

Reconfiguring and Customizing Living Environments with Knowledge: The *Age-It* Decision Support System



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Abstract The aging population presents growing challenges in ensuring independent and autonomous living for older adults, particularly those with chronic conditions and disabilities. Smart environments and Ambient Assisted Living (AAL) technologies offer promising solutions by integrating intelligent systems that adapt to users' needs. However, personalizing or reconfiguring living spaces to accommodate AAL technologies requires a multidisciplinary approach that considers health conditions, assistive devices, and spatial constraints. This study presents the *Age-It* Decision Support System (DSS), a tool designed to assist architects and designers in selecting and integrating AAL solutions into domestic environments. The DSS leverages an ontological framework to model individual health conditions, environmental constraints, and assistive technologies, enabling a structured decision-making process. By incorporating a knowledge-based reasoning system, the DSS suggests user-centered and suitable modifications and device placements while ensuring compatibility with the physical space. The system communicates with Autodesk Revit, allowing seamless data exchange through XML-based file processing. This enables early-stage simulations of AAL device integration, facilitating collaborative decision-making among designers, healthcare professionals, and end users. A case study demonstrates the DSS's effectiveness in recommending assistive solutions for a user with reduced mobility, considering spatial constraints and usability factors. Future developments aim to enhance the ontology with a broader range of health conditions and assistive devices, improving its robustness and usability in real-world applications. The proposed DSS represents a significant step toward personalized and adaptive home environments, fostering independent living and improving the quality of life for older adults.

Keywords Ambient assisted living · Decision support system · Ontology · Smart environments · Building information modeling

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1 Introduction: Aging Population, Smart Environments, and Service Personalization

In the context of an aging population characterized by older adults, smart environments can support occupants in living independently. This section explores the main features of aging and recent technologies' role in creating smart environments. Finally, the issue of reconfiguring living environments for older adult's specific needs is addressed within the framework of the *Age-It* research project.

1.1 Aging Population

Western countries are experiencing an increase in the elderly population—i.e., citizens aged 65 and over [1]. This increase is mainly caused by the improvements in general living conditions, resulting in a higher average life expectancy. This demographic trend began emerging in the 1990s, and in some countries, including Italy, it has been accompanied by a considerable decline in birth rates. Many European countries are seeing an increase in the percentage of elderly people while the younger age groups are shrinking (the European average for older adults is around 21.3%, while in Italy, it reaches 24%) [2]. The aging phenomenon in Europe also significantly impacts healthcare services, which face increasing demands from patients with chronic illnesses [3, 4]. Moreover, it raises challenges related to managing elderly individuals (especially those with chronic and disabling conditions resulting in a physical or cognitive limitation, permanently affecting their independence): ensuring autonomous and independent living for the elderly has become increasingly urgent.

1.2 Smart Environments and Ambient Assisted Living: A Multidisciplinary Approach for Aging

The recent integration of Artificial Intelligence (AI), the Internet of Things (IoT), and distributed data management systems has driven the creation of increasingly intelligent living environments capable of offering “smart” services to their occupants. The term “smart environment” stands for a living space (equipped with devices) capable of anticipating and satisfying occupants' needs. Designing smart living environments capable of customizing their services requires a significant multidisciplinary effort [5] involving the medical sector, architects, designers, and residents: it is a process requiring understanding individual needs, identifying devices that support these needs, and designing spaces that accommodate the specific characteristics of the individual and the devices they may require.

The set of technologies (both software and hardware) operating in a living environment to monitor, support, and improve residents' quality of life was defined as

Ambient Assisted Living (AAL) [6] in the early 2000s. It quickly became apparent that AAL offered a promising solution for supporting elderly residents [7]. AAL shares four fundamental challenges with redesigning spaces for specific users; the most relevant in *Age-It* are: *a.* Identifying reliable information about the user’s physical and cognitive characteristics for understanding which services to personalize; *b.* Deploying smart devices in a home, which implies context-dependent technical challenges; *c.* Designing spaces within spatial constraints (of rooms and devices)—knowledge often outside the expertise of designers and architects; *d.* Selecting and “prescribing” devices and aids must account for healthcare professionals’ input.

Without a multidisciplinary approach to address these issues, designing (or reconfiguring) spaces for vulnerable residents would be challenging for architects. Therefore, within the *Age-It* project, the effort focused on designing and developing a Decision Support System (DSS) to assist architects and designers in making occupant- and AAL-oriented reconfiguration decisions. These decisions include selecting devices and aids for specific occupants and ensuring compatibility with physical environments.

