Assessment of Reference Architectures and Reference Models for Ambient Assisted Living Systems:
Results of a Systematic Literature Review

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ABSTRACT

The innovation and development of software systems in the Ambient Assisted Living (AAL) domain have brought huge challenges for academia and software industry as well. Despite the existence of architectural models that can be used as references to build AAL systems, their selection for new AAL projects is a difficult task. In this work, the authors present the state of the art on Reference Architectures (RA) and Reference Models (RM) found through the conduction of a systematic literature review. The authors identified, analyzed, and assessed 24 existing RA&RM for AAL domain, and, as result, the authors spotted interesting research directions that should be further explored to improve existing and future RA&RM and software systems for that domain.

KEYWORDS

Ambient Assisted Living, e-Health, Reference Architecture, Reference Model, Software Architecture, Systematic Literature Review

1. INTRODUCTION

Ambient Assisted Living (AAL) is a relatively new field that has become an increasingly important, interdisciplinary research topic for the governmental services, and the medical and technological research communities (Broek, Cavallo & Wehrmann, 2010). AAL refers to concepts, products, and services aiming at enhancing several aspects of people's quality of life, including autonomy/independence, comfort, safety, security, and health in all stages of their life (Broek et al., 2010). AAL software systems can be seen as super-set of Ambient Intelligence (AmI) that includes concepts and technologies from smart homes, robotics, sensor networks, and eHealth (Buchmayr & Kurschl, 2011).

Considering the relevance of AAL software systems for society, and the diversity of application domains and technologies that AAL embraces, researchers, practitioners, and organizations have advised the importance of creating heterogeneous, interoperable, open, and reusable platforms and standards for the AAL domain. For this reason, several reference architectures (RA) and reference

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models (RM) have been proposed, supported, for instance, by the European Commission under the FP6 and FP7 research calls[1]. In short, RA are a generic type of software architecture that presents a well-recognized understanding of specific domains, promoting reuse of domain and design expertise, and facilitating the development, standardization, and evolution of software systems (Nakagawa, Oquendo & Maldonado, 2014). Meanwhile, RM are considered abstract frameworks whose purpose is the domain modelling, representing relationships between domain entities. In a RM, entities can be further mapped into software architecture structures (Bass, Clements & Kazman, 2003).

In the AAL context, it is possible to find different RA&RM, such as UniversAAL (Hanke et al., 2011), proposed to guide the AAL providers and consolidate the AAL market. Nowadays, the selection of RA&RM for developing, standardizing, and evolving AAL systems is a rather difficult task, because the heterogeneity of technologies, and complex purposes of those systems. However, to the best of our knowledge, there is a lack of a complete and detailed analysis and assessment of the existing RA&RM for the AAL domain. The main objective of this paper is to present the state of the art obtained by assessing those RA&RM regarding their completeness and congruence. The identification and selection of RA&RM was made through the conduction of a systematic literature based on well-known guidelines presented in (Kitchenham & Charters, 2007).

The remainder of this article is organized as follows. Section 2 presents the background. Section 3 details related work. Section 4 summarizes the protocol of the conducted systematic literature review. Section 5 reports the results of our review. Discussions about our research questions are presented in Section 6. Section 7 exposes threats to validity. Finally, Section 8 presents our conclusions and future work.

2. BACKGROUND

In this section, the theoretical background containing the main topics embraced in this work, namely, AAL, reference architectures, and reference models, is given.

2.1. Ambient Assisted Living

Aiming at enhancing the quality of life for everyone, the Ambient Assisted Living (AAL) concept emerged in the 1990s, but just from the middle of the 2000s it has received more attention. AAL is a relatively new field and has become an essential, multidisciplinary research topic, aiming at providing software systems and services to assist people with disabilities, chronic illness, or low autonomy, in their every life activities. In this context, efforts in the AAL domain intend to improve autonomy/independence, comfort, safety, security, and health, for everyone (with a focus on elderly persons) in all stages of their life (Broek et al., 2010). AAL is primarily concerned with the individual in his or her immediate environment (e.g., at home, community, or work) by offering user-friendly interfaces for all sorts of equipment in the home and outside, taking into account that many older people have impairments in vision, hearing, mobility, or dexterity (Pieper, M., Antona, M., & Cortés, U., 2011).

Table 1 shows the classification of AAL goals (G) proposed originally by Afsarmanesh (2011). Shortly, AAL systems can be constructed to address three general goals (G1, G2, and G3) depending of the environment in which the system will work (i.e., personal environment, such as home, work, or community). The three general goals can be refined in more detailed objectives (for instance, G1A.b as sub-goal of G1), as detailed in Table 1.

2.1.1. Technologies in Ambient Assisted Living

To develop successful AAL systems, knowledge provided by a heterogeneous set of disciplines (as those showed in Figure 1) must be integrated. AAL software systems can be seen as an evolution of Ambient Intelligence (AmI) technologies, including also technological advances from Smart Homes and e-Health (Buchmayr & Kurschl, 2011). Figure 1 shows relationships between different technologies from the AAL point of view. Smart Homes focus on controlling devices installed at people's houses,

Table 1. AAL goals

Category	Goals	
G1. AAL for persons	G1.A. AAL for health, rehabilitation, and care	G1.A.a. Person-centered health management (at home and away from home)
		G1.A.b. Tele-monitoring and self-management of chronic diseases
		G1.A.c. Support for care givers and care organizations
	G1.B. Personal and home safety and security	
	G1.C. Personal activity management	
	G1.D. Person-centered services	G1.D.a. Shopping
		G1.D.b. Feeding
		G1.D.c. Personal care
		G1.D.d. Social interaction and communication
G2. AAL in the community	G2.A. Social inclusion	G2.A.a. Participation in community activities
		G2.A.b. Creativity, hobbies, and sports
		G2.A.c. Cultural and experience exchanges
	G2.B. Entertainment and leisure	
	G2.C. Mobility	G2.C.a. Supporting individual physical mobility
		G2.C.b. Assisted driving
		G2.C.c.Public transport
G3. AAL at work	G3.A. Assuring environmental working conditions	
	G3.B. Support for working	
	G3.C. Prevention of diseases and injuries	

