The low duty cycle approach also suffers from network latency and the need for complex protocols to achieve synchronization while power is wasted during periods of no transmission [53]. To reach the ideal case of zero DC power consumption in standby mode, the passive wake-up receivers have been proposed [54]. Passive wake-up radios are those which are using the wake-up signal itself as the energy source [52]. They are also known as energy harvesting receivers because the wake-up signal is also powering the receiver, usually by charging a capacitor sufficient time to react to the signal. Prevention of false wake-ups and maximizing signal sensitivity while consuming minimal power are challenges with implementing an always online wake-up circuit [53].

The main challenge with WuRx is device selection. As the circuit of the WuRx must be simple to ensure low energy usage, we cannot implement a real addressing scheme. When the frequency of remote triggers is infrequent, the most straightforward approach is to accept that all devices with this capability will wake up and start listening to LoRa messages. Once they determine they are not the intended target, they power off. Some techniques implement identifier schemes using a frequency spectrum pattern [54]. In [54] an identification mechanism, using frequency fingerprints, is proposed and studied. This paper presents orthogonal frequency-division multiplexing (OFDM) transmitter which can generate an identifier without any additional hardware. When the identifier is sent as a frequency spectrum pattern, a simple analog circuit may be used for device selection [52].

A WuRx has direct implications in our first user story. A WuRx can be used to activate an otherwise dormant GPS device with LoRa communication.

5.2. Light Wake-Up Signal

Light can be used as a wake-up signal to detect a change in the environment or as a type of remote control device to device. However, the latter has the line of sight limitation and can be used only by IoT nodes in the same room. Due to this limitation and lack of clear advantages over RF wake-up approaches such as Bluetooth, we do not consider this approach. On the other hand, sensing the light in the environment can indicate events that the IoT device should monitor. An example of such an event is turning on the light in the bedroom. Here, the challenge is to ensure that the wake-up signal is not generated during daylight. One solution is to limit the incoming light's direction towards the light fixture and away from the windows. There are several light sensor types: photo-emissive cells, photo-conductive cells, photovoltaic cells, and photo-junction devices.

5.3. Sound Wake-Up

Sound wake-up detector relies on detecting sound waves and can be based on frequency detection [55]. We consider two scenarios for sound wake-up: trigger from the person or the environment and device to device trigger.

The first scenario is helpful for the user story in Section 2.3. A sound wake-up can be used to react to environmental changes. Loud noise can indicate an accident so that a sound amplitude trigger can wake up a specific sensor. In the first scenario, a patient could use voice to activate an IoT device to control the environment or provide feedback to the care providers, including calling for help. The suitable candidate for this is the piezoelectric device as described in [56]. It will only activate upon reaching the sound threshold and then process the sound. This microphone has sleep mode with a power consumption of only 6 μW. While the wake-up signal is lost after the wake-up circuit is activated [55], the sound generated during an accident is one of the most valuable pieces of information. Losing this sound limits the system's ability to identify the event. However, the device described in [56] can go from sleep mode to full power in 200 μs, thus allowing fast reaction time to record and process sound, including a call for help.

In the second scenario, a sound beyond adult people's hearing abilities, an ultrasound, can be used for the wake-up signal between IoT devices or between a healthcare gateway and the IoT devices. In this application, the devices do not need a line of sight. Instead, they require proximity for the sound signal to travel from the source and be detected by the target device. However, the solution presented in [55], which meets the power requirements, is too complex and costly to be implemented in the simple sensor modules.

5.4. Mechanical Wake-Up

A mechanical wake-up circuit is the most straightforward way to trigger a wake-up. The mechanical sensors can detect vibration, movement, tilt, bending, pressure, skin contact. Most of these sensors consume zero power when on stand-by since their mechanism is usually contact that closes an open circuit. For example, a pressure sensor placed under the mattress, a vibration sensor placed on the bed, or a modified push-down button could trigger the bed movement sensor. Similar sensors can be placed on doorknobs, door frames, or floor mats to detect when a person is moving in and out of a room or the house, which will indicate when the IoT nodes should enter or wake up from deep sleep.

We will briefly describe several of these mechanical switches.

- Reed switch has two contacts that are very close to each other but normally separated. In the presence of a magnet, they will touch and close the circuit.
- Tilt switch uses a metal ball or a drop of mercury that, when tilted, drops toward two contact leads and makes a closed circuit between them.
- Vibration sensor has a sturdy metal wire in the middle surrounded by an elastic metal spring. The spring does not touch the wire even when titled but will touch if there is a vibration.
- Bi-metal thermostat detects temperature changes. Depending on the model, it makes contact closing the circuit for temperatures above or below the set value.
- Pressure switch/button creates contact on pressure.

The main challenge with this kind of sensor is a frequent wake-up signal. For example, a vibration or pressure sensor can be placed in the person's shoes to activate when they are wearing them. However, this would mean a wake-up signal is sent with each step. The workaround is to have a secondary ultra low power timer (i.e., TPL5111) that would be placed before the mechanical switch, as shown in Figure 10.

Figure 10. Mechanical wake-up with delay circuit.

6. Discussion

The increased life-expectancy of people due to improved living standards would burden medical systems. Connected healthcare provides an opportunity for affordable and sustainable medical services. The current research takes advantage of well-established network infrastructure and thus offloads the communication component to prior investments. Enhanced living environments (ELE) and smart homes could establish a common framework for providing services and interaction with inhabitants of the house [57]. However, a healthcare system for the rural population would not benefit or would have limited benefits from such infrastructures. For this reason, a new architecture focused on the constraints associated with rural environments is needed.

We review several diverse scenarios that present a starting point to identify challenges the system would face to address this issue. These scenarios should be analyzed in the context of a rural environment. We can illustrate this point for the lost person scenario. In urban areas, such cases would be reported to emergency services that have resources that, when mobilized, could extend the search in a large geographical area. Eyewitnesses and social media could be used to locate the person. Technology assistance is also available, including phone tracking of internet-connected devices, cell tower-based locations. Bluetooth tags attached to clothes or personal items could also be used [58]. Each of these options is very limited or nonexistent in rural areas. Emergency services are usually located at a greater distance and have fewer staff and resources. There is less chance of finding eyewitnesses, and using technology to locate a person is very limited. The case of environmental and safety monitoring could be considered a part of the smart home system. Designing or upgrading houses for smart homes is more difficult for rural places, considering that some solutions require cloud connection, and the investment could be prohibitively expensive.

The main challenges in implementing the connected healthcare system in rural areas arise from the high likelihood of lack of connectivity infrastructure, including mobile networks, and the need to make the system affordable. A viable system should be self-sufficient and assume the worst case, rather than the best case, from the point of view of established infrastructure. Thus, we assume no prior network exists for the system to take advantage of. We analyzed the existing network solutions, including extended-range networks, and we identified that the LPWAN network is the best fit. The main factor in determining this is to ensure the minimal cost for installing few IoT devices to address a specific need instead of requiring a full deployment for each household. In the extreme case, we would have a single IoT device deployed, in which case the device should have a communication link to the network without deploying additional network devices. In addition, all IoT devices are required to have a battery operation capability as, in some cases, external power might not be available or require additional installation.

Based on the previous comparison of LPWAN technologies [5], we are using LoRa communication with the LoRaWAN MAC layer for network communication. We propose a fog-based architecture emphasizing offloading data collection, pre-processing, and partial decision-making to the e-healthcare gateways. Due to the limited bandwidth of LoRa and the need for energy preservation, each node in the fog network should maximize longevity unless a priority event is suspected that requires the full performance of the system. Long-term data storage exists at each network layer to minimize bandwidth utilization while preserving valuable data. This data is extracted during servicing of the devices.

In addition to reducing network utilization, there are additional tactics that can be used for energy conservation. We found that the most commonly addressed approach is minimizing energy usage by tweaking the LoRa parameters. We identify and provide scenarios for other means to reduce energy usage, focusing on the device's smart duty cycle. While modern microcontrollers, such as the ESP-32, can have multiple sleep stages, nano-Ampere timers can be used to push this approach even further. The energy consumption of the sensors must also be minimized by a balanced approach of reducing the duty cycle of the sensors while still collecting the data when needed. Variable scanning resolution is used to ensure valuable data is collected and wasteful cycles are minimized.

The battery extension that we have achieved is in the range of tens of times, depending on the utilization profile of the microcontroller, for low utilization even up to 80 times longer battery life [50]. In [59], the authors have achieved 95.2% reduction, and they measured a sleep mode current of 33 nA. While we have achieved 99% reduction, this is due to the higher current that our chosen microcontroller draws during sleep. A similar decrease in inactive current by 90–95% was shown in [60]. In [61], the authors have achieved 40 times battery extension using an event-driven system for continuous and long-term operation of a wireless sensor to monitor civil infrastructure given a 1% event probability. While direct comparison cannot be measured due to the difference in the power profile of the IoT microcontroller and the implementation, our results are comparable to the ones published in the literature.

While the proposed architecture allows rural healthcare to be implemented, the constraints of low network bandwidth and the need to reduce the active time of the IoT nodes limit the capabilities of the system. For example, sensors that generate a large quantity of data cannot effectively be used in the proposed architecture. In addition, the proposed architecture is very sensitive to bugs in firmware and software that prevent the device from booting correctly or entering a low power state. Such bugs could drain the battery rendering the node unusable until it is serviced, decreasing the benefits of the proposed architecture.

We expect the most challenging aspect of the deployment of the proposed architecture to be the initial deployment, specially the communication hub that would require power supply and battery backup to ensure reliable operation.

7. Conclusions and Future Work

The rural population often lacks access to quality healthcare. This issue is not new, and often the urban areas have more staff and better equipped medical institutions. Connected healthcare is a paradigm that is promising to reduce healthcare costs and provide better access. However, research is often focused on taking advantage of the latest developments in communication networks, including 5G technologies. In contrast, the rural population is left behind on this promise for better, more affordable healthcare. We describe several user stories in order to illustrate the constraints that are imposed in low connectivity areas. We then design architecture that would work within the given constraints. The architecture considers the sparse distribution of houses in rural communities, the lack of infrastructure for smart homes, and the high cost of converting homes. Thus the IoT sensors are assumed to be battery-powered, and the service interval is infrequent. We proposed multiple techniques for energy conservation, and we conducted measurements showing that external ULP timers can be used to extend battery life in the order of tens of times, depending on the usage profile of the IoT node. While ULP deep sleep states can extend the battery life for years, the system's usability is evaluated by being responsive when needed. For this, we propose wake-up triggers for the microcontrollers and the sensors. Certain observed events could act as triggers either by generating an electrical charge or closing an open circuit, thus allowing for zero energy sensors. Sensors that detect mechanical changes such as pressure contacts detect and also trigger an event. Very low-power wake-up signals are used for resuming the operation of a microcontroller in a sleep state. These triggers include RF wake-up and light and sound wake signals.

In the future, we will create granular energy profiles of the microcontrollers and sensors for each operational stage. Then, using the architecture presented in this paper, we can design a specific usage profile that would minimize energy consumption for given functional expectations of the IoT nodes. Having this data, we can simulate the battery usage of the IoT nodes and develop battery specifications for each type of sensor device.

In addition, we will investigate how different ML algorithms and approaches perform in the proposed architecture, especially given the network constraints, and influence its main benefits.

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3.4. Artículo 4: Design and Development of a Heterogeneous Active Assisted Living Solution for Monitoring and Following-up with Chronic Heart Failure Patients in Spain

En el cuarto artículo se presenta una solución AAL basada en IoT que proporciona una plataforma de teleasistencia a pacientes del Servicio Murciano de Salud. Inicialmente centrado en pacientes con insuficiencia cardíaca de 55 años o más, el estudio también incluyó a los cuidadores formales e informales y a los profesionales sanitarios y plantea dos escenarios para ofrecer una solución sanitaria integral: Angel of Health y Care@Home.

La metodología comprendió la identificación y representación de los requisitos del usuario, que llevó a la definición de los escenarios de casos de uso del piloto y a los requisitos técnicos, el desarrollo del sistema, abordando las adaptaciones necesarias para el cumplimiento de todos los requisitos, el desarrollo e integración de las tecnologías y servicios en la plataforma, y la fase de prevalidación, organizada en pruebas a pequeña escala con un número limitado de participantes que representan a los diferentes usuarios. Esta evaluación inicial en cuanto a la funcionalidad y utilidad de las tecnologías y plataformas comprende el primer paso obligatorio antes del despliegue de un piloto a gran escala que llevará a mejorar la innovación del sistema desde su actual nivel de preparación tecnológica (TRL) (6) hasta el mercado (9).

Los resultados dieron lugar a un conjunto de objetivos de calidad, funcionales y emocionales, que asentaron las bases para definir los tres goal models del piloto murciano. También ayudaron a identificar, clarificar y organizar los requisitos del sistema mediante la definición de siete casos de uso y los requisitos técnicos asociados, que llevaron a la selección de las tecnologías a implementar para cubrir los dos escenarios, los modelos de objetivos y los casos de uso con las aplicaciones y las plataformas requeridas. Los desarrolladores de dichas aplicaciones y plataformas realizaron las adaptaciones pertinentes para el cumplimiento de todas las necesidades de los usuarios y su integración en la plataforma siguiendo la arquitectura acordada.