The core element of the proposed DSS approach is knowledge—formalized relying on domain ontologies [8]—shared computable conceptualizations of essential information (or “facts”) relevant to the domain(s) of interest. The remainder of this Chapter delves into the proposed DSS architecture (Sect. 2); Sect. 3 details the ontological framework and its engineering choices. Section 4 presents a use case to illustrate the DSS functioning. Finally, the Conclusions wrap up the main outcomes of this chapter.

2 The *Age-It* DSS for Reconfiguring Living Environments

This section outlines the architecture for the proposed DSS, focusing on its ontological framework and engineering choices.

2.1 *Age-It* DSS Requirements and General Architecture

Leveraging similar architectures [9, 10] and taking into account the specific requirements of architects and designers when they are called to (re)design a living environment for an elderly user, a DSS designed specifically for these specialists should take into account:

1. The tools and technologies that architects and designers use in their work practice
2. Their actual knowledge related to the domains of interest (e.g., health and disabilities of users, devices, and aids for assistance, etc.)
3. The efficiency of the timing of the support provided by the DSS

Regarding the first point, the main tool for the digital design of environments is Computer-Assisted Design (CAD), a family of software technologies for creating environment or product designs, often resulting in a three-dimensional representation (3D model) of the object. Among these, Autodesk Revit is characterized by the ability to import and export different types of files, and, for these reasons, it became one of the main players in the CAD market. Considering the diffusion and specific characteristics of Autodesk Revit, the DSS discussed below is mainly designed for this software—though, its functionalities can easily be extended to other similar design software.

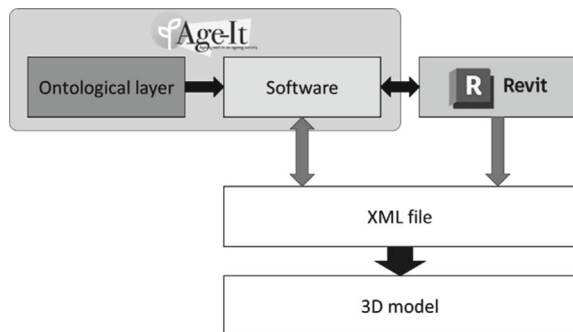
Regarding the second group of requirements, architects and designers are not required to know the health condition of the user for whom they are designing a living environment: it is, therefore, necessary that the DSS takes into account that its users may be utterly agnostic regarding a good portion of the knowledge modeled in it.

Finally, the DSS results must be quickly accessible so that—upon user request—the information produced by the DSS is available. It implies the development of a software component that can receive and exchange data from Revit from the ontological layer without affecting or slowing down the users’ work.

The DSS, therefore, consists of two parts (Fig. 1): 1. The ontological layer, which contains the modeled knowledge (described in the following subsection); 2. The software that allows the reception and sending of data to/from a file operable with Revit.

The DSS architecture does not act directly on the Revit software: it acquires and modifies its data. In fact, among the various options available, Revit allows export in XML, a markup language used precisely for data interchange. In this way, the DSS results can be calculated from the data entered in the XML file and reinserted into the file itself to be used in the development phase of the three-dimensional model. This “lightweight” DSS architecture has the dual advantage of allowing more agile prototypal development based on widely used data formats in practice and not directly interfering with the work of architects and designers. The inferences generated by the ontological layer are exported (in XML) by the software and added to the XML file produced by Revit, then made available to Revit file users.

Fig. 1 A schematic representation of the *Age-It* DSS architecture. The system, composed of the ontological layer and software, acts directly on the Revit output, i.e., the XML file used to create the three-dimensional model



2.2 *Ontology Engineering: Available Ontologies for Age-It*

This subsection provides an overview of the main ontological models available for representing knowledge in the three areas relevant to *Age-It*—the human occupants and their health conditions, the built environment requiring reconfiguration, the modifications to be implemented in the environment.

People and health. The development of ontologies aimed at capturing relevant knowledge about individuals was among the first areas investigated in the Semantic Web. The controlled vocabulary Friend of A Friend (FOAF) [11], and Semantically-Interlinked Online Communities (SIOC) [12] are two examples of models for describing people. More recently, the Person Ontology [13] represents an ongoing effort to develop a foundational ontology about people.

Regarding the ability to model health conditions—including temporary or permanent disabilities and chronic conditions—between the early 2000s and today, there has been a shift towards using standard models [14]. Research highlights the widespread adoption of the International Classification of Functioning, Disability and Health (ICF) [15], a standard classification developed by the World Health Organization (WHO). Unlike ICD, ICF does not catalog diseases; instead, it describes a person's functioning in terms of body functions, structures (which may be subject to disabilities for various reasons), activity limitations, and participation. Using a comprehensive set of codes taxonomically organized, ICF provides a “snapshot” of a person's functioning at a given moment, capturing both individual and contextual factors. While ICF is less commonly employed in clinical practice than ICD, efforts to make it a full-flagged clinical tool have grown over the years [16]. These efforts include the creation of Core Sets—subsets of ICF codes designed for rapid assessments of functioning in individuals diagnosed with specific conditions.