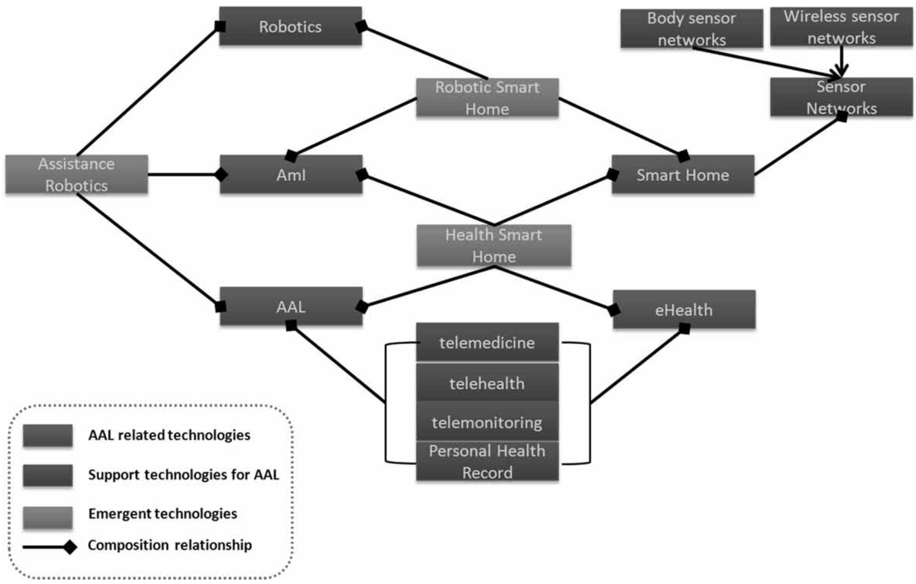
Adapted from Afsarmanesh (2011).

while AmI focuses on the perception of the environment and emergency situations detection. eHealth provides necessary concepts and methodologies to integrate assistive technologies and services into existing systems of nursery, healthcare and eldercare (Buchmayr & Kurschl, 2011). Interactions among eHealth, AmI, Smart Home, and AAL systems, jointly with robotics and sensor networks systems, have contributed to the emergence of new technologies, such as assistance robotics, robotic homes, and Health Smart Homes (HSH) (Garcés et al., 2015a) as presented in Figure 1.

2.2. Reference Architectures and Reference Models

In computer science, the architecture of a software system is defined as the "structure or structures of the system, which comprise software elements (e.g., components, services, modules), the externally visible properties of those elements (e.g., interfaces, protocols), and the relationships among them (e.g., type of connectors and communication)" (Bass et al., 2003). Reference architectures are a special type of software architectures. More specifically, as defined by Nakagawa et al. (2014), "a reference architecture encompasses the knowledge about how to design concrete architectures of systems of a given application domain (e.g., e-Health, AAL, robotics); therefore, it must address the business rules, solutions to address requirements of quality attributes (such as, security, reliability, performance), best practices of software development (for instance, architectural decisions, domain constraints, legislation, and standards), and the software elements (e.g., components, services, modules, legacy

Figure 1. Technologies used in AAL systems



systems) that support the development of systems for that domain. All of these must be supported by a unified, unambiguous, and widely understood domain terminology". Reference architectures can be proposed aiming two goals (Angelov et al., 2012): (i) to standardize existing and new software systems in a domain, giving guidelines about how to address requirements of quality attributes, such as interoperability (offering standard interfaces and protocols), security, reliability, and safety; and (ii) to facilitate the domain understanding, proposing different solutions for specific problems and promoting the consolidation of the domain.

Sometimes the terms reference architecture and reference model have been used interchanged. However, a reference model is an abstract framework for understanding significant relationships among the entities of some domain. It enables the development of specific reference or concrete architectures using consistent standards or specifications supporting domain specifications (Brown et al., 2012). A reference model consists of a minimal set of unifying concepts, axioms, and relationships within a particular problem domain, and is independent of specific standards, technologies, implementations, or other concrete details (Brown et al., 2012). In this perspective, conceptual models that present concepts and their relationships, as well as ontologies of a given domain, can be considered as reference models (Nakagawa et al., 2014).

Moreover, the concepts defined in a reference model can be mapped onto interconnected software elements and used as a backbone to construct reference architectures for a domain (Bass et al., 2003). In this context, whereas a reference model divides the functionality, a reference architecture is the mapping of that functionality onto a system decomposition. The mapping may be, but by no means necessarily is, one to one; i.e., a software element may implement part of a function or several functions from those defined in the reference model (Bass et al., 2003).

3. RELATED WORKS

Currently, several studies (i.e., surveys and literature reviews) can be found presenting important contributions for the architectural design of software systems in the AAL domain.

