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REFERENCE ARCHITECTURES AND REFERENCE MODELS FOR AMBIENT ASSISTED LIVING SYSTEMS: A SYSTEMATIC LITERATURE REVIEW

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Reference Architectures and Reference Models for Ambient Assisted Living Systems: A Systematic Literature Review

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Abstract

Ambient Assisted Living (AAL) intends to support the everyday lives of elderly people, promoting mainly their independence and dignity. Due to the growing interest on AAL from both academia and society, AAL software systems have widely contributed to set up an AAL research area. Similarly to most software areas that are in their infancy, AAL is in need of fundamental research, dealing with the basic aspects required by a new domain, e.g. software architectures. In this perspective, the investigation of Reference Architectures (RA) and Reference Models (RM) specialized for the domain of AAL is expected to be interesting to both researchers and practitioners of this community. However, to the best of our knowledge, there is a lack of a complete, detailed state of the art on RA&RM for the AAL domain. This lack makes the selection of RA&RM, when intending to use them to develop, standardize, and evolve AAL systems, a rather difficult task. In this paper we present the state of the art on such RA&RM, through a systematic literature review. As main results, we identified and analyzed important RA&RM for AAL, and spotted interesting research directions that should be explored in order to improve existing and future RA&RM for that domain.

Keywords:
Ambient Assisted Living, Reference Architecture, Reference Model, Systematic Literature Review.

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1. Introduction

Ambient Assisted Living (AAL) is a relatively new field that has become an increasingly important, interdisciplinary research topic for both the medical and the technological research communities (Broek et al. , 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). Moreover, software systems for AAL can be seen as superset of Ambient Intelligence (AmI) that includes concepts and technologies from smart homes and eHealth (Buchmayr and Kurschl , 2011). In general, Smart Home technologies focus on controlling devices, while AmI focuses on the perception of the environment. Furthermore, eHealth provides necessary concepts and methodologies to integrate assistive technologies and services into existing systems of nursery, healthcare and eldercare providers (Buchmayr and Kurschl , 2011).

Considering the relevance of AAL software systems in the society, and the diversity of application domains and technologies that AAL embrace, researchers, practitioners, and organizations have advised the importance of creating heterogeneous, interoperable, open, and reusable platforms and standards for AAL domain. For this reason, several reference architectures (RA) and reference models (RM) have been proposed, supported, principally, by the European Commission, under the FP6 and FP7 research calls[1]. In short, RA&RM are a generic type of software architecture that achieves well-recognized understanding of specific domains, which promotes reuse of design expertise and facilitates the development, standardization, and evolution of software systems. Using RA&RM facilitates the development of AAL software systems in a cheaper, faster and more efficient way. Moreover RA&RM could support further growth of AAL market, a market that has not been consolidated despite the efforts made in the last years. However, despite the importance of RA&RM for AAL software systems, to the best of our knowledge there is a lack, in the state of the art, about a complete, and detailed analysis of the RA&RM for the AAL domain. This lack makes the selection of RA&RM for developing, standardizing, and evolving AAL systems a rather difficult task.

In this context, the main objective of this paper is to present the results

[1]http://cordis.europa.eu/fp7/

obtained from conducting a systematic literature review on RA&RM for AAL software systems, based on well-known guidelines presented in Kitchenham and Charters (2007). Additionally, to provide a systematic analysis of the RA&RM that we identified, we used the Angelov's framework (Angelov et al. , 2009) and the RAModel (Nakagawa et al., 2012). The three-dimensional framework proposed by Angelov (Angelov et al. , 2009) allows to analyse if a RA is congruent (i.e., if the RA has relevant goals for its context, and if its design reflects the goals and the context of such RA).

The remainder of this paper is organized as follows. Section 2 presents the background. Section 3 details related work. Section 4 presents the systematic literature review that was conducted, as well as the selected primary studies. 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 conclusion and future work.

2. Background

2.1. Ambient Assisted Living

Aiming at enhancing the quality of life for everyone, the Ambient Assisted Living (AAL) concept emerged in the 1990s, and since the middle of the 2000s it has received more attention. AAL is a relatively new field and has become an increasingly important, multidisciplinary research topic for both the medical and the technological research communities. AAL refers to concepts, products, and services, improving 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., home 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 et al. , 2011). To achieve these goals, AAL interlinks, improves, and proposes new technologies and combines ICT (Information and Communication Technologies) and social environments. In this perspective, AAL can also refer to intelligent systems of assistance (or age-based assistance systems) (Broek et al. , 2010; Pieper et al. , 2011).