The taxonomic structure of ICD and ICF, as well as their primary role in healthcare, has led to the development of two important ontologies—BioPortal ICD [17] and BioPortal ICF [18]. Also, local classifications and taxonomies—adopted by national healthcare communities—play a complementary role when paired with ICD and ICF, as they differentiate and expand the perspective of healthcare domains to align more closely with end users' needs. End users may lack deep knowledge of ICD or ICF, making them more comfortable using tools that are familiar to them in their daily practices.

Knowledge and built environment: architecture and BIM. In the built environment sector, ontologies have also been seen as a powerful tool for representing and conveying information about buildings, their components, and their energy performance. In particular, ontologies can be seen as a tool for building information modeling (BIM) [19], a process to develop virtual and multi-dimensional models generated with digital applications. This domain is characterized by considerable complexity, deriving from its multidisciplinary nature (combining architecture, engineering, and information management) and the existence of different standards (local or international, not always reconcilable). This complexity has led to developing

and evolving an ontological fragmented scenario characterized by poor interoperability. Among the primary efforts for developing ontologies in this domain, the most discussed in the literature are the following:

- *Industry Foundation Classes (IFC)*: The IFC model was developed as an international standard (ISO 16739:2013) for modeling information related to buildings. Its main purpose is to ensure interoperability between design, construction, and building lifecycle management software. It adopts a geometrically detailed approach to describe built environments, and it is translated into ontology with ifcOWL—but it presents a significantly complex structure, making its implementation difficult. This problem is particularly felt in the scientific community, which has been working for years to try to reduce the complexity of ifcOWL [20, 21].
- *Building Topology Ontology (BOT)*: The BOT model [22] was developed to improve the topology representation and spatial relationships within built environments. It describes spatial and functional relationships between environments, such as rooms, corridors, buildings, and other components, without going into geometric detail as in other BIM models. Topology is represented through entities and properties, such as rooms, floors, and buildings, and defining connections between them (e.g., walls, accesses, doors). However, the geometric representation of spaces is not the model's primary objective. BOT provides a simple and (relatively) limited vocabulary, characterizing itself as a simple and flexible model. This results in greater ease of implementation. Like ifcOWL, BOT is not specifically designed to represent furniture or other functional objects. The lack of geometric definition in the model (in total opposition to the hyper-detailed representation of IFC) allows BOT to focus on environments and their properties while maintaining the possibility of being extended.
- *A Uniform Metadata Schema for Buildings: Brick* [23] was developed to standardize the representation of building data, particularly for building automation and intelligent control. Brick adopts a data-oriented approach, where spaces are represented as “entities” and “subsystems”. For these reasons, its use is recommended for specific building automation projects. Additionally, its implementation may require integration with other domain ontologies [24].
- *Building Ontology (BO)*: The Building Ontology model [25] was developed with the goal of facilitating intelligent building management throughout the entire lifecycle, from design to maintenance. Compared to other models (and similarly to ifcOWL), BO is complex to implement as it requires a solid knowledge of the reference ontological model.

Knowledge and aids: a standards-based approach. The possibilities of representing knowledge in the health field have also paved the way for representing aids and assistive technologies. However, the assistive technology sector has only recently been working to identify a common framework [26]. Therefore, the first prototypes of ontologies on this topic do not follow common guidelines. On the contrary, aids are highly regulated in almost all countries and, above all, standardized: the “ISO 9999 Technical Aids for Disabled Persons—Classification” defines a classification and standard terminology for assistive products intended for people with disabilities.

It creates a common language and an organized system for cataloging all those tools, devices, and technologies that help people with disabilities perform daily activities and improve their quality of life.

2.3 The Age-It Ontological Framework

This subsection presents the ontological layer, the “decision-making heart” of the *Age-It* DSS. The ontology engineering process heavily relies on models’ reuse, one of the Semantic Web’s best practices. Therefore, considering the considerations made in the previous sections, the *Age-It* ontologies were developed following an agile methodology (AgiSCOnt [27]) that allows analyzing the domains in question from different points of view, favoring collaborative knowledge elicitation activities. The *Age-It* ontology is organized as follows: a Common Box imports all the modules that, in fact, make up the ontology. Although not all modules are physically developed as separate files (i.e., the TBox and Abox are modeled within a single.owl file for the smaller modules), the schema depicts all the constituent elements of the ontological layer, also providing the indication of reused ontologies (according to the best practice of the Semantic Web) and the domain to which they are applied. Figure 2 schematizes the modular structure of the *Age-It* ontology.