Garcés et al. (2017a) conducted a systematic mapping to report and detail the most important requirements of quality attributes to be considered in software architectures of AAL systems, namely, reliability, efficiency, performance, usability, security, and safety. Fagerberg et al. (2010) reported a research made by 20 highly qualified experts regarding the standardization of AAL platforms. The aim of this study was to state the importance of creating a common platform for AAL domain. In a similar perspective, Antonino et al. (2011) presented an evaluation based on semi-structured interviews about the most representative AAL platforms according to requirements of quality attributes (i.e., reliability, security, maintainability, efficiency, and safety) and their characteristics. Memon et al. (2014) provided a literature survey on AAL frameworks, systems, and platforms to identify the essential aspects of such systems and investigate the critical issues regarding design, technology, quality of service, and user experience. Garcia & Rodrigues (2015) provided an extensive coverage of applications, software, and information management for AAL, as well as a broad description of hardware and software for ergonomic design pertaining to AAL. Dobre et al. (2016) offered a broader view about existing technological solutions for the main issues regarding AAL and ELE (Enhanced Living Environments), and described resource and data management, fault tolerance, security, monitoring, and control in those solutions. Moreover, Dobre's work presented some scientific and commercial applications and platforms to support the development of AAL and ELE systems. Garcés et al. (2015, 2017b) analyzed different RA for e-Health and related domains; however, their contributions were limited comparing with the ones presented in this work. A more recent study (El murabet, 2018) reported some liabilities of existing models proposed in the AAL domain, and stated the necessity of constructing a general infrastructure for this domain.

Despite the efforts to study approaches for supporting AAL systems development with a focus on quality, there is a lack of studies analyzing how feasible the RA&RM proposed in the AAL domain are.

Considering the need of a detailed panorama on RA&RM for the AAL domain, important contributions of our systematic review are the identification, selection, data extraction, analysis, synthesis, and reporting about: i) the RA&RM proposed for the construction of software architectures in the AAL domain; ii) the categorization of AAL goals for which those RA&RM have been established; iii) the completeness level of RA&RM following the approach presented in (Nakagawa et al., 2012); iv) the evaluation of congruence of RA&RM using the framework proposed in (Angelov et al., 2012); and v) possible improvements for those RA&RM.

4. METHODS

To conduct our systematic literature review, we followed the process proposed by Kitchenham & Charters (2007), which is composed of three main phases: planning, conduction, and reporting. In the planning phase, described in Section 4.1, the objectives, research questions, search strategy, selection criteria, and methods for data extraction and synthesis are detailed. In the conduction phase, presented in Section 5, the search strategy executed is presented together with the selection criteria applied to identify the primary studies for the review. Moreover, in Section 5 is also described the relevant data extracted and used as evidence to answer the research questions. Finally, in the last phase, the results were analyzed and synthesized, and are described in Section 6.

4.1. Planning the Systematic Review

Goals and Research Questions: The main goal of this study is "to identify, analyze, and assess RA and RM proposed in the AAL domain, regarding their applicability, completeness, and congruence." To achieve our goal, the following research questions (RQ) were defined:

RQ1: What are the applications of existing RA&RM for AAL software systems? To have a better understanding of those RA&RM, the RQ1 was refined in two sub-questions:
RQ1.1: Which AAL goals (from those listed in Table 1) the RA&RM address?

RQ1.2: Which were the proposed technologies (e.g., IoT, smart homes, robotics, AmI, etc.) in the RA&RM to address the AAL goals?
RQ2: How complete are the RA&RM for the AAL domain in the definition of their elements?
RQ3: How congruent are the RA&RM for the AAL domain regarding their goals, context, and design?

Search Strategy and Selection Criteria: To answer the RQs, we initially identified the following main keywords: Ambient Assisted Living, Reference Architecture, and Reference Model. Next, we identified related terms for these keywords, and considered the plural form of all keywords and related terms, resulting in the search string presented in Table 2.

We executed the search string in the digital libraries suggested as important for computer science in Dyba et al. (2007) and Kitchenham and Charters (2007): ACM Digital Library, IEEE Xplore, SpringerLink, ScienceDirect, Engineering Village, Scopus, and Web of Science. Furthermore, aiming at not missing any important primary study, we also conducting the snowballing technique, considering studies presented as related work in the reference list of the primary studies considered in our review.

Two selection criteria were used to include relevant studies for our review. We included works that address: (IC1) RA for AAL systems, or (IC2) RM for AAL systems. We excluded works that address: (EC1) architectural design in AAL systems that are out of the definition of RA&RM given in Section 2.2; or (EC2) RA&RM for other domains.

Data Extraction and Synthesis: To obtain the evidence required for answering the RQs, we created a data extraction form[2]. We included in this form information about: (i) AAL goals detailed in Table 1 to answer RQ1.1, (ii) elements that must be contained in RA&RM proposed in (Nakagawa et al., 2012) to answer RQ1.2 and RQ2, and (iii) information proposed in (Angelov et al., 2012) to assess the congruence in RA&RM to answer RQ3. For the data analysis, we used qualitative and narrative synthesis methods as recommended in (Felizardo et al., 2016).

5. RESULTS

Our systematic review was conducted by three researchers with experience in AAL, software architecture, and systematic literature reviews. The conduction of this review was executed in two periods of time. A first execution was made from October 2013 to March 2014, and a recent update was made from March 2018 to April 2018. In this work, we presented all results obtained from both executions.

5.1. Primary Studies Identification

We adapted the search string to each digital library mentioned in Section 4.1. During the search conduction, time limits were not placed, and filters on title, abstract, or keywords were not used. On the completion of this search, we obtained 357 studies. The title and abstract of each study were inspected and the selection criteria (described in Section 4.1) were applied. A total of 282 studies were excluded and 75 studies were selected for detailed inspection. The full text of each one of these studies was read and the selection criteria were again applied. As a result, 18 primary studies were selected to be included in this systematic review. In addition to that, and as planned, we inspected the related work (i.e., the list of references) of each selected primary study and included 4 relevant works.

Table 2. Search string

(“ambient assisted living” OR “ambient assisted” OR “ambient assistance” OR “assisted environments” OR “assistive environments” OR “assisted environment” OR “assistive environment” OR “AAL environment” OR “AAL environments” OR “independent living” OR “assisted life” OR “intelligent living” OR “pervasive healthcare” OR “pervasive health-care” OR “pervasive care”) AND (“reference architecture” OR “reference architectures” OR “reference model” OR “reference models”)

Moreover, 2 additional works were found through manual inspection using the Google Scholar search engine. In total, 24 studies were selected as primary studies for this systematic literature review, and they are listed in Table 3.