AAL systems have been developed in the last years for a variety of sub-domains. Table 1 shows the classification of AAL sub-domains proposed by Afsarmanesh (2011). Furthermore, a range of AAL platforms have been developed in the last years, aimed at supporting and facilitating the development of these systems. In general, these platforms have explored the use of well-known and more consolidated technologies and other key technologies, such as OSGi Alliance (2013), which has been considered one of the most appropriate technologies to be used as a basis for the development of AAL platforms (Antonino et al. , 2011). Currently, the main AAL platforms are: Alhambra (Dimitrov , 2005), Hydra (Hyd, 2013), OASIS (OAS, 2013), Ope (2013), PERSONA (Tazari et al. , 2010a), and UniversAAL (Hanke et al. , 2011). Each of these platforms have been developed for different sub-domains and, correspondingly, has different characteristics (Antonino et al. , 2011).

Table 1: AAL application sub-domains

Category	AAL sub-domains	
D1. AAL for persons	***A.*** *AAL for health, rehabilitation and care*	**a.** Person-centred health management (at home and away from home)
		b. Tele-monitoring and self-management of chronic diseases.
		c. Support for care givers and care organizations;
	B. *Personal and home safety and security*	
	C. *Personal activity management*	
	D. *Biorobotic systems and AAL*	
	E. *Person-centered services*	**a.** Shopping.
		b. Feeding.
		c. Personal care.
		d. Social interaction and communication.
D2. AAL in the community	***A.*** *Social inclusion*	**a.** Participation in community activities.
		b. Creativity, hobbies and sports.
		c. Cultural and experience exchanges.
	B. *Entertainment and leisure*	
	C. *Mobility*	**a.** Supporting individual physical mobility.
		b. Assisted driving (cars/private vehicles).
		c. Public transport.
D3. AAL at work	***A.*** *Assuring environmental working conditions*	
	B. *Support for working*	
	C. *Prevention of diseases and injuries*	
D4. AmI	**A.** Situation awareness	
D5. Smart Environment	**A.** Smart workplace	
	B. Home automation or Smart Home	
D6. AAL ecosystem		

Moreover, AAL software systems must be (Broek et al. , 2010): a) personalizable, i.e., tailored to the users' needs; b) adaptive, i.e., capability to react to the dynamic changes in device/service availability, resource availability, system environment, or user requirements; and c) anticipatory, i.e., anticipating users' desires as far as possible without conscious mediation. Furthermore, AAL systems must also be non-invasive or invisible, distributed throughout the environment or directly integrated into appliances or furniture. Additionally, according to EVAAL[2] (evaluating AAL systems through competitive benchmarking), AAL systems must present the following core functionalities: (i) Sensing: capability of collecting information from any relevant place (e.g., in-/on-body and in-/on-appliance), or environment (e.g., home, outdoor, vehicles, and public spaces); (ii) Reasoning: aggregation, processing, and analysis of data in order to either infer new data or deduce actions to be performed; (iii) Acting: automatic control of the environment through actuators; (iv) Communicating: communications among sensors, reasoning systems, and actuators, where all these components can be connected dynamically; and (v) Interacting: interaction between human users and AAL systems by means of personalized interfaces.

In this perspective, in order to develop AAL systems, knowledge provided by a heterogeneous set of disciplines (e.g., advanced human/machine interfaces, sensors, microelectronics, software, web & network technologies, energy generation or harvesting, control technologies, new materials, and robotics) have to be integrated, resulting in systems that must offer user-centered services. Consequently, one of the main concerns of AAL domain is to embrace diverse technological challenges in order to develop AAL systems.

2.2. Reference Architecture and Reference Models

As defined by Nakagawa et al. (2014), a *reference architecture* refers to an architecture that encompasses the knowledge about how to design concrete architectures of systems of a given application domain; therefore, it must address the business rules, architectural styles (sometimes also defined as architectural patterns that can also address quality attributes in the reference architecture), best practices of software development (for instance, architectural decisions, domain constraints, legislation, and standards), and the software elements that support development of systems for that domain. All of this must be supported by a unified, unambiguous, and widely understood domain terminology (Nakagawa et al., 2014).