Basada en la experiencia de iniciativas similares [37-42], la arquitectura de referencia se basó en el enfoque común de capas funcionales horizontales, que refleja, tanto los elementos que las componen, como las implementaciones IoT en varios dominios, y se amplía con dos dimensiones adicionales: las funciones transversales y las propiedades.

Para la prevalidación, el trabajo muestra el protocolo seguido por los seis pilotos del proyecto para la selección de participantes, su pseudionimización, el desarrollo de las sesiones de testeo, los indicadores clave y sus valores objetivos para valorar las tecnologías y plataformas, y la implementación de correcciones y mejoras en el sistema.

Los resultados de las sesiones de testeo dieron valores para los indicadores clave por encima de todos los valores objetivo para todas las tecnologías y plataformas, cumpliendo los requisitos de la primera fase de pruebas de prevalidación. Mostrando una satisfacción general del sistema por parte de los usuarios en cuanto a usabilidad y funcionalidad. Además, sólo se notificaron dos errores menores que fueron resueltos durante la implementación de correcciones y mejoras en el sistema.

El desarrollo del presente trabajo ha permitido diseñar una solución AAL con un enfoque centrado en el usuario, pero también con la participación de los cuidadores formales e informales y profesionales de la salud, sirviendo de guía útil para proporcionar a la comunidad de I+D inspiración para el desarrollo y despliegue de soluciones AAL basadas en tecnologías IoT heterogéneas, o enfoques similares, para soluciones sanitarias inteligentes en instituciones sanitarias reales.

Durante el desarrollo del presente trabajo, el doctorando actuó coordinando las distintas tareas, además de colaborar, junto con el personal del Servicio Murciano de Salud en la organización de las distintas actividades que llevaron a la definición y priorización de los requisitos de usuario, así como en la organización de las distintas tareas que comprendían la fase de prevalidación.

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Francisco José Melero-Muñoz, María Victoria Bueno-Delgado, Ramón Martínez-Carreras, Rafael Maestre-Ferriz, Miguel Ángel Beteta-Medina, Tomás Puebla-Martínez, Andrés Lorenzo Bleda-Tomás, Gorka Sánchez-Nanclares, Ricardo Pérez-de-Zabala and Mónica Álvarez-Leon

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Design and Development of a Heterogeneous Active Assisted Living Solution for Monitoring and Following Up with Chronic Heart Failure Patients in Spain

Francisco José Melero-Muñoz [1,2,*], María Victoria Bueno-Delgado [2,3], Ramón Martínez-Carreras [2], Rafael Maestre-Ferriz [1], Miguel Ángel Beteta-Medina [1], Tomás Puebla-Martínez [1], Andrés Lorenzo Bleda-Tomás [1], Gorka Sánchez-Nanclares [4], Ricardo Pérez-de-Zabala [5] and Mónica Álvarez-Leon [6]

1 Centro Tecnológico del Mueble y la Madera de Murcia, C/Perales s/n, 30510 Yecla, Spain
2 Department of Information and Communication Technologies, Universidad Politécnica de Cartagena, Plaza Hospital 1, 30202 Cartagena, Spain
3 E-Lighthouse Network Solutions S.L, C/Angel s/n, 30202 Cartagena, Spain
4 Servicio Murciano de Salud, Edif. Habitamia 5º, 30100 Murcia, Spain
5 MIWEnergia, Parque Científico de Murcia, 30100 Espinardo, Spain
6 Minsait–Av. Bruselas 35, 28108 Alcobendas, Spain
* Correspondence: fj.melero@cetem.es

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Abstract: Heart failure is the most common disease among elderly people, and the risk increases with age. The use of smart Internet of Things (IoT) systems for monitoring patients with chronic heart failure (CHF) in a non-intrusive manner can result in better control of the disease, improving proactive healthcare through real-time and historical patient's data, promoting self-care in patients, reducing unneeded interaction between patients and doctors, reducing the number of hospitalizations and saving healthcare costs. This work presents an active assisted living (AAL) solution based on the IoT to provide a tele-assistance platform for CHF patients from the public health service of the region of Murcia in Spain, with formal and informal caregivers and health professionals also as key actors. In this article, we have detailed the methodology, results, and conclusions of the prevalidation phase for the set of IoT technologies to be integrated in the AAL platform, the first mandatory step before the deployment of a large-scale pilot that will lead to improving the innovation of the system from its current technology readiness level to the market. The work presented, in the framework of the H2020 Pharaon project, aims to serve as inspiration to the R&D community for the design, development, and deployment of AAL solutions based on heterogeneous IoT technologies, or similar approaches, for smart healthcare solutions in real healthcare institutions.

Keywords: AAL; IoT; healthcare; prevalidation; deployment; chronic heart failure; large-scale pilot; H2020

1. Introduction

In a rapidly ageing European society, there is a growing need for implementing information and communication technologies (ICT) and digital tools that improve the quality of life, independence, and overall health of older adults. In this context, the concept of ambient intelligence (AmI) appears to achieve a future where technology surrounds the users and helps them in their daily lives [1]. AmI leads to cutting-edge platforms referred to as active assisted living platforms [2,3]. The Internet of Things (IoT) [4] has also emerged as a set of technologies, systems, and design principles [5,6] that enable automation in many fields, such as remote and smart healthcare systems, playing an important role in AAL platforms and healthcare. A typical IoT environment consists of communication interfaces, sensors, advanced algorithms, and cloud interfaces [7]. Sensors are responsible for collecting data from various devices. Additionally, different communication technologies (wired and/or wireless), such as wireless sensor networks (WSN), provide network and communication infrastructure [8], while advanced algorithms are used to analyze and process data [9]. Numerous client/server requests can be exchanged in the cloud environment and allow the users to have access to various types of services simultaneously [10,11]. Due to cloud computing challenges and high requisites of emerging 5G, such as latency, reliability, resource constraints, etc. Fog computing is used to overcome these limitations and run the same applications anywhere close to users with real-time analysis and efficient decision-making features [12,13].

Considerable effort is being made in the R&D community to integrate IoT technologies, communications [14], databases, and computing [15], and to develop standardized and integrated AAL platforms [16], but the diversity of these types of systems has created a very fragmented market and a lack of standardized architectures and protocols [17].

In the healthcare industry, sanitary systems are being revolutionized by the IoT paradigm [18]. This plays an important role in telemonitoring in hospitals, especially at homes for elderly people with chronic diseases [19]. By using this technology, healthcare systems can experience major effects such as a reduction in response time to detect anomalies, high-quality care, low hospitalization costs, and high life expectancy [18].

In the specific case of heart failure (HF), the most common disease in elderly people and one that increases in prevalence with age [20], the use of an IoT system for monitoring patients with chronic heart failure (CHF) in a non-intrusive manner can result in better control of the disease, improving the proactive healthcare and reducing unneeded interaction between patients and doctors, thereby reducing the number of hospitalizations and saving healthcare costs.

HF is a leading cause of hospitalization, representing 1–2% of all hospital admissions [21,22]. In Spain, the prevalence of HF is around 5% (higher than in other EU countries and USA); the rate rises with age to 8% between the ages of 65 and 74, and to 16% in persons aged 75 years and over [23]. These rates mean enormous health care resources are required, e.g., in Spain, during the 2015–2019 period, costs of HF patients were EUR 15,373 per patient, with HF hospitalizations being the most important determinant (51.0%). Medication costs represented only a small proportion of total costs [24]. The latest data published by Eurostat revealed that in 2018, HF caused 19,142 deaths in Spain, constituting 4.5% of all deaths, 3.4% in men and 5.6% in women [25]. Within this frame of reference, cardiologists and family doctors believe that the key to a better control of patients with CHF is creating a proactive healthcare solution through a non-intrusive and integrated monitoring system that unifies patients' medical history and makes it available to all relevant healthcare professionals. This will improve the safety and efficiency of healthcare by increasing the availability of patients' real-time information. In addition, the health and care community are convinced that it is crucial to promote self-care in patients by providing them and their caregivers with health education and training and other social and health resources.

This work presents an AAL solution based on IoT to provide a tele-assistance platform for CHF patients from the public health service of the region of Murcia in Spain. Initially focused on CHF patients aged 55 and over, the study also included formal and informal caregivers and healthcare professionals. For the three user groups, two scenarios are considered to provide a comprehensive healthcare solution:

- Angel of Health, aiming at improving health and care services and follow-up for CHF patients and involving them in the health and care process from the data perspective;
- Care@Home, aiming at reducing the dependency of CHF patients and to detect emergency situations early.

Figure 1 summarizes the goals, roles and description of the two scenarios considered.

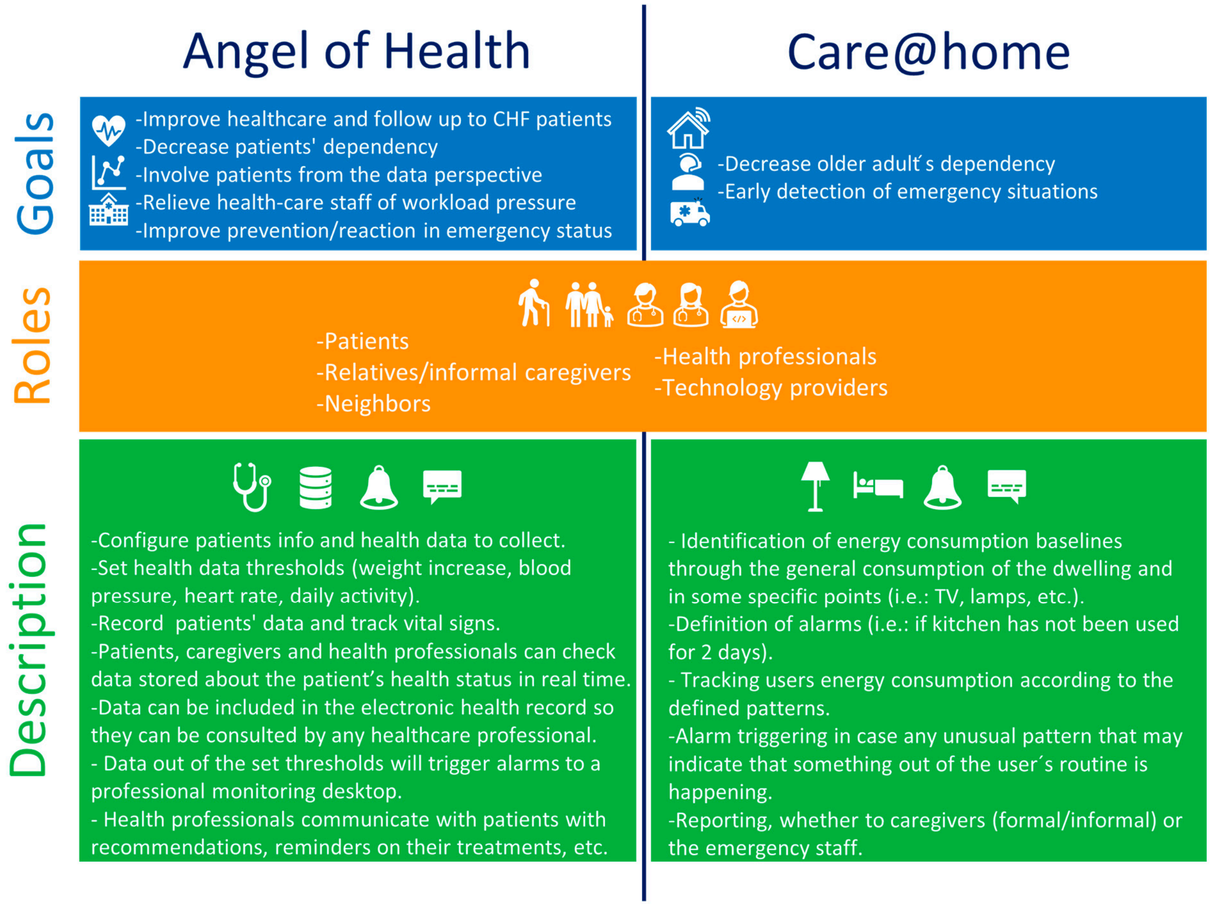

Figure 1. Scenarios of the Pharaon Murcia pilot.

This work is part of the overall research in progress regarding the H2020 Pharaon Project (Pilots for Healthy and Active Ageing) [26], which aims at providing a smart and active lifestyle for Europe's ageing population by creating a set of integrated and highly customizable interoperable open platforms with advanced services, devices, and tools in AAL, including IoT, artificial intelligence, robotics, cloud computing, smart wearables, big data, and intelligent analytics. Built upon mature existing state-of-the-art open platforms and technologies/tools, a user-centric approach is being followed for the deployment and the two-stages validation (prevalidation and large-scale pilots) in six different pilot sites: Murcia and Andalusia (Spain), Portugal, the Netherlands, Slovenia, and Italy.