Table 3 provides: (i) an ID to identify each study (S1 to S24); (ii) authors and publication year; (iii) type of finding, i.e., reference architecture (RA) or reference model (RM); (iv) names of the RA&RM found; (v) IDs of AAL goals (introduced in Table 1 and detailed in Section 5.2.1) to which the RA&RM were proposed; (vi) technological approaches used in those RA&RM (specified in Section 5.2.2); (vii) completeness level of each RA&RM that was defined through the application of the approach proposed in (Nakagawa et al., 2012); (viii) congruence of each RA&RM defined at using the framework proposed by Angelov et al. (2012); and (ix) type of contributors of each RA&RM, i.e., from industry (I) or academy (A), or both.

In the remainder of this section, we present evidence to answer our three RQs introduced in Section 4.1.

5.2. RQ1 - Application of RA&RM for AAL Domain

This RQ provides an overview of existing RA&RM for the AAL domain. We found 24 existing RA&RM for AAL systems depicted in Figure 2. The first RA was published in 2005 and the first RM in 2006. Since then, the creation of RA&RM has been continuous. The year of 2010 has the majority of contributions of RA for AAL systems. As showed in this figure and in Table 3, we found six studies that propose RM (i.e., S2, S15, S16, S19, S20, and S23), sixteen studies that define RA (i.e., S1, S3, S4, S5, S6, S7, S8, S9, S10, S11, S13, S17, S18, S21, S22, and S24), and two studies that propose both RM and RA (i.e., S12 and S14).

5.2.1 AAL Goals of RA&RM

RA&RM have been proposed to achieve different AAL goals (previously presented in Table 1). Existing RA&RM can support the development of AAL systems to address one or more of the following goals:

(G1.A) AAL for health, rehabilitation, and care: Solutions supporting the individualized therapies and care to improve the quality of life of disabled or dependent people or patients with chronic conditions (Broek & Wehrmann, 2010). We identified that, only one study (out 24), specifically S18, can be a possible contributor to guide AAL systems intended for this purpose.

(G1.A.a) Person-centered health management: Solutions that offer medical assistance to people through various wearable, mobile, or implanted sensor devices, and maintain a summary of the person's medical records, containing treatments, diseases, allergies, medications, and other interventions (Broek & Wehrmann, 2010). Systems with this purpose empower the person with relevant knowledge and with online support allowing him or her to take more responsibility for their own health. Eleven RA&RM intend to support the management of people's health, namely, S3, S7, S8, S9, S10, S11, S12, S13, S14, S16, and S21. This goal is the most addressed by RA&RM, since 45.8% (11/24) of studies offer an alternative to achieve this goal.

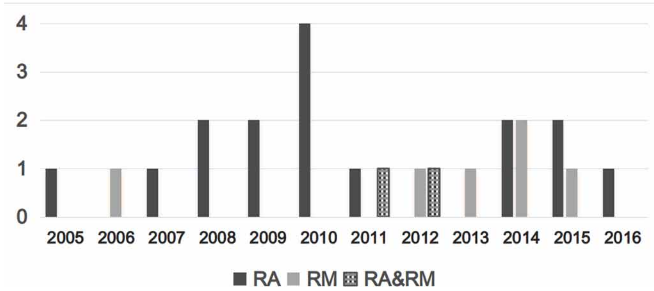
(G1.A.b) Tele-monitoring and self-management of chronic diseases: Solutions that support the remote monitoring of patient's status and self-managing of their chronic diseases (or pathological conditions), for instance, chronic obstructive pulmonary disease or chronic cardiovascular disease. Five studies (20.8% of studies), namely, S8, S9, S10, S14, and S16, are intended to achieve this goal.

(G1.A.c) Support for caregivers and care organizations: Solutions that allow care givers from multiple disciplines to offer an integrated care to the patient. We found that 12.5% (3/24) of studies, i.e., S5, S19, and S22, were defined to guide the development of AAL systems to achieve this purpose.