Sometimes the terms reference architecture and reference model have been

[2] `http://evaal.aaloa.org/`

used interchanged. However, a *reference model* is an abstract framework for understanding significant relationships among the entities of some environment. It enables the development of specific reference or concrete architectures using consistent standards or specifications supporting that environment (OASIS , 2006). 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 (OASIS , 2006). In this perspective, conceptual models that presents concepts and their relationships, as well as ontologies of given domain, can be considered as a reference model (Nakagawa et al., 2014). Moreover, the reference model mapped onto software elements (that cooperatively implement the functionality defined in the reference model) and the data flows between them is considered as a reference architecture 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. This is, a software element may implement part of a function or several functions Bass et al. (2003).

Aiming at analysing of the reference architectures completeness, Nakagawa et al. (2012) proposed the RAModel, a reference model for reference architectures that provides information on possibly all elements (and their relationships) that could be contained in reference architectures, independently from application domains or purpose of such architectures. As detailed in Table 2, RAModel establishes that a reference architecture is complete if it is composed by four groups of elements:

- **Domain:** It contains elements related to self-contained, specific information of the space of human action in the real world, such as domain legislations, standards, and certification processes, which impact systems and related reference architectures;

- **Application:** It contains elements that provide a good understanding of the reference architecture, its capabilities and limitations. It also contains elements related to the business rules (or functionalities) that can be present in software systems built from the reference architecture;

- **Infrastructure:** It refers to elements that can be used to build the software systems based on the reference architecture. These elements are responsible for enabling these systems to auto-mate, for instance, processes, activities, and tasks of a given domain; and

- **Crosscutting Elements:** It aggregates a set of elements that are usually spread across and/or tangled with elements of other three groups (domain, application, and infrastruc-ture). We have observed that communication (that we have identified as internal and external) in the software systems built from the reference architecture, as well as the domain terminology and decisions are present in a spread and tangled way when describing other groups and are, therefore, crosscutting elements.

Table 2: Groups of elements of RAModel. Source: Nakagawa et al. (2012)

Group	Element	Description
Domain	Legislations, standards, and regulations	Laws, standards, and regulations existing int he domain that should be presented in systems resulted from the reference architecture.
	Quality attributes	Quality attributes, for instance, maintainability, portability, and scalability, that are desired in systems resulted from the reference architecture.
	System compliance	Means to verify if systems developed from the reference architecture follow existing legislation, standards, and regulations.
Application	Constraints	Constraints presented by the reference architecture and/or constraints in specific part of a reference architecture.
	Domain data	Common data found in systems of the domain. These data are presented in a higher level of abstraction, considering the higher level of abstraction of the reference architecture.
	Functional requirements	Set of functional requirements that are common in systems developed using this architecture.
	Goal and needs	Intention of the reference architecture and needs that could be covered by the reference architecture.
	Limitations	Limitations presented by the reference architecture and/or limitations in specific part of a reference architecture.
	Risks	Risks in using the reference architecture and/or risks in using some part of such architecture.
	Scope	Scope that is covered by the reference architecture, i.e., the set of systems developed based on the reference architecture.
Infrastructure	Best practices and guidelines	Well-experimented practices to develop systems of the domain, These practices could be accompanied by guidelines and describing how to apply these practices.
	General structure	General structure of the reference architecture, represented sometimes by using existing architectural styles.
	Hardware elements	Elements of hardware, such as server and devices, which host systems resulted from the reference architecture.
	Software elements	Elements of software present in the reference architecture, e.g., subsystems and classes, which could be used to develop software systems.

Table 2 – *(Continuation)*

Group	**Element**	**Description**
Crosscutting Elements	Decisions	Decisions, including description of the decision, options (alternatives), rationale, and tradeoffs, must be reporting during the development of the reference architecture.
	Domain terminology	Set of terms of the domain that are widely accepted by the community related to that domain and are, therefore, used in the description of the reference architecture.
	External communication	Means by which occur exchange of information between the systems resulted from the reference architecture and the external environment.
	Internal communication	Means by which occur exchange of information among internal parts of systems resulted from the reference architecture.