The Pharaon ecosystem integrates a big set of services and functionalities which requires the involvement of a huge number of resources in order to achieve the necessary validation and trials in real-world scenarios. The validation within Pharaon is being performed through the six large-scale pilots proposed with different types of users, requirements, and chosen functionalities. Pharaon aims to carry out the unprecedented validation of different platforms simultaneously, each supporting a wide variety of advanced and customized assistive services and tools in six different large-scale pilots with the necessary resources. For example, the Murcia pilot will validate heart failure and non-intrusive home monitoring with alarm triggering, whereas the pilot in The Netherlands focuses on community building and providing tailored advice towards user empowerment in terms of health literacy.

This approach allows a sufficiently high number of users and healthcare professionals to use the system at each pilot site for a long-term period, and an unprecedented number of use cases, services, and technologies will be tested across all pilots.

In this work, the authors present the methodology, results, and conclusions of the prevalidation phase for the set of IoT solutions and their respective AAL platforms, which will introduce the tele-assistance platform for CHF patients from the public health service of the region of Murcia. The prevalidation stage includes the participation of all actors involved: patients, formal and informal caregivers, and healthcare professionals. Their early feedback regarding the functionality and usefulness of the tested technologies and platforms is the first mandatory step before the deployment of a large-scale pilot that will lead to improving the innovation of the system from its current technology readiness level (TRL) (6) to the market (9). The goal is to provide the R&D community with inspiration in the design and deployment of AAL solutions based on heterogeneous IoT technologies, or similar approaches, for smart healthcare solutions in real healthcare institutions.

The paper is organized as follows: Section 2 describes in detail the Pharaon Murcia pilot and the workplan followed for implementing the smart healthcare solution. Section 3 explains the engineering of user requirement tasks that were performed to identify the scenarios that define the use cases of the AAL healthcare solution and their requisites. Section 4 looks in depth at the system architecture that must perform the use cases and technical features of the hardware/software needed. Section 5 describes the roadmap implemented for the testing phase. Section 6 presents and discusses the results of the testing. Section 7 shows the conclusions and the future work recommendations. Finally, Section 8 presents a short discussion about the research limitations.

2. Pharaon Murcia Pilot: Overview and Workplan for the Healthcare Solution Deployment

The reduction in birth rate and the increase in life expectancy will, in the long term, lead to a progressive ageing of the population in the region of Murcia, which will manifest itself in an uninterrupted decline in the working-age population and a continued increase in the proportion of the population over 65 years of age [27]. One of the priorities of the research and innovation strategy for smart specialization in the region of Murcia [28] is related to health, biomedicine, and welfare, addressing, among other fields, housing care and ITC-supported social services, specialized care, access to services, and remote assistance.

The services and use cases to be deployed under Pharaon in the region of Murcia are aimed at building the foundations of a new telecare line in the region that will transcend the current model of health and care services that rely on the patients to notice when they need help. This new telecare model will allow patients to stay in their preferred environment and provide a more intense, effective, proactive, and less intrusive care and observation service. To do that, this work has been organized into a sequence of main steps, summarized in Figure 2. The first step consists of the elicitation and representation of the user requirements. This leads to the definition of the use case scenarios of the pilot and detailed technical requirements referring to the technologies to be used.

Figure 2. Work sequence within the Pharaon Murcia pilot.

The second step, informed by the results of step 1, has two main goals: to address the adaptations required for the compliance of all requirements, and the development and integration of the technologies and services in the platform.

Finally, step 3 consists of the testing phase, organized into two stages: (1) small-scale testing with a limited number of participants representing the different target users of the Murcia–Pharaon system. They provide early feedback regarding the functionality and usefulness of the system, enabling rapid and iterative improvements to address shortcomings discovered by actual system users while its implications are still manageable. The second stage is (2) running the large-scale pilot, which involves all the pilot users in real-world scenarios for an extended length of time.

3. Engineering of User Requirements in the Pharaon Murcia Pilot

In [29], the authors summarized the co-design and user requirement engineering work carried out in the pilot study of the region of Murcia. During the co-design phase, the methodology for the co-design and representation of user requirements was defined as goal models with a set of components: functional goals, quality goals, and emotional goals, following work in [30]. Corresponding use case scenarios and user stories were also defined.

The methodology entailed several up-to-date co-design methods for user requirements' elicitation. The ISO 9241-210 standard on ergonomics of human–system interaction [31] was followed. The original plan for eliciting and representing user requirements was modified due to the COVID-19 outbreak, following three phases:

The first phase is initial desk research on co-design workshops, data, and results from previous initiatives in which the public health service provider of the region of Murcia participated: ProEmpower [32], ReadiForHealth [33], INC3A [34], and CARPRIMUR [35]. They helped to identify an initial set of requirements from the stakeholder's perspective in the form of functional, quality, and emotional goals.

The second phase is the design and launch of a questionnaire addressing target users of the Pharaon system that helped to define a map of barriers and opportunities in the region regarding the assistance of patients suffering from CHF. The goal was to enrich the results in the previous phase with the opinion of other representatives that were also target groups (older adults, informal caregivers, and health and care professionals). The participants were reached through an online questionnaire that was duly promoted at a regional level, and they participated in a set of virtual co-design sessions in different focus groups. In total, 250 responses (56% were patients, relatives, or caretakers, and 44% were health and care professionals) were gathered, and they helped to complete the initial goal framework.

Next was the virtual co-design phase, consisting of the arrangement of a virtual workshop and the creation of different focus groups where representatives from the different target users of the Pharaon system were involved: health and care providers, older adults, and informal caregivers. In these workshops, different questions were posed regarding the CHF, target users, use cases, scenarios, and technologies. The discussions helped to confirm the goals and requirements identified and new ones appeared.

The outcomes of the three phases resulted in the definitive set of quality, functional, and emotional goals, and this was the basis for defining the three goal models of the Pharaon Murcia Pilot (Figure 3):

- Become involved in the health and care process;
- Improve patient care;
- Detect emergency situations.

The results also helped in identifying, clarifying, and organizing the system requirements in the Murcia pilot through the definition of seven use cases and the associated technology requirements [29]:

- Become involved in the health and care process;
- Assess personal situations and risks;
- Strengthen knowledge of healthy lifestyles and behaviors;
- Improve patient care;
- Boost disease follow-up;
- Upgrade interventions;
- Detect emergency situations.

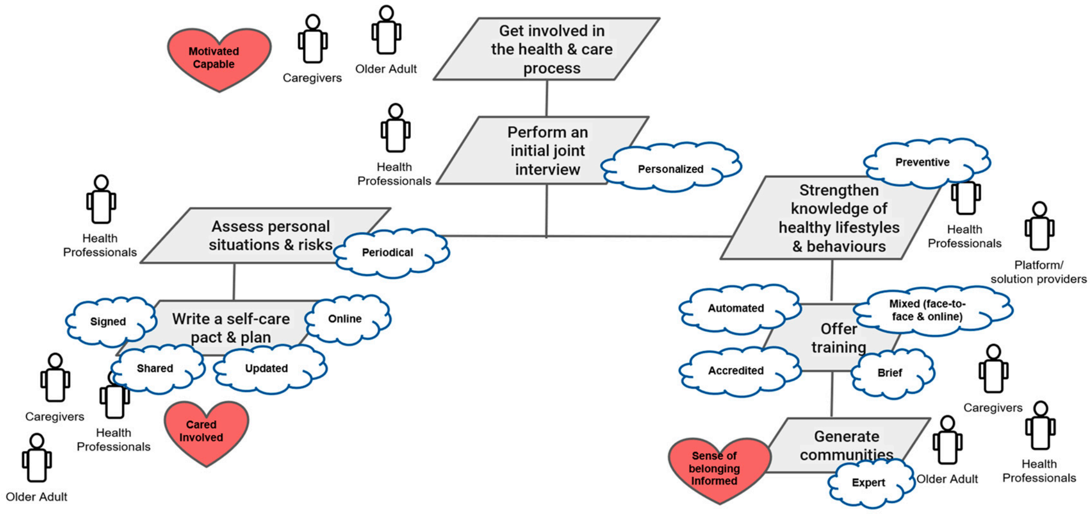

Figure 3. Representation of the Pharaon Murcia Pilot goal model "Get involved in the health and care process" [29].

4. Pharaon Murcia Pilot: Architecture and System Development

The technical requirements identified in the use cases found in step 1 of the workplan led to the selection of the technologies to be implemented (see Table 1) to cover the two scenarios, the goal models and the use cases with the software applications and platforms required (see Figures 4 and 5).

Table 1. Technologies of the Pharaon Murcia pilot.

Technology Name	Technology Classification	Description	Murcia Pilot Scenario	Hardware/Software Components	Technical Pre-Requirements
Amicare (Technical Research Centre of Furniture and Wood of the Region of Murcia)	Indoor non-intrusive tracking of daily habits with configurable triggering alarms on caregivers' smartphone	Non-invasive system that monitors older adults' daily habits and contributes to the peace of mind of relatives and caregivers thanks to the power of IoT. Out-of-sight textile, movement, and ambient sensors are safely connected through the cloud to any smartphone app with a preregistered user. The app can be configured and personalized by its user to trigger alarms if certain actions happen (or do not happen) within specified time windows, such as: "if not in bed at any time between 22:00–0:00", "if on the coach for more than 3 consecutive hours", "if away from bed for more than 45 consecutive minutes between 0:00 and 6:00".	Care@Home	Hardware components: -Textile sensor pad; -HW box including processor, wireless communications, on-board sensors (movement, humidity, luminosity, temperature), and textile sensor connectivity; -App for Android device (smartphone or tablet); -Web-based user interface for group of users (e.g., nursing homes).	Wi-Fi connection is required
uGRID (MIWenergía)	Energy Management Platform	The uGRID software aims to digitize energy consumption, providing the final consumer with more information about their demand of electrical energy. The purpose is to achieve the maximum possible energy efficiency and to control the electricity consumption by setting alerts and generating reports.	Care@Home	Hardware Components: -Dedicated database server; -Dedicated platform web server; -Power metering devices. Software Components: -Web platform based on PHP/Javascript; -MariaDB database (MySQL).	Wi-Fi connection is required

Table 1. *Cont.*

Technology Name	Technology Classification	Description	Murcia Pilot Scenario	Hardware/Software Components	Technical Pre-Requirements
Smartband Solution (based on Mi band 5 of Xiaomi) (Universidad Politécnica de Cartagena)	Wearable	Through a commercial smartband wirelessly connected to the patient's smartphone, the smartband solution allows recording, in a non-invasive way, real-time (and historical) data of patients regarding their heart rate and daily activity in a number of steps. The novelty of this solution is that it also provides the patient data to his/her caregiver and to his/her healthcare professional. Moreover, the healthcare professional can configure alarms if heart rate is lower or higher than a certain threshold.	Care@Home Angel of Health	Hardware Components: -Smartband; -Charger. Software Components: -App for Android devices (smartphone or tablet) to track user's heart rate and daily activity, reporting real-time and historical data to patients, caregivers, and healthcare professionals.	-Connection to a smartphone through Bluetooth is required -Internet connection is required for the smartphone
Onesait Healthcare Data (Indra Minsait)	Telemedicine Health Platform	It allows the treatment and follow-up of chronic patients at home. Through its two user interfaces, the system integrates the above technologies and offers tools for the bidirectional communication among healthcare professionals in the clinical setting and patients at home, so that patients are provided with personalized treatments according to their clinical conditions and progress. Onesait Healthcare currently allows the remote monitoring of patients suffering from specific chronic diseases, such as CHF, diabetes, or hypertension, while enabling mobility-ubiquity of users, personalization, and interoperability between systems (seamless systems).	Care@Home Angel of Health	Software Components: -MDM: includes managers for population information, catalogues and resources, along with a single sign on and an Audit and Log Server; -Onesait Healthcare Global Repository: health data storage standardized under HL7 FHIR® focused on interoperability; -Onesait Healthcare Professional Desktop: for professionals, citizens, managers, researchers, etc. that allows access to the different tools or applications; -Onesait Healthcare HomeCare: for health professionals to monitor patients; -Form Builder: tool for the configuration and parameterization of health questionnaires; -Alert: in charge of managing alarm triggers and its visualization by the operators to whom they are addressed; -MyHealth App: supports the functionalities to be used by Older Adults and their Caregivers.	-Access to smartphone is required for Patients and Caregivers. -Access to personal computer is required for health professional.

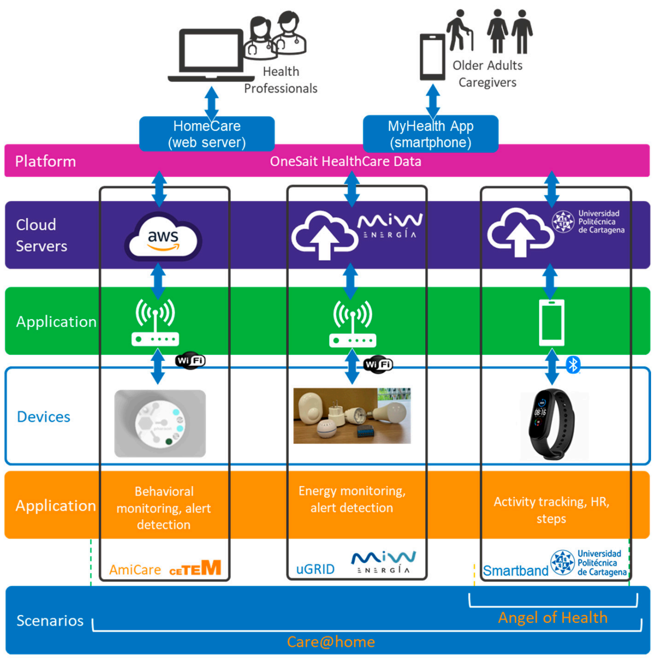

Figure 4. Overview of scenarios, technologies, and platform of the Pharaon Murcia pilot.