Table 3. RA&RM for AAL systems

ID	Author	Type	Name	AAL Goals	Technological Approach	Completeness Level	Congruent	Industry (I) / Academy (A)
S1	Liu et al. (2005)	RA	SISARL	G1.D.c	Smart home & e-Health	Acceptable	No	A
S2	Roussos & Marsh (2006)	RM	NR	G1.D.c	Smart home & e-Health	Acceptable	Yes	A
S3	Berger et al. (2007)	RA	AmIRA	G1.A.a; G1.B; G1.D.c	AmI	High	Yes	A
S4	Kurschl et al. (2008)	RA	NR	G1.D	AmI & Smart home	Acceptable	Yes	A
S5	Beale & Heard (2008)	RA	openEHR	G1A.c.	Electronic Health Records	Acceptable	Yes	I, A
S6	Fernandez Montes et al. (2009)	RA	NR	G1.D	Smart home	High	Yes	I
S7	Hietala et al. (2009)	RA	FeelGood	G1.A.a	e-Health	Very High	Yes	I, A
S8	Kameas & Calemis (2010)	RA	NR	G1.A.a; G1.A.b; G1.C; G1.D.c	Smart home & e-Health	Low	No	A
S9	Kehagias et al. (2010)	RA	OASIS	G1.A.a; G1.A.b; G1.B; G1.C; G2.A.a; G2.C; G3.B	AAL ecosystems	High	Yes	I, A
S10	Wartena et al. (2010)	RA	Continua	G1.A.a; G1.A.b; G1.C; G1.D.c	e-Health	Very High	Yes	I, A
S11	Tazari et al. (2010)	RA	PERSONA	G1.A.a; G1.B; G2.A.a; G2.C	Smart home	High	Yes	I, A
S12	Hanke et al. (2011) and Ferro et al. (2015)	RA&RM	UniversAAL	G1.A.a; G1.B; G2.B	AAL ecosystem	High	No	I, A
S13	Tuomainen & Mikkanen (2011)	RA	Coper	G1.A.a; G1.D.c	Smart home & e-Health	Acceptable	No	I, A
S14	Camarinha-Matos et al. (2012, 2014, 2015)	RA&RM	AAL4ALL	G1.A.a; G1.A.b; G1.D.c; G2.B	AAL ecosystem	Acceptable	Yes	I, A
S15	Sit et al. (2012)	RM	NR	G1.C	Smart home	Low	Yes	A
S16	Faria (2013)	RM	NR	G1.A.a; G1.A.b; G1.D.c; G2.B	AAL ecosystem	Acceptable	Yes	I, A
S17	Denti (2014)	RA	Butlers	G1.B	Smart home	Low	Yes	A
S18	Nitzsche et al. (2014)	RA	AALICE	G1.A	AAL ecosystem	Low	Yes	A
S19	Cavalini & Cook (2012, 2014)	RM	MLHIM	G1A.c.	Electronic Health Records	Very Low	No	A
S20	Pereira (2014)	RM	NIST-CCRA	G1, G2, G3	AAL ecosystem	Very Low	Yes	A
S21	Bandara (2015)	RA	HC-WSO2	G1.A.a	Connected Health	Low	Yes	I
S22	Losavio, Ordaz & Esteller (2015, 2016)	RA	HIS-RA	G1.A.c	Health Information Systems	Very Low	Yes	A
S23	Welge et al. (2015)	RM	OntoAAL	G1, G2, G3	AAL ecosystem	Very Low	Yes	I, A
S24	Samarin (2016)	RA	SHaaSoS	G1.B	Smart home	Very Low	Yes	I

Figure 2. Amount of reference architectures and reference models by year



(G1.B) Personal and home safety and security: Solutions that offer comfort and allow people feeling safe and secure within their own home. Six studies, i.e., S3, S9, S11, S12, S17, and S24, (or 25% of studies) focused on guide the development of this type of solutions.

(G1.C) Personal activity management: Software systems that monitor persons' activities of daily life (ADL) aiming to provide information about a physical or mental condition (Garcés et al., 2015). These systems can signal cognitive decline or prevent incidents. Personal activity management systems can be developed using studies S8, S9, S10, and S15 (or 16.6% of studies), which were proposed to support the AAL activity management systems.

(G1.D) Person-centered services: Solutions oriented to support persons with impairments and disabilities in performing the daily tasks, such as shopping, feeding, personal care, social interaction, and communication, considered important activities to maintain a desirable level of quality of life. We found two studies, S4 and S6 (8.3% of studies), which offer general guidelines to support the construction of AAL systems at offering person-centered services.

(G1.D.c) Personal care: Solutions that, sometimes involve assistance robots, to support people in carrying out personal activities, such as taking medications, dressing and undressing, and personal hygiene (Garcés et al., 2015). Personal care systems can be developed based on the knowledge presented in eight studies, namely, S1, S2, S3, S8, S10, S13, S14, and S16 (or 33.3% of studies).

(G2.A.a) Participation in community activities: Solutions that allow to elderly or disabled people to participate actively in their community, offering information, participation, and physical access to public services and buildings (Broek & Wehrmann, 2010). Knowledge contained in two studies, S9 and S11 (or 8.3% of studies), can be used as a guide to create this type of AAL solutions.

(G2.B) Entertainment and leisure: Solutions that offer to people new ways to keep active and alert, allowing activities for brain training, exercising, and gaming. We found three studies, namely, S12, S14 and S16 (or 12.5% of studies), that can orient the development of AAL systems for entertainment and leisure services.

(G2.C) Mobility: Solutions created to decrease risks in pedestrian environments, supporting the individual mobility to disabled and elder people in both indoor and outdoor environments. We found two studies, S9 and S11 (or 8.3% of studies), that offer knowledge about how AAL systems can assist such mobility.

(G3.A) Support for working: Solutions that offer mechanisms to allow people with disabilities and elderly people to work and extend their employment (Broek & Wehrmann, 2010). We found that just S9 provides instruments to create AAL systems that improve working conditions of disabled and elderly people.

(G1, G2, G3) AAL for persons, in the community, and at work: Two studies S20 and S23 (8.3% of studies) offer generic solutions to support the construction of AAL systems, independently of their goals. Both studies are RM, hence, their abstraction level is higher compared with RA.

5.2.2. Technologies Used in RA&RM for AAL Systems

Technologies that can be presented in AAL systems were described in Section 2.1.1. In our review, we found that RA&RM in the AAL domain consider technologies of Smart Homes, e-Health, AmI, Electronic Health Records (EHR), Health Information Systems (HIS), Connected Health, and AAL ecosystems. Smart homes were proposed by 41.6% (10/24) of studies, namely, S1, S2, S4, S6, S8, S11, S13, S15, S17, and S24; AAL ecosystems were reported in 29.2% (7/24) of studies, i.e., S9, S12, S14, S16, S18, S20, and S23; e-Health solutions were addressed in 25% (6/24) of RA&RM, particularly in S1, S2, S7, S8, S10, and S13; AmI technology was comprised in S3 and S4, representing the 8.3% (2/24) of studies. Similarly, EHR were reported in 8.3% (2/24) of studies, i.e., S5 and S19. Finally, Connected Health and HIS technologies were respectively used in S21 and S22.