The ontology editor selected for developing *Age-It* and its modules is Protégé [28], a successful ontology editor now in version 5.5; the editor was selected due to the possibility of modeling rules in “if-then” format using the Semantic Web Rule Language [29], the possibility of using built-in automatic reasoners—for example, Pellet [30]—and, finally, the possibility of testing the ontology with SPARQL query language [31] through the snapSPARQL plug-in [32]. Protégé allows saving in “.owl” files, with various options for syntax serialization: among these, RDF/XML serialization [33], which uses the markup language format to render triples expressed

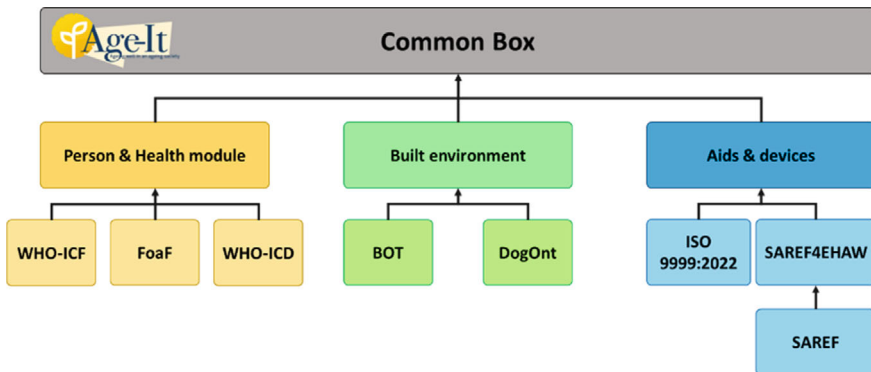


Fig. 2 A schematic representation of the *Age-It* ontology and its “components”

with RDF and OWL, as well as SWRL rules, domains, and ranges of the various properties, and class restrictions.

Person and health condition. In line with what is described in Sect. 2.2, the international classifications ICD and ICF are proposed as ideal candidates for reuse as they are known to healthcare professionals and enjoy broad consensus. The reuse of ICD within *Age-It* is limited to those pathologies that can characterize an elderly inhabitant, while for the ICF, core sets were adopted—following other examples that use ICF core sets as a basis for developing ontological elements (e.g., [34–36]).

From the combination of category codes present in the comprehensive versions of the ICF core sets used to model the personas’ conditions, the ICF core that populates the *Age-It* ontology is constituted. From an authoring perspective, this module reuses the ICF ontology already developed and deposited at the OBO Foundry [18]. Adopting a similar approach, the identification of pathologies within the vast ICD classification (version 11) is carried out through a keyword search. This allows us to identify the groups of pathologies that need to be modeled within this *Age-It* module.

To link the occupants to the ICF and ICD codes describing their pathologies and disabilities, an ontology design pattern was reused, establishing an owl:Individual of the class:HealthCondition between the former and the latter; moreover, the more advanced version of the pattern allows detailing the health condition using descriptor individuals (belonging to the class:HCDescriptor) [37]; each descriptor reifies the n-ary relationships between an ICF or ICD code and the related qualifiers [34]. Graphically, the pattern can be rendered as in Fig. 3.

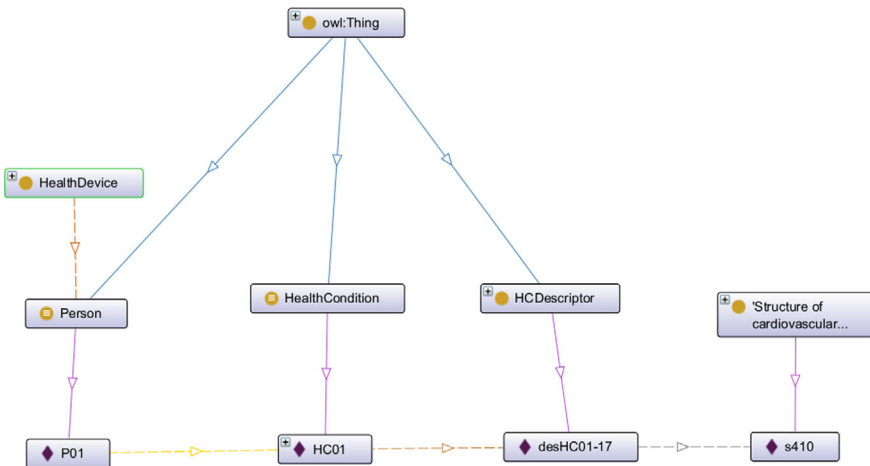


Fig. 3 A (partial) view of the pattern linking a person (P01) with their health condition (HC01) and one of the descriptors describing it (desHC01-17), which involves a specific ICF code (in this case, s4140). The purple prisms represent the owl:Individual, the yellow circles the owl:Class, while the arrows represent different object properties

Reusing the health condition ontology design pattern makes it possible to associate more than one health condition with each inhabitant, to keep track of the evolution of an inhabitant's health condition.