In the same perspective, based on the fact that a high proportion of current reference architectures have been approached, mostly, in an intuitive way without a clearly structured background, Angelov et al. (2012) propose a framework for the classification and analysis of reference architectures. Moreover, Angelov et al. (2009) state that such architectures could be successful if exist congruence among their context, goals, and design/specification. In this perspective, if a reference architecture can be classified in one of the five types defined in the Angelov's framework, that architecture have better chances to become a success. Table 3 summarizes the Angelov's framework (Angelov et al., 2012).

Table 3: Angelov's framework. Source: Angelov et al. (2012)

Dimension			Type1	Type2	Type3	Type4	Type5
Context	Where it will be used?	Single organization		X		X	
		Multiple organizations	X		X		X
	Who defines it?	Software organizations	X	X	X	X	X
		User organizations	X		X		X
		Independent organizations	X		X		X
	When is defined?	Preliminary reference architecture					X
		Classical reference architecture	X	X	X	X	
Goal	Why is it defined?	Standardization	X	X			
		Facilitation			X	X	X
Design	What is described?	Components and connectors	X	X	X	X	X
		Interfaces	X	X	X		
		Protocols					X
		Algorithms					X
		Policies and guidelines	X	X	X	X	
	How detailed is it described?	Detailed		X		X	X
		Semi-detailed	X	X	X	X	X
		Aggregated		X	X	X	
	How concrete is it described?	Concrete		X		X	
		Semi-concrete		X	X	X	
		Abstract	X		X	X	X

Table 3 – *(Continuation)*

Dimension		Type1	Type2	Type3	Type4	Type5
How is it represented?	Formal		X			X
	Semi-formal	X	X	X	X	X
	Informal				X	

3. Related Work

As relevant to our study, we can identify secondary studies and survey articles that either deal with reference architectures, architecture models or AAL. Concerning RA&RM, Oliveira et al. (2010) conducted a systematic literature review, presenting a broad panorama about RA&RM for SOA. This review investigates: (a) the SOA-related characteristics of such RA&RM, (b) the support that they provide for the development of service-oriented systems, (c) the context in which they can be applied (e.g., academy or industry), and (d) their evaluation and usage level. Furthermore, Pardo et al. (2010) conducted a systematic review about reference models oriented to guide the management of software development in an organizations. Specifically, such review aims to analyse works, initiatives, and projects on the harmonization of multiple and heterogeneous reference models (Pardo et al. , 2010). Additionally, a survey was proposed by Fettke et al. (2005) providing a framework to describe business process reference models, and to orient the developing process of such models. Such framework allowed to analyse the such models in base on criteria such as: (a) application domain, (b) used process modelling languages, (c) model's size, (d) known evaluations, and (e) applications of process reference models.

Regarding AAL, it is possible to find several studies presenting comparisons of different AAL platforms. Fagerberg et al. (2010) present a summary of articles, and experiences of twenty highly qualified experts in the standardization of AAL platforms. The aim of Fagerberg's study was to state the importance of creating a common platform for AAL domain. The creation of a common AAL platform is a huge challenge, because AAL platforms have different focus and, different characteristics. In this perspective, Antonino et al. (2011) present an evaluation of the most representative AAL platforms according to architectural based quality attributes (i.e., reliability, security, maintainability, efficiency, and safety) and their characteristics, through semi-structured interviews. A more recent study gived by Memon et al. (2014) provide a literature survey on AAL frameworks, systems and platforms to identify the essential aspects of such systems and investigate the critical issues from design, technology, quality of service, and user experience point of view.

Considering the need of a detailed panorama on RA&RM for the AAL domain, important contributions of our systematic review is the identification of: i) proposed about RA&RM for AAL domain; ii) AAL sub-domains supported by RA&RM; iii) missed elements in the RA&RM; and iv) the evaluation of RA&RM congruency.

4. Systematic Review Application

Our systematic review was conducted from October 2013 to March 2014 by three researchers: two software engineers and one systematic review specialist. To conduct our systematic review, we followed the process proposed by Kitchenham and Charters (2007). In short, this process is composed of three main phases: 1) planning, 2) conducting, and 3) reporting. These phases are explained in more details during the presentation of our systematic review.