5.3. RQ2 - Completeness Assessment of RA&RM for AAL Systems

This RQ investigates groups of elements that should be contained in any RA&RM (i.e., groups of domain, application, infrastructure, and crosscutting elements). Those elements were identified and defined in (Nakagawa et al., 2012), to guide the construction of reliable RA&RM. We applied Nakagawa's approach to identify and understand information contained in existing RA&RM for the AAL domain, and to characterize missing information in those architectures and models. Table 4 summarizes completeness levels of each RA&RM, considering each group of elements. Group of elements are listed in the first column of Table 4. Moreover, a general level of completeness of each study (S1 - S24), considering all elements (listed in second column of Table 4) in all groups of elements is also given in last row of Table 4. We established five categories of completeness level for each group of elements, namely VL (Very Low), L (Low), A (Acceptable), H (High), and VH (Very High). Completeness categories were designated based on the number of elements (by group of elements and in total) presented in each study.

Results of this assessment showed that:

- 21% (5/24) of RA&RM (i.e., S19, S20, S22, S23, and S24) are very incomplete considering all elements groups, since descriptions of most of their elements are of very low quality;
- 21% (5/24) of RA&RM (i.e., S8, S15, S17, S18, and S21) have a low completeness level, since they do not offer enough details about all elements considered in this assessment;
- 29% (7/24) of RA&RM (namely, S1, S2, S4, S5, S13, S14, and S16) have an acceptable level of completeness, contemplating almost all elements of all groups;
- 21% (5/24) of RA&RM (i.e., S3, S6, S9, S11, and S12) present a high completeness level, since they provide comprehensive information of most elements groups;
- Finally, S7 and S10 were considered as the most complete RA, representing 8% (2/24) of studies; hence, both RA achieved a very high completeness level for all elements groups.

Moreover, the group of infrastructure elements was the most considered by RA&RM with 87.5% (21/24) of studies reporting at least one element in this group. The group of crosscutting elements was considered by 83% (20/24) of RA&RM, followed by the last two groups of domain and application elements, each of them with 70.8% (17/24) of RA&RM contemplating at least one element in each group.

Several elements demonstrated to be of utmost concern for RA&RM in the AAL domain. 83% (20/24) of the RA&RM detailed the general structure of their solutions; 75% (18/24) described the software elements contained in their structure; and 66.6% (16/24) specified requirements of quality attributes for their solutions. Moreover, 66.6% of RA&RM defined the terminology and scope for the domain (represented as AAL goals) for which those architectures and models were proposed.

Important elements, such as legislation, standards, regulations, limitations, risks, best practices, and guidelines, were not advised as expected and required for the AAL domain, since less than 29%

Table 4. Completeness assessment of RA for AAL systems

Group	Element	S1	S2*	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Domain elements	Legislation, standards, regulations										X		
	Quality attributes		X	X		X		X		X	X	X	X
	System compliance										X		
Completeness by Group of Domain Elements		VL	L	L	VL	L	VL	L	VL	L	VH	L	L
Application elements	Constraints	X		X			X	X		X	X		
	Domain data	X		X	X	X	X	X		X	X		X
	Functional requirements		X	X	X	X	X	X		X	X	X	X
	Goals and needs		X	X	X		X	X		X	X	X	X
	Limitations		X	X	X		X	X				X	
	Risks				X			X				X	
	Scope		X	X	X	X	X	X	X	X	X	X	X
Completeness by Group of Application Elements		L	A.	H	H	A	H	VH	L	H	H	H	A
Infrastructure elements	Best practices and guidelines					X		X		X	X	X	X
	General structure	X	X	X	X	X	X	X	X	X	X	X	X
	Hardware elements	X	X	X	X	X	X	X	X	X	X	X	X
	Software elements	X	X	X	X	X	X	X	X	X	X	X	X
Completeness by Group of Infrastructure Elements		H	H	H	H	VH	H	VH	H	VH	VH	VH	VH
Crosscutting elements	Decisions		X		X		X	X		X	X	X	X
	Domain terminology	X		X	X	X	X	X	X	X	X	X	X
	External communication	X						X			X		X
	Internal communication	X	X	X		X	X	X		X	X	X	X
Completeness by Group of Crosscutting Elements		H	A	A	A	A	H	VH	L	H	VH	H	VH
Overall Completeness for All Groups of Elements		A	A	H	A	A	H	VH	L	H	VH	H	H
Group	Element	S13	S14	S15*	S16*	S17	S18	S19*	S20*	S21	S22	S23*	S24
Domain elements	Legislation, standards, regulations			X	X			X			X	X	
	Quality attributes	X			X	X		X	X	X	X	X	
	System compliance			X	X								
Completeness by Group of Domain Elements		L	VL	H	VH	L	VL	H	L	L	H	H	VL
Application elements	Constraints					X							
	Domain data	X	X										
	Functional requirements	X	X			X							
	Goals and needs	X	X										
	Limitations	X	X			X							
	Risks												
	Scope	X	X		X	X		X					

continued on following page

Table 4. Continued

Group	Element	S1	S2*	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Completeness by Group of Application Elements		H	H	VL	L	A	VL	L	VL	VL	VL	VL	VL
Infrastructure elements	Best practices and guidelines				X								
	General structure	X	X	X		X	X		X	X			X
	Hardware elements		X				X						
	Software elements	X	X		X		X			X			X
Completeness by Group of Infrastructure Elements		A	H	L	A	L	H	VL	L	A	VL	VL	A
Crosscutting elements	Decisions			X	X								
	Domain terminology		X	X	X						X	X	
	External communication	X		X						X			
	Internal communication						X			X			
Completeness by Group of Crosscutting Elements		L	L	H	A	VL	L	VL	VL	A	L	L	VL
Overall Completeness for All Groups of Elements		A	A	L	A	L	L	VL	VL	L	VL	VL	VL

(Legend: VL - Very Low; L - Low; A - Acceptable; H - High; VH - Very High)

(7/24) of the RA&RM documented such information. Moreover, an important evidence is that less than 50% (12/24) of RA&RM gave information on how to implement internal communication among their components. Similarly, less than 29% (7/24) of RA&RM provide information about how to establish communication between AAL systems with external systems. Therefore, most RA&RM have been proposed without considering interoperability among AAL systems, an open issue that must be overcome by actors in this domain in future works.