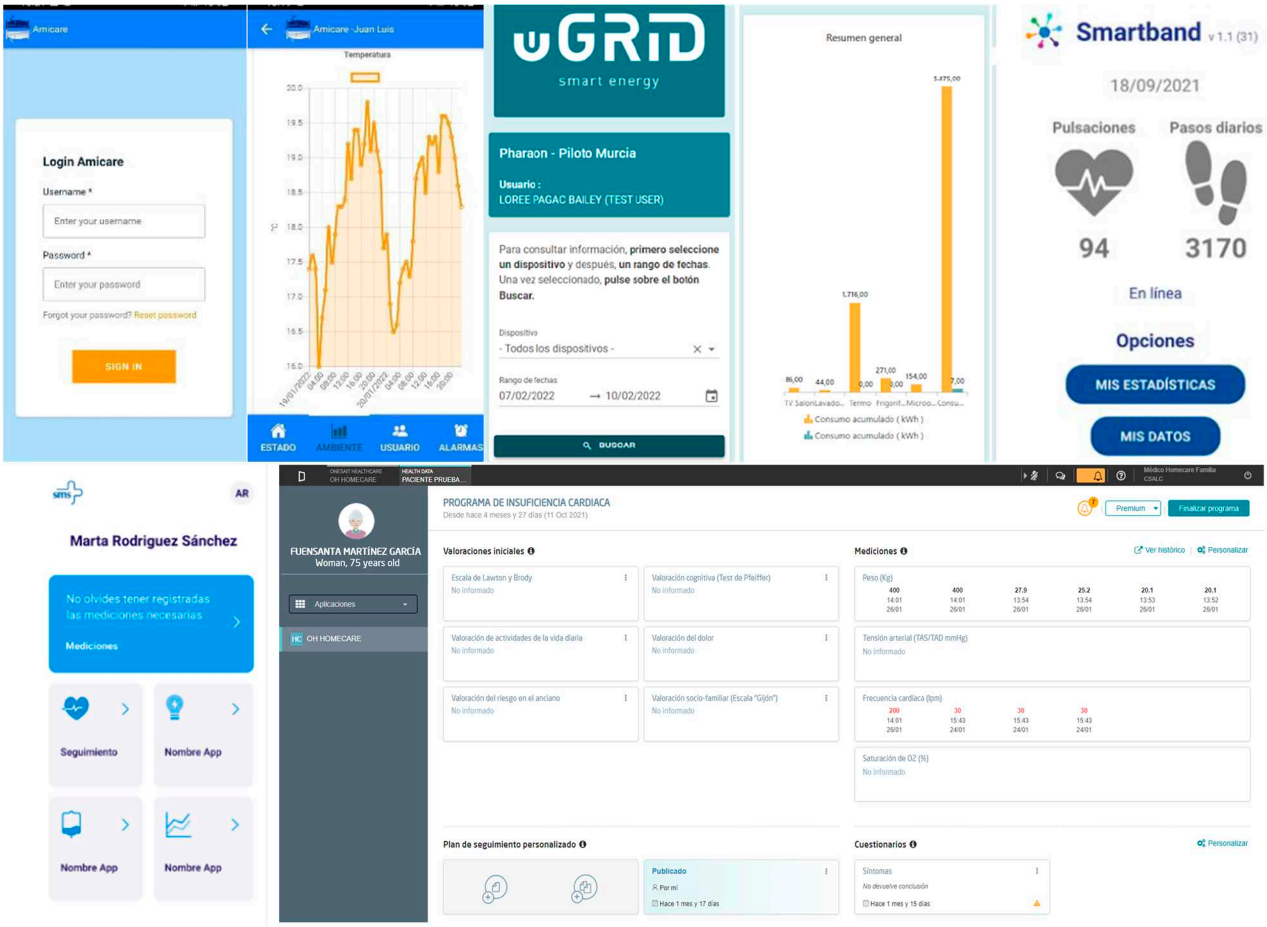

Figure 5. User interfaces of the technologies used in the Pharaon Murcia Pilot.

During step 2, technology providers worked on the adaptations of the technologies for the compliance of all users' needs identified in step 1 and for their integration into the Onesait Healthcare Data Platform, following the architecture agreed (see Figure 6).

For the six pilots, the architecture description was jointly carried out as a modelling exercise, having the defined use case scenarios and requirements for each pilot as the main input. Starting from the high-level abstraction and working towards adding more details, the explicit representation of the concept and the Pharaon ecosystem becomes clearer to everyone involved. It was decided that a technology-agnostic reference architecture model should be followed, focused on standard-based, non-AAL-specific, and somewhat recognized models, along with an adaptation of the 4 + 1 view model of architecture [36] with some additional views to ensure a high degree of coherence in the process of documenting the Pharaon architecture (see Figure 7).

Based on the experience and best practice of previous similar projects and initiatives [37–42], the Pharaon Reference Architecture is built on the common approach to "horizontal" functional layering that reflects the IoT implementations across various domains, and is expanded with two additional dimensions, cross-cutting functions, and properties.

Regarding the functional layers of the Murcia pilot architecture:

1. The device and network layer that represents the functional entities used for sensing, collecting data and actuating, and enabling network connectivity and transmission of data to other higher-level functional entities, includes Amicare, Miband 5, and the power metering devices that send energy consumption data to uGRID.
2. The platform layer, responsible for integration and interoperability of basic functional components for facilitating communication amongst them and exposing the functionality of these components and databases to provide basic data storage and

processing services. It comprises the storage and rule engines from Amicare, uGRID, and Smartband, and the Onesait Healthcare Data platform.

3. The service layer compiles all the services provided by Amicare, uGRID, and Smartband. It represents all functional components that support and ease application development, support mixture of different data streams, analytics and service components, and allow insights from data to be extracted and more complex data processing to be performed. Such services are executed in data centers (Smartband) or in cloud environments (Amicare and uGRID). They uniformly handle the underlying devices and networks, thus hiding the complexities of layers 1 and 2. Among these services, remote device management is included that can perform remote software upgrades, remote diagnostics or recovery, and dynamically reconfigure application processing such as setting event filters. Communication-related functions include publish/subscribe and message queue mechanisms. In general, data storage for anything from raw data to knowledge representations, and processing capabilities, such as data and event capture, filtering, and stream processing, are core services implemented by Amicare, uGrid, and Smartband.
4. The two user interfaces of the Onesait Healthcare data, the Homecare and MyHealth apps, along with the technologies' individual dashboard integrated in MyHealth app, are included in the Application Layer, responsible for representing data in rich visuals and/or interactive dashboards and providing direct functionality of the system from a user perspective. Besides visualization, it represents other functional components that are directly responsible for enabling application-specific visualization and user interaction (such as application-specific backend services).

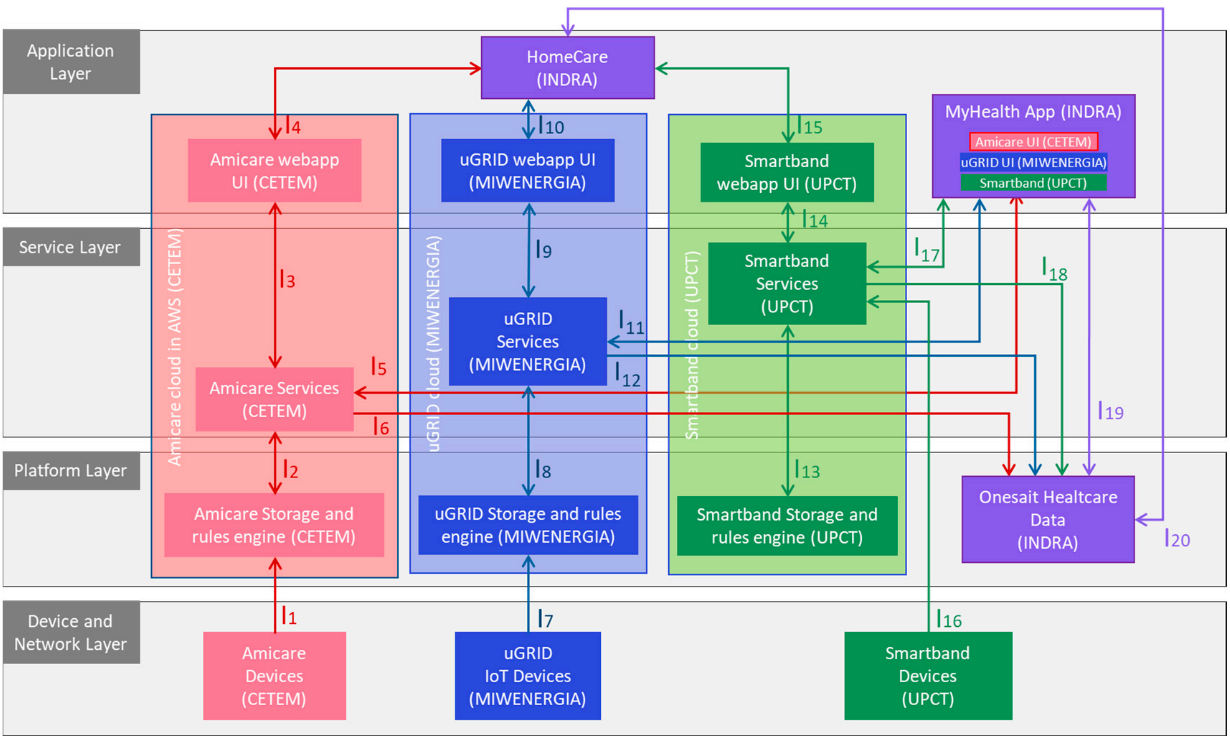

Figure 6. Murcia pilot high-level architecture.

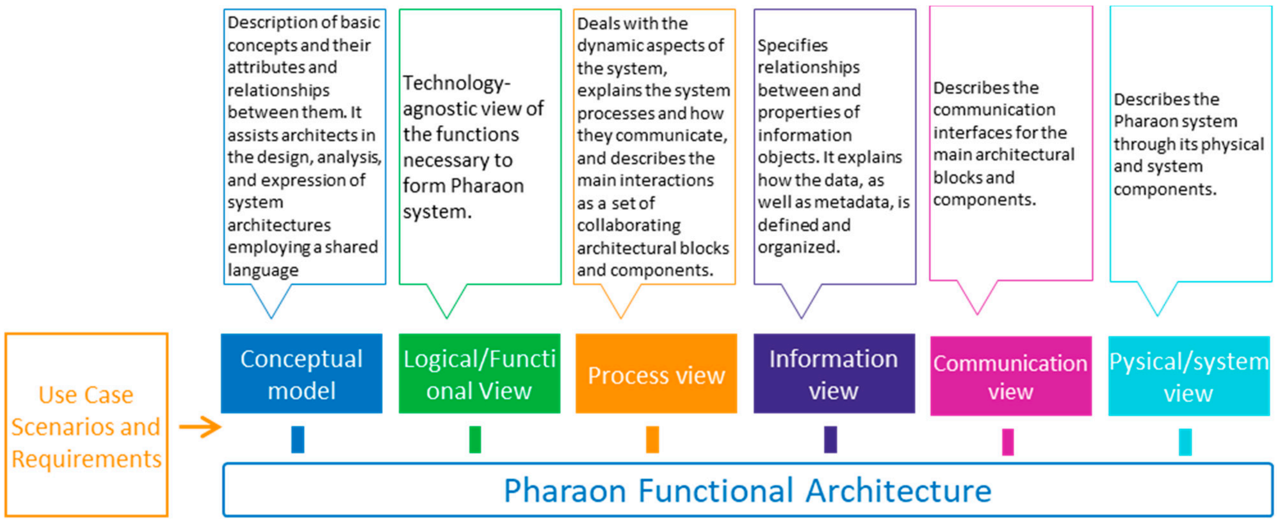

Figure 7. Pharaon architecture view model.

Figure 6 represents the architecture of the Murcia pilot at a high level, showing the elements of each of the horizontal functional layers and their cross-cutting functions, which address additional functionalities that are not linked to a single layer but whose provision requires spanning across several layers. This includes security, privacy, reliability, etc. Table 2 lists the technical description of each technology, including the interactions, technologies, protocols, and security implemented.

Table 2. Interactions between the elements of the Murcia pilot architecture and their technologies, protocols, and security.