4.1. Planning the Systematic Review

In this phase, the objectives and the protocol of the systematic review were defined. In short, the protocol is a predetermined plan that describes: 1) research objectives and questions, 2) search strategy, 3) selection criteria, 4) data extraction, and 5) the synthesis method.

4.1.1. Research Objectives & Questions:

The goal of this systematic review in terms of the Goal-Question-Metric (GQM) formulation (Solingen et al. , 2002) is: *"Analyse RA and RM for the purpose of characterization with respect to their applicability, completeness and congruency, from the point of view of software architects in the domain of AAL"*.

According to the abovementioned goal, we established three Research Questions (RQs) as presented below:

RQ1: What are the RA&RM available for AAL software systems?

- **RQ1.1:** Which AAL sub-domains have been addressed by the RA&RM?
- **RQ1.2:** Which technologies (e.g., AmI, Smart Home, eHealth) support the development of software systems for AAL domains?

RQ2: Which are the established elements (e.g., domain, application, infrastructure, and crosscutting elements) to design AAL software systems?

RQ3: Do the identified RA&RM have congruent goals, context, and design?

4.1.2. Search Strategy:

In order to establish the search strategy for answering the aforementioned research questions, 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 following 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 care"****) AND (****"Reference Architecture" OR "reference architectures" OR "reference model" OR "reference models"****)***

The previously defined search string has been automatically applied to seven well-known digital libraries, selected based on the criteria discussed in Dieste and Padua (2007). Therefore, we used the digital libraries proposed by Dyba et al. (2007) and Kitchenham and Charters (2007), as the most relevant sources in computer science area, i.e., 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 considered the papers presented as related work in the reference list of the primary studies considered in our review.

4.1.3. Selection criteria:

The selection criteria were used to assess each primary study obtained from the publication databases, allowing, to include only studies that are relevant to answer the research questions. Our inclusion criteria (IC) and, the most relevant, exclusion criteria (EC) were:

IC1: The study proposes/studies a RA for AAL software systems.

IC2: The study proposes/studies a RM for AAL software systems.

EC1: The study proposes/studies a specific architectural design in AAL domain that do not fits in the definition of RA&RM.

EC2: The study proposes/studies RA&RM in a different domain to AAL.

4.1.4. Data extraction and synthesis strategy:

After completing the inclusion and exclusion of primary studies, the included ones, underwent through a data extraction process. More specifically, we used a data extraction form[3], that contains data related to: (a) AAL sub-domains, (b) the RAModel elements, and (c) the Angelov's framework. Data form was structured as follows:

(a) Application sub-domains. : Table 1 presents a complete list of AAL sub-domains identified in Broek et al. (2010).

(b) RAModel elements. (Nakagawa et al., 2012): For analysing RA&RM using the RAModel, we extracted the following information: i)Domain elements (i.e., legislations, standards, regulations, quality attributes,system compliance); ii) Application elements (i.e., constraints, domain data, functional requirements, goal and needs, limitations, risks, and scope); iii) Infrastructure elements (i.e., best practices and guidelines, general structure, hardware elements, and software elements); and iv) Crosscutting elements (i.e., decisions, domain terminology, external communication, and internal communication).

(c) Angelov's framework. (Angelov et al. , 2009): For applying Angelov's framework the extracted information was: i) Goal (e.g., standardization or facilitation); ii) Context (e.g., used by single/ multiple organizations, defined by organizations/ researchers, and preliminary/ futuristic); iii) Design (e.g., components/ protocols/ interfaces, design elements description detailed/ semi-detailed/ aggregated, concrete/ semi-concrete/ abstract representation, and informal/ semi-formal/ informal representation).

[3]The data extraction form is available to download in: `https://www.dropbox.com/s/6zxlnlzp3zeo7ng/Data_Extraction_Form_SLR_RARM_AAL.xlsx`

Moreover, during the data extraction, the data of each primary study were extracted by one researcher involved in this review. In case of doubt, discussions with the other researcher were conducted. As data analysis methods, we performed statistical synthesis.