5.4. RQ3 - Congruence Analysis of RA&RM for AAL Systems

This RQ investigates whether RA&RM have been approached in an intuitive way without a clearly structured background, or if they have been established in a consistent way. Therefore, we applied the framework proposed in (Angelov et al., 2012) that defines five different types of congruence (i.e., Type1 to Type5) that could be presented in RA. Results of applying the Angelov's framework are presented in Table 5.

The Angelov's framework describes that RA&RM can be constructed with the goal of supporting standardization of systems in the domain, or to facilitate the understanding about how to create such systems. The context of RA&RM is defined by their practical use (i.e., in single or multiple organizations), type of organizations that define the RA&RM (i.e., software organizations, user organizations, or independent organizations), and how the RA&RM are defined (i.e., classical, based on well-known domain knowledge; or preliminary, laying the backbone of innovative systems in the domain). Finally, the design proposed in RA&RM is analyzed regarding their internal software structures (components, connectors, interfaces, protocols, and algorithms), the level of detail at describing such structures, the level of abstraction used to define responsibilities of such structures, and the level of formalization used to represent structures, their responsibilities, functionalities, and relationships among those structures. The remainder of this section presents details about types of congruence of the RA&RM found in our systematic review. Information about the goal, context, design and type for each study are provided in Table 4.

Table 5. Congruence assessment of RA for AAL systems

ID	Goal	Context Metrics			Design				RA Type
		Scope of Use	Designed by	Defined as	Structure	Detail Level	Concrete Level	Representation	
S1	Standardize	Multiple organizations	RC	Classical	Components	Aggregated	Abstract	Informal	-
S2*	Facilitate	Multiple organizations	RC	Classical	Components	Aggregated	Abstract	Informal	Type 4
S3	Standardize	Multiple organizations	RC	Classical	Components, Interfaces	Semi-detailed	Abstract	Informal	Type 1
S4	Facilitate	Multiple organizations	RC	Classical	Components	Semi-detailed	Semi-concrete	Informal	Type 4
S5	Standardize	Multiple organizations	RC, SO	Classical	Components, Interfaces, Guidelines, Protocols	Detailed	Concrete	Informal	Type2
S6	Facilitate	Multiple organizations	RC	Preliminary	Components, Algorithms	Semi-detailed	Abstract	Informal	Type 5
S7	Facilitate	Multiple organizations	RC, SO, UO	Preliminary	Components, Interfaces, Guidelines	Semi-detailed	Abstract	Informal	Type 5
S8	Facilitate	Multiple organizations	RC	Classical	Components	Semi-detailed	Abstract	Informal	-
S9	Facilitate	Multiple organizations	RC, SO, UO	Preliminary	Components, algorithms	Detailed	Abstract	Formal	Type 5
S10	Standardize	Multiple organizations	RC, SO, UO StdO	Classical	Components, Interfaces, Guidelines, Protocols	Semi-detailed	Abstract	Formal	Type 1
S11	Facilitate	Multiple organizations	RC, SO	Classical	Components, Interfaces, Guidelines, Protocols	Semi-detailed	Concrete	Semi-formal	Type 3
S12	Standardize	Multiple organizations	RC, SO, UO	Classical	Components, Interfaces	Detailed	Abstract	Formal	-
S13	Facilitate	Multiple organizations	RC, SO, UO	Classical	Components	Aggregated	Abstract	Informal	-
S14	Facilitate	Multiple organizations	RC, SO	Preliminary	Components	Aggregated	Abstract	Semi-formal	Type 5
S15*	Facilitate	Multiple organizations	RC	Preliminary	Components	Aggregated	Abstract	Formal	Type 5
S16*	Facilitate	Multiple organizations	RC, SO	Preliminary	Components, Processes	Aggregated	Abstract	Informal	Type 5
S17	Facilitate	Multiple organizations	RC	Preliminary	Components, Techniques	Aggregated	Abstract	Informal	Type 5
S18	Standardize	Multiple organizations	RC	Classical	Components	Aggregated	Abstract	Semi-formal	Type 1
S19*	Standardize	Multiple organizations	RC	Preliminary	Policies, Guidelines	Aggregated	Abstract	Semi-formal	-
S20*	Facilitate	Multiple organizations	RC	Preliminary	Components, Processes	Aggregated	Abstract	Informal	Type 5
S21	Facilitate	Multiple organizations	SO	Preliminary	Components	Aggregated	Abstract	Informal	Type 5

continued on following page

Table 5. Continued

ID	Goal	Context Metrics			Design				RA Type
		Scope of Use	Designed by	Defined as	Structure	Detail Level	Concrete Level	Representation	
S22	Facilitate	Multiple organizations	RC	Classical	Components, Interfaces, Guidelines, Protocols	Semi-detailed	Semi-concrete	Formal	Type 3
S23*	Facilitate	Multiple organizations	RC, SO, SP	Preliminary	Components, Interfaces, Guidelines	Semi-detailed	Abstract	Informal	Type 5
S24	Facilitate	Multiple organizations	SD	Preliminary	Components	Aggregated	Abstract	Informal	Type 5

Legend: RC - Research Centers, SO - Software Organizations, UO - Users Organizations, StdO - Standardization Organizations, SP - Services Providers, SD - Software Designers

Type 1: RA in this category are classical, oriented to standardize software systems offered by multiple organizations. The design effort is made mostly by independent organizations (e.g., standardization organizations). In most cases, components and interfaces are detailed, since these are the targets for standardization, and guidelines and protocols are defined for the same purpose (Angelov et al., 2012). Elements in those RA are defined in an abstract way (i.e., their description is partially detailed), and are informally represented to facilitate their global understanding by all stakeholders. In this category, we classified three RA (12.5% of studies), namely, S3, S10, and S18.