Built environment. The choice of a possible reuse model for the built environment was based on the possibility of adopting a lightweight model (with a low impact on ontological commitment), the possibility of referring to the built environment also in terms of its spaces (e.g., volume, areas, zones, etc.), and the possibility to extend the model to include features of interest for *Age-It*. The lowest level of commitment, while maintaining the ontology's objective, is found in the Building Topology Ontology (BOT), an ontology that reflects the principle of non-overlapping DSS results with what can be developed and implemented using Revit alone.

The built environment module reuses some BOT concepts, among which `bot:Element`: (a loosely-defined class that includes the physical parts of construction), `bot:Zone`, and `bot:Interface`: (a class that includes entities that “interpose” between two elements or two zones, or between an element and a zone). Exploiting the possibility of extending `bot:Element`, this module represents from scratch `Construction_element` (e.g., doors, windows, and their openings in the walls, pillars, etc.), `Furniture`, and `Device`. The `Device` class is logically equivalent to the homonymous class described in the next subsection. Construction elements are characterized by three subclasses borrowed from the soft reuse of *DogOnt* [38]. This ontology allows reusing rather common concepts already widely used in other models, such as those related to some construction elements. Additionally, *DogOnt* was chosen because it contains classes to represent room types and the most common furniture types.

As mentioned in previous paragraphs, BOT does not have a mechanism for describing the geometry of elements or spaces. Remembering that one of the DSS's purposes is to understand the free and occupied space within built environments, the geometry representation uses simple datatype properties—`:XDimension`, `:YDimension`, and `:ZDimension`, which are expressed in cubic meters, and `:Weight`, expressed in kilograms. With the first three of these minimal properties, it is possible to calculate the value of a fifth property, `:BoundingBox`, obtained by multiplying the values of the three properties (i.e., calculating the volume of a parallelepiped). This space is obtained to calculate the maximum volume an element can occupy, thus configuring it as an “invisible box” that completely envelops an object or group of objects in a 3D drawing. The calculation of the `:BoundingBox` datatype property's value is entrusted to an SWRL rule, which uses the language's built-ins to set the parameters and variables for multiplication.

Devices and aids. This module represents the taxonomy reported in the ISO 9999:2022 and leverages SAREF and its extension for eHealth Ageing Well domain [39]. This ontology enables the representation of devices, their services, the power source(s) they adopt, and the health service they deliver. Using `saref:Sensor` and `saref:Actuator` classes it also allows for the definition of specific subclasses of `saref:Device`, which are capable of measuring relevant indoor comfort metrics (e.g., temperature, humidity, air quality, etc.). A particular subclass of `saref:Device` is

s4ehaw:HealthDevice, which identifies those devices created for health purposes; these are then further categorized according to ISO 9999:2022.

Reasoning with Age-It (example). The matching between individuals representing users, their health conditions, the devices, the environment and its constraints leverages SWRL rules. This type of condition-action rules enables a deductive reasoning process leveraging arguments represented within the knowledge base. In this way, the original information modelled within the ontology cannot be changed by reasoning results, while new information can be added as a result of a reasoning process. For instance, a person who is in a health condition characterized by J44.1 “Chronic obstruction pulmonary disease with (acute) exacerbations” and associated severe impairments, can benefit from a set of devices, which includes iso9999:2022 04.03.18 “Oxygen units”, 04.03.03 “Inhalation equipment”, 04.03.12 “Respirators”. The matching is represented by the rule:

Person(?p), isInHealthCondition(?p, ?hc), isDescribedBy(?hc, ?desc), ICDCode(?descr1, “J44.1”), ICFCode (?descr2; “b440”), qualifier(?descr2, “3”), 04.03.12 (?resp), suitableFor(?resp, “J44.1”), suitableFor(?resp, “b440”), suggestedForSeverity(?resp, ?x), greaterThanOrEqual(?x, 3) - > suggestedDevices(?p, ?resp).

Therefore, taking into account both the specific disease or impairment and their severity, it is possible to “filter” the best option available. Similarly—and adopting different rules—it is possible to consider some spatial constraints characterizing the inferred devices, to support in the identification of those fitting in the occupant’s room.