4.2. Conducting the Systematic Review

In this phase, we adapted the search string established during planning to each data library. During conducting the search, time limits were not placed, and filters on title, abstract, or keywords were not used. On the completion of this process, we obtained 273 primary studies. The title and abstract of each study were inspected and the selection criteria were applied. In total 59 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, 9 primary studies were selected to be included in this systematic review. In addition to that, as planned,we inspected the related work (i.e., the list of references) of each selected primary study. Among all evaluated related work, we selected 5 relevant primary studies (i.e., Berger et al. (2007), FernandezMontes et al. (2009), Hietala et al. (2009), Liu et al. (2005), and Wartena et al. (2010)), which had not been previously identified. Finally, a set of 14 studies was selected as the most relevant for our systematic review and are presented in Table 4.

5. Reporting

During the reporting phase the obtained results, concerning each research question, are presented. The remaining section is organized according to the research questions presented in section 4.1.1.

5.1. RQ1: RA&RM for AAL

This research question provides an overview of existing RA&RM for AAL. As showed in Table 4, we found three studies that propose RM (i.e., Roussos and Marsh (2006), Camarinha-Matos et al. (2012), and Sit et al. (2012)), and ten studies that present RA (i.e., Liu et al. (2005), Berger et al. (2007), Kurschl et al. (2008), FernandezMontes et al. (2009), Hietala et al. (2009), Kameas and Calemis (2010), Kehagias et al. (2010), Wartena et al. (2010), Tazari et al. (2010), and Tuomainen and Mikkanen (2011)). In addition, we have identified the UniversAAL project (Hanke et al. , 2011), which proposes both a RM and a RA for AAL.

Table 4: Reference Architectures and Reference Models in the AAL domain

ID	Author	Title	Type	Technology	Sub-domains
S1	Liu et al. (2005)	Reference Architecture of Intelligent Appliances for the Elderly	RA	Smart Home & eHealth	(D1.E.c)
S2	Roussos and Marsh (2006)	A Blueprint for pervasive Self-Care Infraestructure	RM	Smart Home & eHealth	(D1.E.c)
S3	Berger et al. (2007)	Ambient Intelligence - From Personal Assistance to Intelligent Megacities	RA	AmI	(D1.A.a), (D1.B), (D1.E.c), and (D4)
S4	Kurschl et al. (2008)	An engineering toolbox to build situation aware ambient assisted living systems	RA	AmI & Smart Home	(D4.1)
S5	FernandezMontes et al. (2009)	Smart Environment Software Reference Architecture	RA	Smart Home	(D5)
S6	Hietala et al. (2009)	FeelGood - Ecosystem of PHR based products and services	RA	eHealth	(D1.A.a)
S7	Kameas and Calemis (2010)	Pervasive Systems in Health Care	RA	Smart Home & eHealth	(D1.A.a), (D1.A.b), (D1.C), and (D1.E.c).
S8	Kehagias et al. (2010)	Implementing an Open Reference Architecture Based on Web Service Mining for the Integration of Distributed Applications and Multi-Agent Systems	RA	AAL	(D1.A.a), (D1.A.b), (D1.B), (D1.C),(D2.A.a), (D2.C), (D3.B), and (D5.A).
S9	Wartena et al. (2010)	Continua: The Reference Architecture of a Personal Telehealth Ecosystem	RA	eHealth	(D1.A.a), (D1.A.b), (D1.C), and (D1.E.c)
S10	Tazari et al. (2010)	PERSONA (PERceptive Spaces prOmoting iNdependent Aging)	RA	AAL	(D1.A.a), (D1.B), (D2.A.a), (D2.C), and (D5.B).
S11	Hanke et al. (2011)	UniversAAL	RA & RM	AAL	(D1.A.a), (D1.B), and (D2.B)
S12	Tuomainen and Mikkanen (2011)	Reference architecture of application services for personal well-being information management.	RA	Smart Home & eHealth	(D1.A.a) and (D1.E.c).
S13	Camarinha-Matos et al. (2012)	A Collaborative Services Ecosystem for Ambient Assisted Living	RM	Smart Home & eHealth	(D1.A.a), (D1.A.b), (D1.E.c), (D2.B), and (D6).
S14	Sit et al. (2012)	Application-Oriented Fusion and Aggregation of Sensor Data	RM	AmI & Smart Home	(D1.C), and (D6).