	Interaction	Technologies and Protocols	Security
Amicare 1–6	I1	MQTT over Wi-Fi	Authentication
	I2	VNP	Authentication
	I3	REST API	TLS, AWS STS (Security Token Service)
	I4	HTTPS	JWT, SSL
	I5	REST API	TLS, AWS STS (Security Token Service)
	I6	REST API	Authentication in Rest services is through a JWT token signed with its private key
uGRID 7–12	I7	MQTT over Wi-Fi	Login
	I8	REST API	Uses SSL, API Key
	I9	REST API	Uses SSL, API Key
	I10	.NET Core (Blazor Server)	Uses SSL, Login
	I11	Ionic + Angular + Cordova	Uses SSL, Login
	I12	API REST/REST FHIR	Authentication in Rest services is through a JWT token signed with its private key
Smartband 13–18	I13	Local host socket	Authentication
	I14	HTTPS	Authentication (SSL)
	I15	HTTPS	JWT, SSL
	I16	Bluetooth	Authentication
	I17	HTTPS REST API	JWT, SSL
	I18	API REST/REST FHIR	Authentication in Rest services is through a JWT token signed with its private key
Onesait Healthcare Data 19–20	I19	API REST/REST FHIR	Oauth 2
	I20	API REST/REST FHIR	Oauth 2

5. Pharaon Murcia Pilot: Testing the Smart Healthcare Solution

A two-stage approach was defined for testing the Pharaon system with target users in all pilots:

1. The prevalidation stage, consisting of some initial real-world validation at a small scale, where a reduced number of participants representing the different target users (older adults, informal caregivers, and health professionals) test the technologies described above. The goal is to collect the opinion of the users regarding the use of these technologies in specific situations and to analyze the key performance indicators

(KPIs) focused on the users' level of autonomy, confidence, technology experience, usability, etc. These tests also help to detect bugs/problems/improvements and solve them before large-scale deployment.

2. The deployment of large-scale pilots with a significant number of target users testing the Pharaon system for a period of at least 12 months, where the impact is assessed at different levels according to a set of indicators agreed.

The present work includes the methods employed and results obtained during the prevalidation stage because, at the time of writing, the large-scale deployment had just started, and no significant data have been collected to evaluate the impact.

The six Pharaon pilots followed a common methodology described in a prevalidation protocol for all pilot sites to assess difficulties and willingness to use and for bug collection. For the Murcia pilot, this protocol comprised the following steps (see Figure 8):

- The initial approval of the study by the ethics authority where the prevalidation takes place. For the case of the Murcia pilot, the ethics committee of the Murcia Institute of Biomedical investigation, as the main ethics authority in the region in clinical research studies, issued a favorable opinion after the assessment of the proposed study, considering the relevance of its implementation, compliance with all basic principles in terms of ethics, and the suitability requirements of the protocol in relation to the research goals, along with the capacity of the researchers involved and the appropriateness of the available resources.
- The selection of the participants according to a set of inclusion and exclusion criteria determined by the nature and objectives of each pilot's requirements and the living conditions, digital skills, and health status of the volunteers (see Table 3).
- The definition of the key scenarios for users to perform and assess the technologies during the test sessions (see Table 4) and the definition of the key performance indicators (KPIs) (see Table 5).
- The pseudonymization of each participant and the compilation of socio-demographic data needed for correlation calculation under impact assessment.
- Technology set-up and configuration following a predefined protocol including all safety measures, explanations to users for each device that was installed, explanation and signature of the informed consent.
- The arrangement of test sessions where participants assessed a set of predefined scenarios and KPIs in two steps as well: 6 (1) where participants assessed the technologies individually, and 6 (2) where participants assessed the platform with the technologies integrated within it.
- The identification of bugs, their registration in a specific space created in Gitlab, and further improvements.

Table 3. Inclusion and exclusion criteria defined for users involved in the Pharaon Murcia pilot.

User Type	Inclusion Criteria	Exclusion Criteria
Older Adults	- CHF with any level of left ventricular ejection fraction (LVEF); - Frailty score preferably between 4 (vulnerable) and 6 (moderately frail) [1]; - Signed consent form; - Digital skills; - Availability of certain electronic devices and Wi-Fi Connection; - Digital skills, knowledge in e-health devices or higher knowledge in his/her pathologies.	- Planned heart transplantation, cardiac surgery, or left ventricular assisted device (LVAD) implant; - Chronic renal replacement therapy (haemodialysis, peritoneal dialysis, or transplant); - Evidence of active or suspected cancer or a history of malignancy in the last five years; - Inability or unwillingness to provide informed consent or to comply with study requirements; - Life expectancy below 1 year (due to another cause excluding HF) or a frailty scale of 7 and above; - Serious psychiatric illness; - Participation in another clinical trial.

Table 3. *Cont.*

User Type	Inclusion Criteria	Exclusion Criteria
Caregivers	- Older than 18 years old; - Digital skills; - Availability of electronic devices.	None
Health Professionals	- Digital skills; - Proactivity; - Motivation.	None

[1] According to the clinical frailty scale of the Canadian Study on Health and Ageing (CSHA) living at home [43].

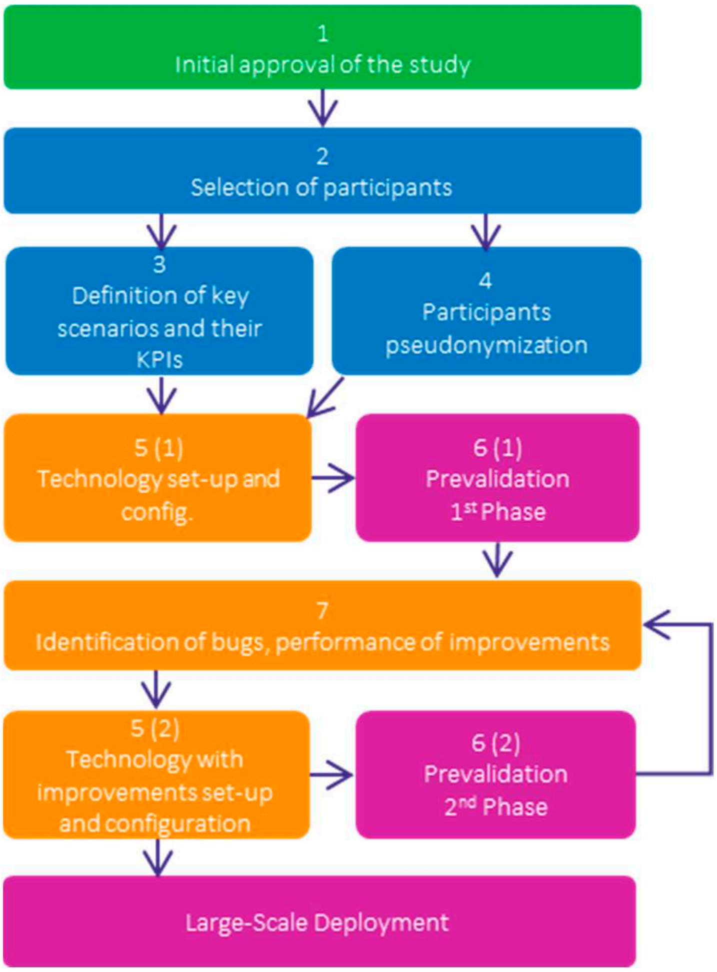

Figure 8. Prevalidation protocol followed by the six Pharaon pilots.

Table 4. Scenarios defined for each technology of the Pharaon Murcia pilot.

Technology	User Type	Scenario
Amicare	Patient	1. You want to find out the time you went to bed on a specific date according to Amicare. 2. You want to know the humidity in your home today.
	Caregiver	1. You want to check that Mrs. X's home temperature is between 19 °C and 25 °C. 2. You want to see if Mrs. X's movements in her flat were regular over the last 3 days. 3. You want to check that you will receive an alert when the alarm configuration is fulfilled.

Table 4. *Cont.*

Technology	User Type	Scenario
uGRID	Patient	1. You want to know your real-time electricity consumption. 2. You want to know if the kitchen has been used for cooking. 3. You want to know which electrical device consumes the most electricity in your home.
	Caregiver	1. You want to know which electrical device consumes the most electricity at the patient's home. 2. You want to know if Mrs. X has used the washing machine this week. 3. You want to see if you have received any alarms or events about changes in the power consumption patterns of Mrs. X.
Smartband	Patient	1. You want to see your heart rate. 2. You want to know how many steps you have taken today.
	Caregiver	1. You want to find Mr. X´s heart rate. 2. You want to know how many steps Mr. X has taken today.
Onesait Healthcare Data	Patient	1. You want to manually register a weight value/blood pressure. 2. You want to access your CHF program to fill in a health questionnaire. 3. You want to access your CHF follow-up program and consult your personal care plan.
	Caregiver	1. You want to manually register a weight/blood pressure value of Mrs. Z. 2. You want to access to the follow-up details of Mrs. Z. 3. You want to access Mrs. X´s CHF program to fill in a health questionnaire. 4. You want to access Mrs. X´s CHF follow-up program and consult her personal care plan.
	Health Professional	1. You want to access Mrs. X's CHF follow-up program. 2. You want to perform an initial clinical assessment of Mrs. X. 3. You want to create and publish the personal care plan (PCP) for Mrs. X through a template so she can consult it through the MyHealth App. 4. You want to customize what measures (vital signs) Mrs. X must include in the CHF follow-up. 5. You want to include a weight range between 50 and 62 kg, outside of which you will receive an alert for Mrs. X. 6. You want to customize what health questionnaires Mrs. X must fill in from MyHealth App and how she will have them available: only once, or any time to be filled whenever she wants. 7. You want to consult the most recent records of Mrs. X's heart rate and her heart rate history (Smartband). 8. You want to consult the history of personalized follow-up plans of Mrs. X (the details of the plan, which professional published it and when). 9. You want to know if Mrs. X has used the washing machine (or any other device that is being monitored) this week (MIW+). 10. You want to check that you will receive an alert when the alarm configuration is fulfilled (Amicare). 11. You want to check what patients have alerts from the list of patients of the CHF follow-up program. 12. You want to finalize Mrs. X´s CHF follow-up program.

Table 5. Key performance indicators used during the prevalidation stage.

KPI	Evaluation Area	Data Source	Kind of Data Source	Target
Identification of potential bugs	Number of bugs detected during test session	Gitlab Platform	Test of functionalities and usage scenarios	Table of bugs number
Usage difficulties	User acceptance	Questionnaire	After-Scenario Questionnaire (ASQ)	Medium score ≥ 5
Willingness to use	User acceptance	Questionnaire	System Usability Scale (SUS)	Medium score ≥ 68

Regarding the KPIs agreed upon (see Table 5), the one focused on usage difficulties found by the users has been evaluated through the ASQ questionnaire, with three questions (see Table 6) and a seven-level scale for each one. For the analysis of the results, the rates equal to or higher than 5 were interpreted as no difficulty. The questionnaire also comprised a "Comments" section for registering any difficulties or positive feedback about the scenario evaluated. The KPI focused on willingness to use was assessed by the System Usability Scale (SUS) questionnaire (see Table 7), a method that allows us to obtain a general view of subjective assessments of usability for a wide variety of products and services, including hardware, software, mobile devices, websites, and applications. Due to the heterogeneity of ICT solutions that comprise the Pharaon pilots, SUS was the user-testing tool agreed upon by all partners in the Pharaon project, even though there is other research focused on healthcare solutions that use the popular Technology Acquisition Model (TAM) questionnaire as the tool to measure the technology acceptability [44].

Table 6. Sample questions in the After Scenario Questionnaire (ASQ).

ASQ1: Overall, I Am Satisfied with the Ease of Completing the Tasks in This Scenario.								
Disagree	1	2	3	4	5	6	7	Agree
Comment: specification of agreement or disagreement.								
ASQ2: Overall, I Am Satisfied with the Amount of Time It Took to Complete the Tasks in This Scenario.								
Disagree	1	2	3	4	5	6	7	Agree
Comment: specification of agreement or disagreement.								
ASQ3: Overall, I Am Satisfied with the Support Information (Online-Help, Messages, Documentation) When Completing the Tasks.								
Disagree	1	2	3	4	5	6	7	Agree
Comment: specification of agreement or disagreement.								

Table 7. System Usability Scale (SUS).

SUS1. I Think That I Would Like to Use This System Frequently.						
Strongly disagree	1	2	3	4	5	Strongly agree
SUS2. I Found the System Unnecessarily Complex.						
Strongly disagree	1	2	3	4	5	Strongly agree
SUS3. I Thought the System Was Easy to Use.						
Strongly disagree	1	2	3	4	5	Strongly agree
SUS4. I Think I Would Need the Support of a Technical Person to Be Able to Use This System.						
Strongly disagree	1	2	3	4	5	Strongly agree
SUS5. I Found the Various Functions in This System Were Well Integrated.						
Strongly disagree	1	2	3	4	5	Strongly agree
SUS6. I Thought There Was Too Much Inconsistency in This System.						
Strongly disagree	1	2	3	4	5	Strongly agree
SUS7. I Would Imagine That Most People Would Learn to Use This System Very Quickly.						
Strongly disagree	1	2	3	4	5	Strongly agree
SUS8. I Found the System Very Cumbersome to Use.						
Strongly disagree	1	2	3	4	5	Strongly agree
SUS9. I Felt Very Confident Using the System.						
Strongly disagree	1	2	3	4	5	Strongly agree
SUS10. I Needed to Learn a Lot of Things Before I Could Get Going with This System.						
Strongly disagree	1	2	3	4	5	Strongly agree

The SUS scale comprises 10 items that participants had to score from 1 to 5 once the scenarios of each technology were finalized; the calculation of the results based on the participants' scores gives a general score between 0 and 100.

$$\text{SUS Score} = 2.5 \times [(\text{SUS1} + \text{SUS3} + \text{SUS5} + \text{SUS7} + \text{SUS9-5}) + (25 - \text{SUS2} - \text{SUS4} - \text{SUS6} - \text{SUS8} - \text{SUS10})]$$

Table 8 shows the general guideline on SUS Score interpretation provided by some authors [45]. The prevalidation protocol considered those solutions as accepted if the average score of SUS was graded as A (excellent) or B (Good).