3 Use Case: An Example of Age-It Reasoning

To illustrate the Age-It DSS functioning, two use cases are presented (taken from [40, 41]). The first use case refers to a 65-year-old user named Mark, who suffers from a condition that makes him unable to move independently, forcing him to spend most of his day in bed. Mark’s caregiver (his wife) needs an aid to help lift him from bed to a wheelchair. The IFC codes describing his condition are d420 Transferring oneself, d450 Walking, d455 Moving around, and d460 Moving around in different locations. Leveraging Age-It rules and semantic reasoning, the system retrieves a set of alternative products, associated with ISO category 9999.2022 12.36 “Auxiliary products for lifting people.” Among these, within the module “aids and assistive devices” are four types of lifts (Table 1, adapted from [40, 41]).

As illustrated above, each aid is modeled considering its required environmental features. Therefore, by comparing these requirements with the information obtained from the bedroom model represented in the ontology, the system discards the ceiling

Table 1 The devices, aids, and furnishings provided via ontological reasoning for Mark

Devices inferred for mark (Use case 1)			
Persona’s health condition	Assistive devices, aids, and furnishings	Aids type/instance id products	Spatial and technological requirements
Reduced mobility (ICF codes d420, d450, d455 d460)	12.36.12 Stationary hoists fixed to walls, floor or ceiling	Ceiling track hoist	<ul style="list-style-type: none"> – Flat slab – Slab resistance to concentrated vertical loads of 2 kN (200 kg)
		Wall lift (dim. 8 × 115 × 240 cm)	<ul style="list-style-type: none"> – Max height between floors 350 cm – Absence of false ceiling
	12.36.18 Stationary free-standing hoists	Stationary free-standing hoists (dim. 320 × 420 × 205 cm)	<ul style="list-style-type: none"> – Free space around the bed of 120 cm
	12.36.03 Mobile hoists for transferring a person in sitting position with sling seats	Mobile hoist (dim. 110 × 110 × 140 cm)	<ul style="list-style-type: none"> – Free space under the bed of 15 cm – Free passages 110 cm wide – Availability of a circular area with a radius of 150 cm for the movement of hoist

track hoist hypothesis due to the presence of a sloping exposed beam ceiling. Similarly, the hypothesis of a stationary free-standing hoist is discarded because it would require more free space around the bed than the residual volume available.

4 Conclusions and Future Works

The growing need for support among the elderly is driving the widespread adoption of AAL technologies and devices. Care teams must choose these devices based on the individual’s specific needs and integrate them into the home environment with minimal visual disruption.

To aid in this decision-making process, the *Age-It DSS* proposed in this study serves as a support tool for designers, ensuring a consistent consideration of the individual’s health and functional status, the required devices to enhance autonomy or assist caregivers, and the characteristics of the living space.

The proposed DSS is not meant to replace professionals responsible for recommending aids and devices. Instead, it is designed to be integrated into the decision-making process by leveraging digital information (including individual, device, and space characteristics) to create a virtual exchange platform. This platform

enhances collaboration among various professionals, such as healthcare providers and designers, while also supporting the co-design of home environments with end users.

By exploiting Revit’s three-dimensional visualization of the environment model, the tool allows for early-stage simulations of AAL device integration, enabling an assessment of their impact on the living space. This approach helps identify the most suitable solutions for the individual’s specific needs and guides subsequent design decisions.

Future works foresee developing and testing more use cases to address various living conditions, impairments, disease-related limitations, and aids. In the future, the ontology underlying the system will be populated with several use cases, leveraging clinical collaboration and more matching between aids and the health conditions they address. This would enhance the system’s robustness and pave the way for validation with designers and architects.

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References

1. Bijak, J., Kupiszewska, D., Kupiszewski, M., & Saczuk, K. (2013). Population ageing, population decline and replacement migration in Europe. In *International Migration and the Future of Populations and Labour in Europe*. https://doi.org/10.1007/978-90-481-8948-9_14
2. Commission, E., Eurostat, Corselli-Nordblad, L., & Strandell, H. (2020). *Ageing Europe—Looking at the lives of older people in the EU—2020 edition*. Publications Office. <https://doi.org/10.2785/628105>
3. Lloyd-Sherlock, P. (2000). Population ageing in developed and developing regions: Implications for health policy. *Social Science and Medicine*, *51*, 887–895. [https://doi.org/10.1016/S0277-9536\(00\)00068-X](https://doi.org/10.1016/S0277-9536(00)00068-X)
4. Tinker, A. (2002). The social implications of an ageing population. *Mechanisms of Ageing and Development*, *123*, 729–735. [https://doi.org/10.1016/S0047-6374\(01\)00418-3](https://doi.org/10.1016/S0047-6374(01)00418-3)
5. Ma, C., Guerra-Santin, O., & Mohammadi, M. (2022). Smart home modification design strategies for ageing in place: A systematic review. *Journal of Housing and the Built Environment*, *37*, 625–651. <https://doi.org/10.1007/s10901-021-09888-z>
6. Costa, R., Carneiro, D., Novais, P., Lima, L., Machado, J., Marques, A., & Neves, J.: Ambient assisted living. In *3rd Symposium of Ubiquitous Computing and Ambient Intelligence 2008* (pp. 86–94). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-85867-6_10
7. Rashidi, P., & Mihailidis, A. (2013). A survey on ambient-assisted living tools for older adults. *IEEE Journal of Biomedical and Health Informatics*, *17*, 579–590. <https://doi.org/10.1109/JBHI.2012.2234129>
8. Gruber, T. R. (1993). A translation approach to portable ontology specifications. *Knowledge Acquisition*, *5*. <https://doi.org/10.1006/knac.1993.1008>
9. Spoladore, D., Mahroo, A., Trombetta, A., & Sacco, M.: Comfont: A semantic framework for indoor comfort and energy saving in smart homes. *Electronics (Switzerland)*, *8*. <https://doi.org/10.3390/electronics8121449>