Type 2: RA in this category are considered classical architectures to be used for standardization in the domain. Similar to type 1, type 2 architectures can define components and interfaces; however, they can be more detailed at describing their elements, specifying more concrete decisions, and representing the knowledge informally. Only one RA, S5, was classified in this category.

Type 3: RA of type 3 are classical architectures to facilitate the understanding of the domain and technical decisions. In most of the cases, these architectures define components, interfaces, protocols, and guidelines in a semi-detailed way, differentiating them from the ones in type 1 and type 2. Two RA (8.4% of studies) were classified as type 3, namely, S11 and S22.

Type 4: RA&RM in this category are classical constructed for facilitation purposes. Their knowledge is informally represented, providing few details about how to realize their elements, and describing functionalities in an abstract or semi-concrete ways. Two RA&RM (8.4% of studies) were categorized as type 4, i.e., S2 and S4.

Type 5: RA&RM are preliminary solutions with facilitation purposes, designed mostly by research centers to be used in multiple organizations in futuristic systems. Therefore, they are considered innovative solutions. An interesting finding of our review was that the majority of RA&RM can be classified in this category. Specifically, 11 RA&RM (45.8% of studies) are futuristic solutions, i.e., S6, S7, S9, S14, S15, S16, S17, S20, S21, S23, and S24. Moreover, four of five RM are in this category, supporting the novelty of their solutions for developing AAL systems in new scenarios and environments not considered until now, such as, AAL ecosystems.

The remainder five RA (20.8% of studies) were not classified in any type, since the information provided did not allow us to find congruence among their goals, context, and design. Hence, they were considered as "*no-congruent*" solutions, as presented in Table 3. Non-congruent RA&RM are reported in S1, S8, S12, S13, and S19.

6. DISCUSSION OF RESULTS

Results evidenced that 45.8% (11/24) of RA&RM found in this literature review are complete (i.e., with acceptable, high or very high completeness levels) and congruent (i.e., classified in any of the five types of congruence). Complete and congruent RA&RM are reported in S2, S3, S4, S5, S6, S7, S9, S10, S11, S14 and S16. Furthermore, academia and software industry in the AAL domain can find in those 11 RA&RM solutions for supporting all AAL goals presented in Section 5.2.1. We also identified that only three complete and congruent RA&RM are oriented to standardization of AAL software systems, i.e., S3, S5, and S10. The remainder eight RA&RM, considered for facilitation purposes, lack of guidelines about how to implement communication between AAL systems and external systems, characteristic of utmost importance to allow the integration and interoperability between those systems.

Considering requirements of quality attributes, we found that the 11 complete and congruent RA&RM determined the following set of attributes as the most important to be addressed in AAL systems: (i) security, giving importance to data protection, people confidentiality, authentication of users and systems (or components, services, software elements), and data integrity; (ii) interoperability, defining mechanisms to AAL systems (or their internal elements) integration; (iii) reliability, considering systems robustness, recovery from faults, trustworthiness of operations, and accuracy in software operations; (iv) scalability, incorporating new systems or attending increasing amount of users and organizations; (v) adaptivity, making modifications and reconfigurations at real-time with limited human interventions; (vi) flexibility, allowing installation of AAL software in different devices and with different settings; (vii) maintainability, facilitating modifications, evolution, and modularization of software systems; (viii) usability, allowing personalization and accessibility considering people disabilities or conditions; and (ix) performance, executing desired operations quickly, avoiding delays in responses to requests, and allowing the quickly response in critical situations. More details about quality attributes for AAL systems are provided in (Garcés et al., 2016, 2017a).

We observed most of the complete and congruent RA&RM were proposed through cooperation between industry and academia. Specifically, we found eight of those architectures and models whose specification was mainly defined by research centers and software organizations. This evidence can be used as a good practice for new RA&RM for AAL systems or other domains, since we consider that interactions between academia and practitioners are important to create innovative software products, improving the sustainability of RA&RM over time (Volpato et al., 2017).

Despite the existence of RA&RM as important artifacts to develop AAL systems, we found a lack of works to promote the reuse of design expertise and facilitate the development, standardization, and evolution of AAL software systems for the following goals: assisting activities of shopping, feeding, and social interaction and communication. Moreover, solutions to support social inclusion, people's creativity, hobbies, sports, and cultural and experience exchanges, are open research issues. Similarly, contributions to engineer technologies to support individual physical mobility, assisted driving, public transport, assurance of environmental working conditions, and prevention of diseases and injuries at work, are also required.

7. CONCLUSION AND FUTURE WORK

The main contribution of this work was to present an assessment of existing RA&RM for AAL domain. Specifically, we presented an analysis of their completeness and congruence using well-known methods in the area of RA. We expect results presented in this work could orient in the selection of the better alternative to be adopted in AAL software projects, independently of their goals. We also intend academia, software industry, or governmental organizations can use this work as a guide to understand the scope of their projects and identify and select pre-defined architectural decisions for their AAL systems. Finally, we expect recent initiatives as AAPELE (Architectures, Algorithms and Platforms for Enhanced Living Environments), a COST Action[3], can use this work as blueprint for their research.

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ENDNOTES

1. http://cordis.europa.eu/fp7/
2. The data extraction form is available to download in: https://www.dropbox.com/s/6zxlnlzp3zeo7ng/Data_Extraction_Form_SLR_RARM_AAL.xlsx
3. AAPELE project can be consulted in: http://www.cost.eu/COST_Actions/ict/IC1303

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