Table 8. General guideline of SUS Score interpretation [45].

SUS Score	Grade	Adjective Rating
>80.3	A	Excellent
68.0–80.3	B	Good
68	C	Okay
51–68	D	Poor
<51	E	Awful

Finally, it is necessary to provide a deeper explanation of the way the steps 5–7 were performed during the prevalidation (see Figure 8):

- Steps 5 (1) and 6 (1) were carried out together for each participant (patient and his/her caregiver), that is, on a fixed date, the technologies were installed and configured at the participant's home. In that visit, the patient and his/her caregiver took time testing the technologies individually, performing the predefined scenarios for each technology shown in Table 4 and filling out the ASQ and SUS questionnaires.
- Step 7 was carried out, analyzing the results gathered in the steps before, identifying and solving bugs and problems, and improving the technologies accordingly. In some cases, the technologies or their improvements could involve new set-ups or configurations; then, step 5 (2) was included.
- After the first 5-6-7 iteration, step 6 (2) was performed in different sessions, organized by type of participant. On the one hand, healthcare professionals participated in the testing sessions, performing the scenarios defined with the Onesait Homecare Healthcare software tool, where all technologies were integrated (see Table 2). After that, they completed the ASQ and SUS. On the other hand, patients and caregivers performed the second testing round with the improved technology result of step 7 and 5 (2), and all of them already integrated in the MyHealth App. As in the previous testing session, they completed the ASQ and SUS.

It is important to remark that the second prevalidation phase was affected by COVID-19 restrictions, and some testing sessions were performed in hybrid mode following the premises of the Murcia health service.

6. Results

During the prevalidation stages, 44 people participated in testing sessions 6 (1) and 6 (2), namely:

- Prevalidation phase 1. Testing sessions in 6 (1): nine sessions were performed with a total of fifteen participants—nine older adults and six informal caregivers—from four municipalities of the region (Murcia, Cartagena, Alcantarilla and Yecla).
- Prevalidation phase 2. Testing session in 6 (2): twelve sessions were performed with 14 health professionals, ranging from cardiologists, to nurses, family doctors, neurologists, and pharmacists, and two sessions with eight older adults (two of them online), and seven informal caregivers.

Table 9 shows data from participants related to the following five variables: type of user, gender, year of birth, digital skills, and education level.

Table 9. Socio-demographic information of the recruited participants.

Type of User	Gender	Year of Birth	Digital Skills (*)	Education Level (**)	Pre-Validation Phases Involved
Patients	Female	1964	Some Experience	EQF Level 6	Phase1, Phase 2
	Female	1946	Some Experience	EQF Level 7	Phase1, Phase 2
	Male	1959	Some Experience	EQF Level 6	Phase1, Phase 2
	Male	1936	Some Experience	EQF Level 6	Phase1, Phase 2
	Male	1968	Experienced/Proficient	EQF Level 7	Phase1, Phase 2
	Female	1946	Some Experience	EQF Level 6	Phase1, Phase 2
	Male	1955	Some Experience	EQF Level 4	Phase1, Phase 2
	Female	1957	Some Experience	EQF Level 6	Phase1, Phase 2
	Female	1962	Some experience	EQF Level 5	Phase1, Phase 2
Caregivers	Female	1962	Some experience	EQF Level 5	Phase1, Phase 2
	Male	1995	Experienced/Proficient	EQF Level 7	Phase1, Phase 2
	Female	1972	Some experience with autonomy	EQF Level 5	Phase 2
	Male	1945	Some experience	EQF Level 6	Phase1, Phase 2
	Female	1956	Experienced/Proficient	EQF Level 3	Phase1, Phase 2
	Female	1955	Some experience	EQF Level 5	Phase1, Phase 2
	Male	1955	Some experience with autonomy	EQF Level 7	Phase1, Phase 2
Health Professionals	Male	1970	Some experience with autonomy	EQF Level 8	Phase 2
	Male	1977	Some experience with autonomy	EQF Level 8	Phase 2
	Female	1962	Some experience with autonomy	EQF Level 6	Phase 2
	Female	1982	Some experience with autonomy	EQF Level 6	Phase 2
	Male	1965	Some experience with autonomy	EQF Level 8	Phase 2
	Female	1974	Some experience with autonomy	EQF Level 6	Phase 2
	Male	1969	Experienced/Proficient	EQF Level 7	Phase 2
	Male	1974	Some experience with autonomy	EQF Level 8	Phase 2
	Female	1981	Some experience with autonomy	EQF Level 8	Phase 2
	Female	1973	Some experience with autonomy	EQF Level 8	Phase 2

Table 9. *Cont.*

Type of User	Gender	Year of Birth	Digital Skills (*)	Education Level (**)	Pre-Validation Phases Involved
	Female	1959	Some experience with autonomy	EQF Level 6	Phase 2
	Male	1973	Some experience with autonomy	EQF Level 8	Phase 2
	Female	1960	Some experience with autonomy	EQF Level 8	Phase 2
	Male	1979	Some experience with autonomy	EQF Level 8	Phase 2

(*) No experience, Some experience, Some experience with autonomy, Experienced/Proficient. (**) EQF Level 1: Primary Education; EQF Level 2: Academic Secondary School Lower Cycle, New Secondary School, and Lower Secondary School; EQF Level 3: Academic Secondary School Upper Cycle, Intermediate and Higher VET (up to 3rd grade); EQF Level 4: Post-secondary non-tertiary education; EQF Level 5: Short-cycle tertiary education; EQF Level 6: Bachelor's Degree, Higher Apprenticeship; EQF Level 7: Master's Degree, postgraduate certificate and diplomas; EQF Level 8: Doctorate or Equivalent.

Note that, although the number of participants (samples) in the prevalidation phase may seem small, many practitioners in the industry have adopted the five-users rule as standard practice for user-testing, which points out that five participants are enough for getting a useful result for testing usability.

All participants filled in the ASQ and SUS. The statistical methodology used consisted of a set of sequential procedures for handling the qualitative and quantitative research data: collection, counting, presentation, synthesis, and analysis. The analysis was performed using descriptive and exploratory analysis. The descriptive analysis served to describe the set of data, thus obtaining the parameters that distinguish the characteristics of a set of data. The reasons for carrying out this analysis are that it allowed us to know, in detail, the information we had and to know the way in which the information was structured. It helps to make deductions directly from the data and parameters obtained. The exploratory analysis consisted of a set of statistical techniques whose purpose was to obtain a basic understanding of the data, allowing the detection of salient features, such as unexpected and outliers. In this work, the mean was the main statistical technique used. The mean scores and global mean for each questionnaire and question are summarized in Tables 10–13.

Table 10. ASQ mean scores for the individual technologies during the pre-validation phase 1.

Technology	Type of User	Scenario	Mean Scores for Individual Questions			Global Mean
			ASQ1	ASQ2	ASQ3	
Amicare	Patients	1. You want to find out the time you went to bed on a specific date according to Amicare.	6.00	5.89	6.56	6.15
		2. You want to know the humidity in your home today.	6.89	6.78	6.67	6.78
	Caregivers	1. You want to check that Mrs. X's home temperature is between 19 °C and 25 °C.	6.67	6.83	7.00	6.83
		2. You want to see if Mrs. X's movements in her flat were regular over the last 3 days.	6.00	6.17	6.50	6.22
		3. You want to check that you receive an alert when the alarm configuration is fulfilled.	6.33	6.50	6.50	6.44

Table 10. *Cont.*

Technology	Type of User	Scenario	Mean Scores for Individual Questions			Global Mean
			ASQ1	ASQ2	ASQ3	
uGRID	Patients	1. You want to know your real-time electricity consumption.	5.75	5.38	6.25	5.79
		2. You want to know if the kitchen has been used for cooking.	5.88	5.88	6.00	5.92
		3. You want to know which electrical device consumes the most electricity in your home.	6.25	6.25	6.38	6.29
	Caregivers	1. You want to know which electrical device consumes the most electricity at the patient´s home.	6.67	6.83	7.00	6.83
		2. You want to know if Mrs. X has used the washing machine this week.	6.00	6.17	6.50	6.22
		3. You want to see if you have received any alarms or events about changes in power consumption patterns of Mrs. X.	6.33	6.50	6.50	6.44
Smartband Solution	Patients	1. You want to consult your heart rate.	6.86	6.86	6.71	6.81
		2. You want to know how many steps you have taken today.	7.00	7.00	6.86	6.95
	Caregivers	1. You want to consult Mr. X´s heart rate.	5.33	5.50	5.67	5.50
		2. You want to know how many steps Mr. X has taken today.	5.67	5.50	5.83	5.67

Table 11. SUS mean scores for the individual technologies during the pre-validation phase 1.

Technology	Type of User	Mean Scores for Individual Questions										SUS Mean Score
		SUS1	SUS2	SUS3	SUS4	SUS5	SUS6	SUS7	SUS8	SUS9	SUS10	
Amicare	Patient	4.44	1.44	4.78	1.78	4.67	1.33	4.44	1.44	4.56	1.44	88.61
	Caregiver	4.67	1.83	4.50	1.33	4.67	1.83	3.33	1.33	4.50	1.50	84.58
uGRID	Patient	4.00	1.50	4.38	1.75	4.38	1.63	3.88	1.50	4.50	1.75	82.50
	Caregiver	4.50	1.33	4.83	1.33	4.17	1.33	4.17	1.17	4.83	1.00	90.83
Smartband Solution	Patient	4.86	1.14	4.86	1.43	4.71	1.14	4.86	1.14	4.29	1.29	93.57
	Caregiver	4.60	2.00	4.80	1.20	5.00	1.00	3.80	1.20	4.80	1.20	91.00

In the first prevalidation phase, the mean score of the ASQ questions for each technology/scenario resulted in a value higher than 5 for all questions (see Table 10). Only one of nine patients (11.11%) scored questions ASQ1 and ASQ2 below 5 for Amicare scenario 1, considering the scenario somewhat difficult and not so fast to complete. The global mean for all questions reveals that almost all participants performed the requested scenarios with no difficulties, in an acceptable time, and felt supported throughout the process.

Regarding usability, the mean SUS scores obtained from all technologies (Table 10) were above 80.3, achieving an "A" grade (Excellent). Only two participants rated the smartband solution with 80 points.

From the results of the prevalidation phase 1, we concluded that the KPIs were reached for all technologies/scenarios, fulfilling the requisites of the first testing phase of prevalidation.

In the second prevalidation phase, the mean scores (Tables 12 and 13) were better than in the previous sessions in almost all technologies/scenarios, which means that participants are more satisfied with the solution in terms of difficulty and usability. From the eight patients that tested the MyHealth App module from Onesait Healthcare Data, the rates given to the SUS questions of only one patient (12.5%) achieved a score below 80.5. The six caregivers scored all individual ASQ questions with 5 or above, and for the Homecare module from Onesait Healthcare Data, at least one ASQ question from scenarios 5, 6, 9, 10, and 12 were scored as 4 by four professionals (28.5%). The rates given to the SUS questions of two health professionals (12.28%) received a score below 80.5.

Finally, it is important to mention that, during the first prevalidation phase, only two bugs (minor issues) were reported in Gitlab related to the smartband solution that were solved and the software was updated for step 6 (2). No bugs were reported during the second phase of pre-validation.

Table 12. ASQ mean scores for Onesait Healthcare Data with the integrated technologies during the pre-validation phase 2.