10. Spoladore, D., Mahroo, A., Trombetta, A., & Sacco, M. (2022). DOMUS: A domestic ontology managed ubiquitous system. *Journal of Ambient Intelligence and Humanized Computing*, 13. <https://doi.org/10.1007/s12652-021-03138-4>
11. Graves, M., Constabaris, A., & Brickley, D. (2007). FOAF: Connecting people on the Semantic Web. *Cat Classif Q*, 43. https://doi.org/10.1300/J104v43n03_10
12. Passant, A., Bojárs, U., Breslin, J. G., & Decker, S. (2010). The SIOC project: Semantically-interlinked online communities, from humans to machines. In *International Workshop on Coordination, Organizations, Institutions, and Norms in Agent Systems*. https://doi.org/10.1007/978-3-642-14962-7_12
13. Katsumi, M. Person ontology. <http://ontology.eil.utoronto.ca/icity/Person/1.2/>
14. Spoladore, D., Sacco, M., & Trombetta, A. (2023). A review of domain ontologies for disability representation. *Expert Systems with Applications*, 228, Article 120467. <https://doi.org/10.1016/j.eswa.2023.120467>
15. Üstün, T. B., Chatterji, S., Bickenbach, J., Kostanjsek, N., & Schneider, M. (2003). The international classification of functioning, disability and health: A new tool for understanding disability and health. *Disability and Rehabilitation*, 25. <https://doi.org/10.1080/0963828031000137063>
16. Stucki, G., Cieza, A., Ewert, T., Kostanjsek, N., Chatterji, S., & Üstün, T. B. (2002). Application of the International Classification of Functioning, Disability and Health (ICF) in clinical practice. *Disability and Rehabilitation*, 24, 281–282. <https://doi.org/10.1080/09638280110105222>
17. BioPortal: ICD 10 ontology—v. 2021aa. <https://bioportal.bioontology.org/ontologies/ICD10>
18. BioPortal: ICF ontology—v. 1.0.2. <https://bioportal.bioontology.org/ontologies/ICF>
19. Demian, P., & Walters, D. (2014). The advantages of information management through building information modelling. *Construction Management and Economics*, 32, 1153–1165. <https://doi.org/10.1080/01446193.2013.777754>
20. Pauwels, P., Krijnen, T., Terkaj, W., & Beetz, J. (2017). Enhancing the ifcOWL ontology with an alternative representation for geometric data. *Automation in Construction*, 80, 77–94. <https://doi.org/10.1016/j.autcon.2017.03.001>
21. Wang, C., Zhang, L., & Yan, W. (2024). Enhancement and validation of ifcOWL ontology based on Shapes Constraint Language (SHACL). *Automation in Construction*, 160, Article 105293. <https://doi.org/10.1016/j.autcon.2024.105293>
22. Rasmussen, M. H., Lefrançois, M., Schneider, G. F., & Pauwels, P. (2020). BOT: The building topology ontology of the W3C linked building data group. *Semant Web*, 12, 143–161. <https://doi.org/10.3233/SW-200385>
23. Balaji, B., Bhattacharya, A., Fierro, G., Gao, J., Gluck, J., Hong, D., Johansen, A., Koh, J., Ploennigs, J., Agarwal, Y., Berges, M., Culler, D., Gupta, R., Kjærgaard, M. B., Srivastava, M., & Whitehouse, K. (2016). Brick. In *Proceedings of the 3rd ACM International Conference on Systems for Energy-Efficient Built Environments* (pp. 41–50). ACM. <https://doi.org/10.1145/2993422.2993577>
24. Garrido-Hidalgo, C., Fürst, J., Cheng, B., Roda-Sanchez, L., Olivares, T., & Kovacs, E. (2022). Interlinking the brick schema with building domain ontologies. In *Proceedings of the 20th ACM Conference on Embedded Networked Sensor Systems* (pp. 1026–1030). ACM. <https://doi.org/10.1145/3560905.3567761>
25. Chávez-Feria, S., & Poveda Villalón, M. Building ontology (BO). <https://bimerr.iot.linkeddata.es/def/building/>
26. Cook, A. M., Polgar, J. M., & Encarnação, P. (2020). Principles of assistive technology. In *Assistive technologies* (pp. 1–15). Elsevier. <https://doi.org/10.1016/B978-0-323-52338-7.0001-9>
27. Spoladore, D., Pessot, E., & Trombetta, A. (2023). A novel agile ontology engineering methodology for supporting organizations in collaborative ontology development. *Computers in Industry*, 151, Article 103979. <https://doi.org/10.1016/j.compind.2023.103979>
28. Musen, M. A. (2015). The protégé project. *AI Matters*, 1. <https://doi.org/10.1145/2757001.2757003>

29. Horrocks, I., Patel-Schneider, P. F., Boley, H., Tabet, S., Grosz, B., & Dean, M. (2004). SWRL: A semantic web rule language combining OWL and RuleML. *W3C Member Submission*, 21, 1–31.
30. Sirin, E., Parsia, B., Grau, B. C., Kalyanpur, A., & Katz, Y. (2007). Pellet: A practical OWL-DL reasoner. *Journal of Web Semantics*, 5, 51–53. <https://doi.org/10.1016/j.websem.2007.03.004>
31. Hommeaux, E. P., & Seaborne, A. (2008). SPARQL query language for RDF. W3C Recommendation. <http://www.w3.org/TR/rdf-sparql-query/>
32. Horridge, M., & Musen, M. (2016). Snap-SPARQL: A java framework for working with SPARQL and OWL. In *Lecture notes in computer science (including subseries Lecture notes in artificial intelligence and Lecture notes in bioinformatics)*. https://doi.org/10.1007/978-3-319-33245-1_16
33. Patel-Schneider, P., & Siméon, J. (2002). The Yin/Yang web. In *Proceedings of the 11th International Conference on World Wide Web* (pp. 443–453). ACM. <https://doi.org/10.1145/511446.511504>
34. Spoladore, D., Negri, L., Arlati, S., Mahroo, A., Fossati, M., Biffi, E., Davalli, A., Trombetta, A., & Sacco, M. (2024). Towards a knowledge-based decision support system to foster the return to work of wheelchair users. *Computational and Structural Biotechnology Journal*, 24, 374–392. <https://doi.org/10.1016/j.csbj.2024.05.013>
35. Subirats, L., Ceccaroni, L., Gómez-Pérez, C., Caballero, R., Lopez-Blazquez, R., & Miralles, F. (2013). On semantic, rule-based reasoning in the management of functional rehabilitation processes. In *Management Intelligent Systems: Second International Symposium*. https://doi.org/10.1007/978-3-319-00569-0_7
36. Subirats, L., & Ceccaroni, L. (2011). An ontology for computer-based decision support in rehabilitation. In *Advances in Artificial Intelligence: 10th Mexican International Conference on Artificial Intelligence, MICAI 2011*. https://doi.org/10.1007/978-3-642-25324-9_47
37. Sojic, A., Terkaj, W., Contini, G., & Sacco, M. (2016). Modularising ontology and designing inference patterns to personalise health condition assessment: The case of obesity. *Journal of Biomedical Semantics*, 7. <https://doi.org/10.1186/s13326-016-0049-1>
38. Bonino, D., & Corno, F. (2008). DogOnt—Ontology modeling for intelligent domestic environments. In *International Semantic Web Conference*. https://doi.org/10.1007/978-3-540-88564-1_51
39. ETSI. (2020). Extension to SAREF—eHealth/Ageing-well Domain. https://www.etsi.org/deliver/etsi_ts/103400_103499/10341008/01.01.01_60/ts_10341008v010101p.pdf
40. Spoladore, D., Romagnoli, F., Ferrante, T., Sacco, M., Mondellini, M., Mahroo, A., & Villani, T. (2024). Customizing seniors' living spaces: A design support system for reconfiguring bedrooms integrating ambient assisted living solutions. In *International Conference on Computers Helping People with Special Needs*. https://doi.org/10.1007/978-3-031-62849-8_46
41. Spoladore, D., Mahroo, A., Sacco, M., Ferrante, T., Romagnoli, F., & Villani, T. (2024). Reconfiguring domestic environments: A decision support system for ambient assisted living. In *2024 IEEE International Conference on Metrology for eXtended Reality, Artificial Intelligence and Neural Engineering (MetroXRaine)* (pp. 89–94). IEEE. <https://doi.org/10.1109/MetroXRaine62247.2024.10795971>

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