Technology	Type of User	Scenario	Mean Scores for Individual Questions			Total Mean
			ASQ1	ASQ2	ASQ3	
Onesait Healthcare Data	Patients	1. You want to manually register a weight value/blood pressure.	6.50	6.50	7.00	6.67
		2. You want to access your CHF program to fill in a health questionnaire.	7.00	6.50	7.00	6.67
		3. You want to access your CHF follow-up program and consult your personal care plan.	7.00	6.50	7.00	6.67
	Caregivers	1. You want to manually register a weight/blood pressure value of Mrs. Z.	7.00	7.00	7.00	7.00
		2. You want to access to the follow-up details of Mrs. Z.	6.67	6.67	6.83	6.72
		3. You want to access Mrs. X´s CHF program to fill in a health questionnaire.	6.67	6.67	7.00	6.78
		4. You want to access Mrs. X´s CHF follow-up program and consult her personal care plan.	6.83	7.00	7.00	6.94
	Health Professionals	1. You want to access Mrs. X CHF follow-up program.	7.00	6.67	6.83	6.83
		2. You want to perform the initial clinical assessment to Mrs. X.	6.75	6.58	6.58	6.64
		3. You want to create and publish the personal care plan (PCP) for Mrs. X through a template so she can consult it through the MyHealth App.	6.58	6.50	6.50	6.53
		4. You want to customize what measures (vital signs) Mrs. X must include in the CHF follow-up.	6.92	6.83	6.92	6.89
		5. You want to include a weight range between 50 and 62 kg, outside of which you will receive an alert for Mrs. X.	6.83	6.58	6.58	6.67
		6. You want to customize what health questionnaires Mrs. X must fill in from MyHealth App and how she will have them available: only once, or anytime to be filled in whenever she wants.	6.42	6.83	6.42	6.56
		7. You want to consult the last records of Mrs. X's heart rate and her heart rate history (Smartband).	5.92	6.25	6.08	6.08
		8. You want to consult the history of personalized follow-up plans of Mrs. X (the details of the plan, which professional published it and when).	6.92	6.92	6.92	6.92
		9. You want to know if Mrs. X has used the washing machine (or any other device that is being monitored) this week (MIW+).	6.60	6.50	6.40	6.50
		10. You want to check that you receive an alert when the alarm configuration is fulfilled (Amicare).	6.33	6.25	6.25	6.28
		11. You want to check what patients have alerts from the list of patients of the CHF follow-up program.	6.58	6.67	6.50	6.58
		12. You want to finalize the Mrs. X´s CHF follow-up program.	6.67	6.67	6.67	6.67

Table 13. SUS mean scores for Onesait Healthcare Data with the integrated technologies during the pre-validation phase 2.

Technology	Type of User	Mean Scores for Individual Questions										SUS Mean Score
		SUS1	SUS2	SUS3	SUS4	SUS5	SUS6	SUS7	SUS8	SUS9	SUS10	
Onesait Healthcare Data	Patients	4.38	1.50	4.75	1.75	4.75	1.50	3.88	1.38	4.38	2.00	85.00
	Caregivers	4.67	1.17	5.00	1.00	4.83	1.16	4.16	1.16	4.83	1.16	92.50
	Health Professionals	4.33	1.67	4.75	2.00	4.33	1.25	3.92	1.33	4.58	1.25	86.04

7. Conclusions and Future work

This work presented an innovative AAL solution built upon novel and mature existing IoT technologies with the aim of providing a tele-assistance platform for CHF patients from the public health service of the region of Murcia in Spain. The solution has been designed with a user-centric approach, but also involves formal and informal caregivers and health professionals. From the authors' point of view, this work has been used as a useful guideline to provide the R&D community with inspiration for the design and deployment of AAL solutions based on heterogeneous IoT technologies, or similar approaches, for smart healthcare solutions in real healthcare institutions.

It is important to note some key points of the work presented, as follows. The starting point must be a set of needs identified. Normally, healthcare professionals or institutions are the ones who detect the need. In this work, the needs were detected by the healthcare institution of the Murcia region for CHF patients. After that, a workplan of well-defined steps must be agreed upon by all parties. It must include at least engineering of user requirements, design of the system architecture and development, and testing of the solution for a final step of large-scale deployment. For each step, a clear methodology must be defined and executed with a set of expected outputs identified, which will serve as input for the next step(s). The results obtained from each step must be analyzed, identifying the improvements to implement and lessons learnt.

Regarding the steps defined for this work in depth, it is important to highlight some important issues regarding timing, participants, key points of the execution, and lessons learnt. In the engineering of user requirements, at least six months of implementation were required, with the participation of representatives of all target users involved in the final AAL solution. In a healthcare solution such as the one presented, patients, formal and informal caregivers, and healthcare professionals are expected to be involved at least. Moreover, a high number of participants help to better define the co-design and representation of user requirements as goal models, use case scenarios, and user stories. In this work, up to 250 people participated in the different initiatives, workshops, and meetings organized to define them.

The step focused on architecture definition, development, and integration is a technical approach with a high load of software development. The duration will depend on the maturity of the technologies involved, the functional requirements, and the final healthcare product expected. In this work, this step was planned for one year of work and was focused on two sequential goals. First, the definition of a functional architecture with a set of functional layers and others spanned across several layers, such as security, privacy and reliability, defining the interactions and protocols to use. Second, the development and adaptations of three innovative IoT technologies—Amicare, Smartband, uGRID—and the Homecare and MyHealth App as modules of the Onesait Healthcare Data platform. The main lesson learnt was the importance of using open and interoperable interfaces. Although some IoT solutions are shown as plug and play, minor or major adoptions must almost always be carried out. Data privacy and security are also a must.

Regarding the prevalidation step of the AAL solution, the mandatory assessment of the functionality, usability, and acceptance of the solution by the final users is noteworthy. It entails the participation of all actors involved in this work: patients, formal and informal caregivers, and health professionals. Moreover, all technologies must be monitored during the prevalidation to ensure good performance. In this work, the prevalidation involved the testing of each stand-alone IoT technology and the testing of all IoT technologies integrated in the final healthcare platform solution. Over two months, the authors collected feedback on the tested solution in both phases with 44 participants involved. From the results, the authors concluded that, on average, the rate of acceptance and usability of all technologies and software solutions was higher than expected, and no major bugs or unexpected issues were detected. Then, the product will be ready to be launched in a large-scale pilot.

As a final conclusion, the steps executed, explained in detail in this paper, have been essential in utilizing the future actions that will improve the innovation of the healthcare platform solution presented at its current TRL of 6, to launch a final development in view of creating a large-scale pilot, where around 450 participants are expected in the Murcia region, and to design and develop the impact, exploitation, and business plan.

8. Discussion

Although the work presented has been performed to a high professional quality, following guidelines agreed under a H2020 European project framework, and the results of the work performed have been very positive and useful, it is also important to mention that the authors have identified in this contribution a set of limitations without undermining the quality and integrity of the research. In this section, we summarize them and discuss how they could impact the work and results, and we provide countermeasures and alternatives for future work if this applies.

This work has been performed thanks to the collaborative work of six different organizations and professionals of different disciplines. In addition, more than 300 participants have been reached to participate during the different stages of the research work, which involved difficult organization and coordination. The COVID-19 outbreak added more difficulties due to the impossibility of performing face-to-face meetings and other organizational problems, which resulted in all tasks being redesigned and rescheduled. Time constraints also affected the research negatively, setting as future work some tasks that could have been finished or that at least had sufficient results which could have been included at the time this contribution was written, e.g., the experience of the large-scale pilot under execution.

Some research/development limitations have been also identified during the development of the integrated ICT solution, due to the architecture complexity and high-quality requirements and/or the lack of knowledge of some specific programming languages mandatory for the final integration with the platforms provided by Indra-Minsait.

Data and statistics have also been a limiting factor of the research performed. During the prevalidation phase, 44 participants were reached. Although it is a sufficient sample size for analyzing usability using SUS, the use of other evaluation questionnaires may need more samples, or some researchers may even consider 44 a low number of participants in a testing phase of a large healthcare ICT solution.

The lack of similar research works in the scientific literature has also limited the comparison with similar approaches and the enrichment that a state of art offer to the research contributions.

Finally, we remark that the work developed has been an ad hoc solution for specific target users and healthcare providers, and may show a strong regional focus, limiting its impact. However, some regional, national, and international stakeholders have already shown interest in the work for replicating the solution, or part of it, for other healthcare systems or types of patients (e.g., palliative healthcare).

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4. Conclusiones del Trabajo de Tesis

En el primer trabajo presentado en esta tesis por compendio se realizó un análisis exhaustivo del estado del arte, patentes y otros, para poder establecer una definición precisa del concepto de Mobiliario Inteligente que permita destacar sus propiedades en cuanto a funcionalidad, al elemento digital activo y conectado, e incidir en que el mobiliario inteligente debe ser considerado un ente integrado en el concepto de Ciudades Inteligentes o Calidad de Vida. Además, el establecimiento de una definición precisa puede ayudar a crear el impacto adecuado de todos los actores involucrados en el ecosistema: usuarios, fabricantes, investigadores, autoridades, etc.

La definición propuesta introduce el concepto dentro de una nueva generación de soluciones TIC comprendidas en una ciudad inteligente. Su contenido evidencia la necesidad de crear un debate más organizado y orientado a los resultados entre usuarios, investigadores, fabricantes, autoridades y la administración pública, para poder desarrollar políticas y agendas globales y sostenibles para la investigación en mobiliario inteligente. También enfatiza la necesidad de fomentar la colaboración entre la investigación TIC y la investigación socioeconómica debido a la naturaleza interdisciplinar que trae consigo la investigación de las ciudades y los hogares inteligentes. En estos escenarios el mobiliario inteligente tiene un papel destacado, por lo que se hace necesario centrar el diseño en el usuario para mejorar su bienestar y calidad de vida, así como trabajar en la convergencia entre los requerimientos de dichos usuarios con los tecnológicos y económicos. La definición de Mobiliario Inteligente se presenta como un punto de partida para discutir las cuestiones de investigación para la elaboración de políticas existentes a distintos niveles, así como un primer intento para introducir dicho enfoque dentro de la investigación sobre ciudades inteligentes y la calidad de vida [56].

En el trabajo también se identificaron las tecnologías más comunes que se incorporan en las soluciones de mobiliario inteligente, así como identificación de usuarios y casos de uso. El resultado sirve de guía de apoyo a los actores involucrados en el ecosistema o potenciales interesados.

El segundo trabajo presentado se ha realizado una investigación minuciosa revisando con una herramienta de procesado de lenguaje natural el estado del arte sobre envejecimiento de la población activa, tendencias recientes, direcciones futuras, y envejecimiento en el trabajo. El análisis ha permitido extraer conclusiones en cuanto a los principales problemas de motivación y soluciones para apoyar el concepto de envejecimiento en el trabajo, así como valorar la viabilidad de establecer un posible marco de transformación laboral que contemple el envejecimiento en el trabajo, hoja de ruta para los responsables en la toma de decisiones a nivel público o privado y en la formulación de políticas en este ámbito. En concreto, de los artículos analizados se extrae como conclusión que los trabajos más destacados sugieren políticas y prácticas que apoyan el aprendizaje a lo largo de toda la vida, una mano de obra que comprende tanto a trabajadores jóvenes como a trabajadores de avanzada edad, y una jubilación gradual, así como aquellas que fomentan tanto la capacidad laboral a una edad avanzada como el bienestar de los trabajadores seniors. Enfoques como éstos pueden ser la mejor respuesta a los problemas de la globalización, la reducción de la mano de obra, el mantenimiento de la independencia financiera de la mano de obra de edad avanzada y otros beneficios sociales.

Este trabajo abre la puerta a continuar la investigación sobre la normalización de los enfoques de este problema en distintos países, con el apoyo de autoridades en el ámbito laboral. El objetivo no debería ser implementar los mismos enfoques en diferentes entornos, ya que no abarcaría todos los factores culturales, sociológicos y económicos. En cambio, en este trabajo se considera que unos enfoques sistemáticamente documentados y bien enfocados facilitarán la medición de los resultados y el análisis causal al investigar los beneficios y los inconvenientes.

En el tercer trabajo presentado se ha propuesto una arquitectura IoT de bajo rango para ayudar a abordar los retos de despliegue de servicios e-health en áreas rurales. Se han analizado los retos planteados para cuatro escenarios para ilustrar las limitaciones en zonas con conectividad limitada y se han identificado las principales limitaciones que hay en los entornos rurales y los retos para el despliegue de la arquitectura propuesta, basada en el uso de la tecnología de comunicación de bajo consumo y largo alcance (LPWAN), la tecnología de modulación de amplio espectro LoRa, procesamiento Fog Computing y conectividad de satélites de órbita terrestre baja (LEO). En el trabajo se presenta una prueba de concepto de la arquitectura propuesta para asistir a personas de avanzada edad en áreas rurales: se utiliza la red LoRaWAN, la red pública the Things Network, y el microcontrolador ESP-32, además de proponer distintas opciones para la conservación de la energía y prolongar la vida de las baterías y activar los microcontroladores y sensores cuando éstos están en reposo a partir de activadores por radiofrecuencia, luz, sonido y mecánicos. Siendo éstos últimos la base de numerosos sistemas no intrusivos de monitorización en mobiliario inteligente, como el sistema AMICARE usado y descrito en el cuarto trabajo.

Finalmente, el cuarto artículo detalla la metodología, resultados y conclusiones del trabajo llevado a cabo en el piloto murciano del proyecto europeo Pharaon, enfocado a mejorar la calidad de vida y la asistencia de los pacientes con insuficiencia cardíaca mayores de 55 años. De dicho trabajo, se puede resaltar, como punto de partida, la importancia de la identificación de necesidades de los usuarios, que normalmente se lleva a cabo por los profesionales sanitarios involucrados. Después, todas las partes involucradas deben acordar un plan de trabajo con pasos bien definidos. Incluyendo la ingeniería de los requisitos del usuario, el diseño de la arquitectura del sistema y su desarrollo, y la prueba de la solución en un entorno controlado como paso previo al despliegue a gran escala. Para cada paso, debe definirse y ejecutarse una metodología clara con un conjunto de resultados esperados identificados, que servirán de entrada para el siguiente paso o pasos. Los resultados obtenidos en cada paso deben ser analizados, identificando las mejoras a implementar y las lecciones aprendidas.

La etapa del desarrollo del sistema, integración de componentes y definición de la arquitectura, es evidentemente la de más enfoque técnico y con mayor carga de desarrollo de software. Su duración dependerá de la madurez de las tecnologías implicadas, de los requisitos funcionales y de la solución final prevista. En este trabajo, dicha etapa se planificó para un año de trabajo y se centró en dos objetivos secuenciales:

- La definición de una arquitectura funcional con un conjunto de capas funcionales y otras que abarcan varias capas, como las de seguridad, privacidad y fiabilidad, definiendo las interacciones y los protocolos a utilizar.
- El desarrollo y las adaptaciones de tres tecnologías IoT innovadoras -Amicare, Smartband, uGRID- y la aplicación Homecare y MyHealth como módulos de la plataforma Onesait Healthcare Data.

La principal lección aprendida fue la importancia de utilizar interfaces abiertas e interoperables. Aunque algunas soluciones IoT se muestren como plug and play, casi siempre hay que llevar a cabo adaptaciones de mayor o menor índole. La privacidad y la seguridad de los datos también son imprescindibles.

En cuanto a la etapa de prevalidación de la solución AAL, destaca necesidad de evaluar la funcionalidad, usabilidad y aceptación de la solución por parte de los usuarios finales. Implicando a todos los actores: pacientes, cuidadores formales e informales y profesionales sanitarios. Además, todas las tecnologías deben ser supervisadas durante la pre-validación para garantizar su buen funcionamiento. En este trabajo, la pre-validación implicó la prueba de cada tecnología IoT de manera independiente, en un primer paso, y la prueba de todas las tecnologías IoT integradas en la plataforma sanitaria en un segundo paso. A lo largo de dos meses, se recopilaron opiniones sobre la solución probada en ambas fases con 44 participantes. A partir de los resultados, los autores concluyeron que, en promedio, la tasa de aceptación y usabilidad de todas las tecnologías y soluciones de software fue superior a la esperada, y no se detectaron errores importantes ni problemas inesperados. Lo que posiciona la solución en un escenario muy favorable para su despliegue a gran escala.

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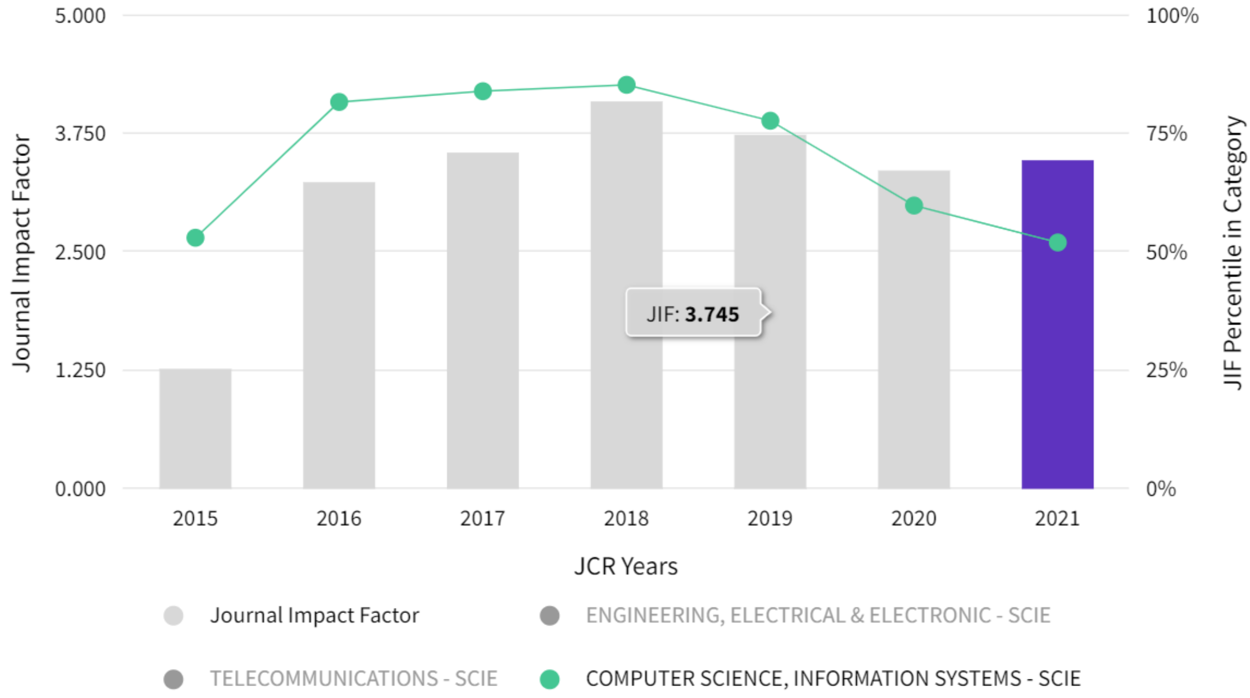
Apéndice: Documentos acreditativos del cuartil e índice de impacto de las publicaciones incluidas en la tesis del año de publicación o último año disponible

- IEEE Access (Artículo 1)



Rank by Journal Impact Factor

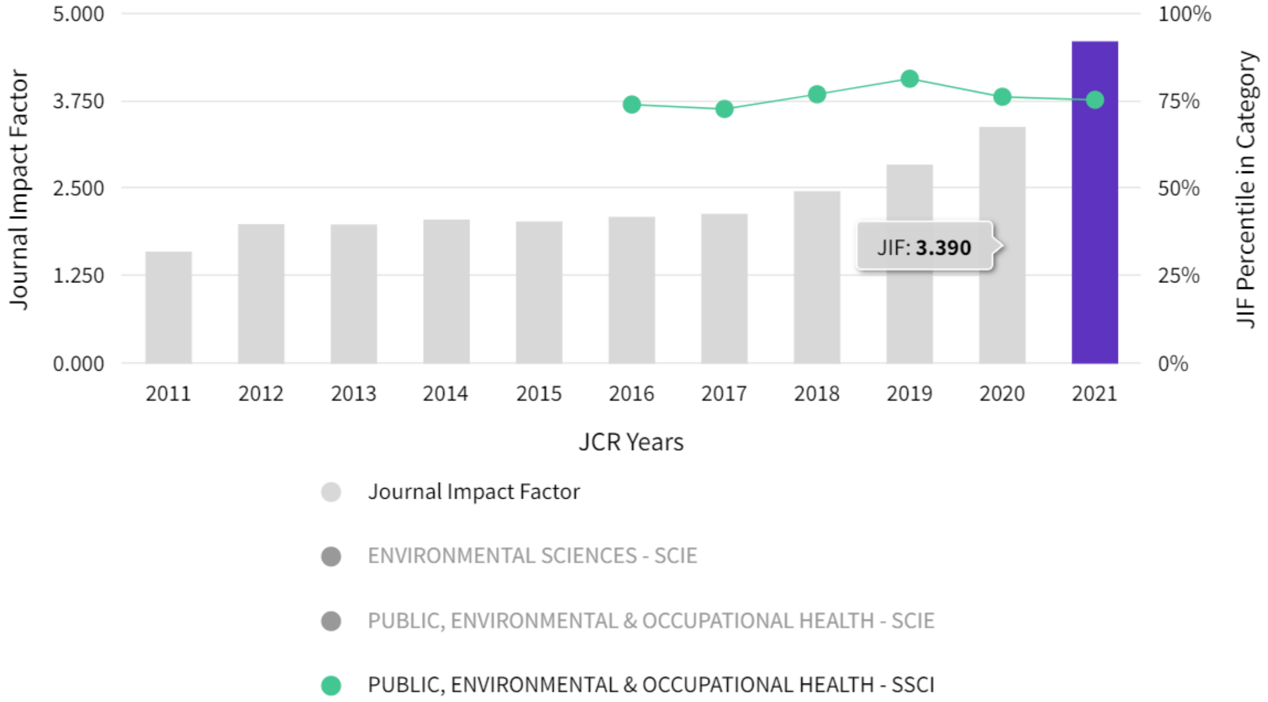
Journals within a category are sorted in descending order by Journal Impact Factor (JIF) resulting in the Category Ranking below. A separate rank is shown for each category in which the journal is listed in JCR. Data for the most recent year is presented at the top of the list, with other years shown in reverse chronological order. Learn more

EDITION
Science Citation Index Expanded (SCIE)

CATEGORY
COMPUTER SCIENCE, INFORMATION SYSTEMS
79/164

JCR YEAR	JIF RANK	JIF QUARTILE	JIF PERCENTILE
2021	79/164	Q2	52.13
2020	65/161	Q2	59.94
2019	35/156	Q1	77.88
2018	23/155	Q1	85.48
2017	24/148	Q1	84.12

- International Journal of environmental research and public health (Artículos 2 y 3)



Rank by Journal Impact Factor

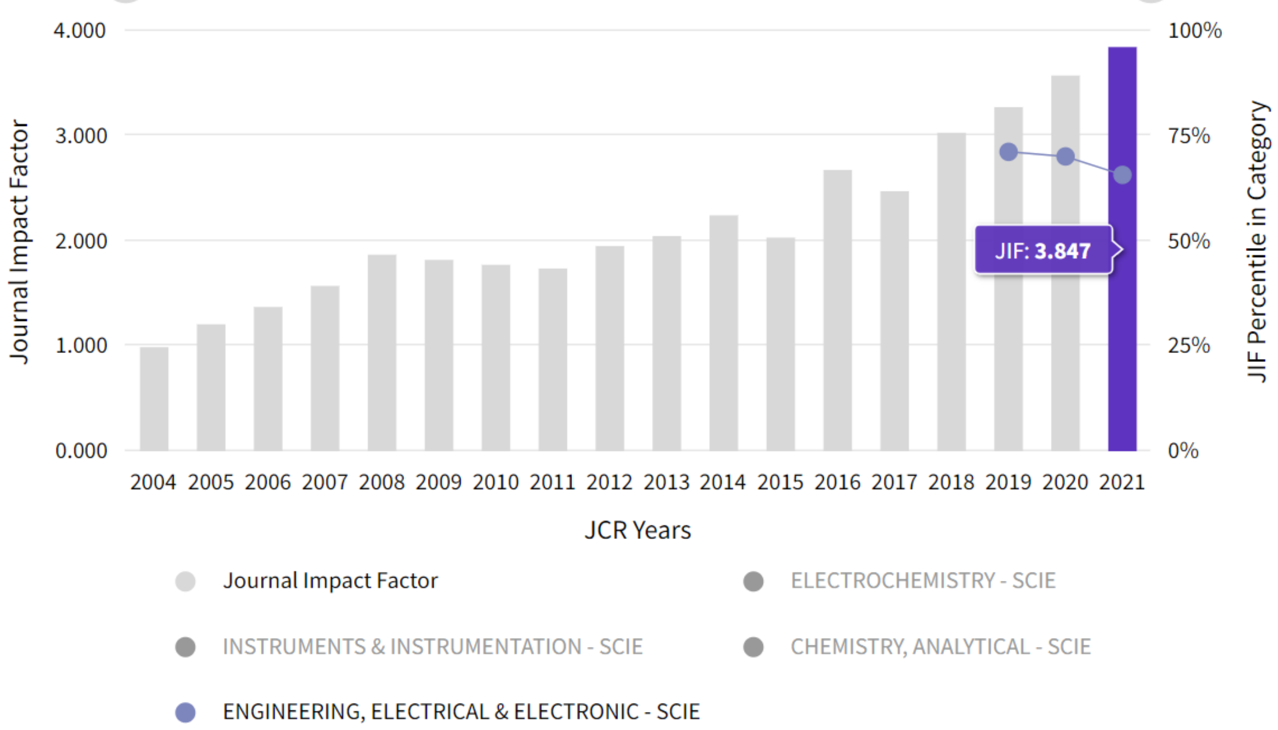
Journals within a category are sorted in descending order by Journal Impact Factor (JIF) resulting in the Category Ranking below. A separate rank is shown for each category in which the journal is listed in JCR. Data for the most recent year is presented at the top of the list, with other years shown in reverse chronological order. Learn more

EDITION
Social Sciences Citation Index (SSCI)

CATEGORY
PUBLIC, ENVIRONMENTAL & OCCUPATIONAL HEALTH
45/182

JCR YEAR	JIF RANK	JIF QUARTILE	JIF PERCENTILE
2021	45/182	Q1	75.55
2020	42/176	Q1	76.42
2019	32/171	Q1	81.58
2018	38/164	Q1	77.13
2017	43/157	Q2	72.93

- Sensors (Artículo 4)



Rank by Journal Impact Factor

Journals within a category are sorted in descending order by Journal Impact Factor (JIF) resulting in the Category Ranking below. A separate rank is shown for each category in which the journal is listed in JCR. Data for the most recent year is presented at the top of the list, with other years shown in reverse chronological order. Learn more

EDITION

Science Citation Index Expanded (SCIE)

CATEGORY

ENGINEERING, ELECTRICAL & ELECTRONIC

95/276

JCR YEAR	JIF RANK	JIF QUARTILE	JIF PERCENTILE
2021	95/276	Q2	65.76
2020	82/273	Q2	70.15
2019	77/266	Q2	71.24
2018	N/A	N/A	N/A
2017	N/A	N/A	N/A