AAL sub-domains of RA&RM:

Concerning application sub-domains of AAL, for which RA&RM have been proposed, relevant results are presented in the last column of Table 4. The detailed list of the corresponding sub-domains is showed in Table 1. It worths mentioning that 64.3% (i.e., 9/11) of RA&RM were established for person-centred health management systems (D1.A.a). Additionally, Personal care systems (D1.E.c) are supported by the 50% (i.e., 7/14) of the proposed RA&RM. Other sub-domains that are quite sufficiently handled by RA&RM (i.e., considered in the 28.6% of studies) are: i) tele-monitoring and self-management of chronic diseases (D1.A.b); ii) personal and home safety and security (D1.B), and iii) personal activity management (D1.C).

Technologies on RA&RM:

Finally, Table 4 presents the technologies (e.g., Smart Home, AmI, and eHealth) that are used by the RA&RM in the AAL domain. Thus, we underline that 35.7% (i.e., 5/14) of RA&RM utilize eHealth & Smart Home technologies (i.e., S1, S2, S7, S12, and S13). AmI & Smart Home technologies are used by 14.3% (i.e., 2/14) of RA&RM (i.e., S4, and S14). Furthermore, 21.4% (i.e., 3/14) of RA are oriented to more heterogeneous AAL systems, intending to involve all scope of AAL domain (i.e., S8, S10, and S11).

5.2. RQ2: RA&RM elements

This research question investigates the elements (i.e., domain, application, infrastructure, and crosscutting elements), defined in RAModel (Nakagawa et al., 2012), in order to understand which information is contained, and which is missing, in the definitions of RA&RM proposed for AAL software systems.

5.2.1. Domain elements:

Concerning domain elements, the results of our systematic review, suggest that corresponding standards, defined just in S9 and S12, are related with healthcare information management (e.g., Health Level 7 -HL7). Also, it is worth to notice that Continua (i.e., S9), is the only RA that offers a homogeneous security framework that helps service providers to ensure compliance with legislation. Another important finding is that the most commonly occurring domain element (i.e., defined by 57.1% of studies, or 8/14) is the definition of quality attributes (QAs). The most common QAs addressed by the RA&RM for AAL domain are [4]: (a) *interoperability* by 87.5% (i.e., 7/8), (b) *scalability* by 50% (i.e., 4/8), (c) *confidentiality*, *maintainability*, *privacy*, and *trustability*, by 37.5% (i.e., 3/8) of RA&RM. Moreover, RA&RM for AAL software systems deal with the following critical attributes: (a) *security* by 50% (i.e., 4/8), (b) *reliability* by 37.5% (i.e., 3/8), (c) *integrity* and *performance* by 25% (i.e., 2/8), and (d) *availability*, *dependability*, and *safety* by 12.5% (i.e., 1/8) of RA&RM.

5.2.2. Application elements:

Regarding application elements, functional requirements, goals & needs were specified by 78.57% (i.e., 11/14) of studies. In addition, with respect to functional requirements, OASIS [5] and UniversAAL [6], offer a complete analysis on reference use cases. Moreover, from Table 5, we can induce that current RA&RM do not describe their risks when such RA&RM are used.

5.2.3. Infrastructure elements:

An important remark is that information about general structure, hardware and software elements were contemplated by 93% (i.e., 13/14) of studies. Moreover, just 35.7% (i.e., 5/14) of RA&RM defined best practices and guidelines to orient the development of AAL software systems. In this perspective, we can induce that most RA&RM are oriented to describe technical software and hardware architecture.

With respect to the general structure of AAL systems, it was possible to identify several reuse technologies (e.g., architectural styles, frameworks, ontologies, or meta-models) adopted/proposed by the RA&RM. Thus, 64.3% (i.e., 9/14) studies used multi-layered styles (i.e., S1, S3, S4, S5, S6, S7, S11, S13, and S14), whereas Service Oriented Architecture (SOA) style was used by 35.7% (i.e., 5/14) of studies (i.e., S2, S6, S8, S11, and S12). Additionally, multi agents were used by S8, and publish-subscribe style was applied by S10 and S14. Finally, frameworks were proposed by 42.8% (i.e., 6/14) of studies (i.e., S1, S8, S9, S10, S11, and S12), meta-models were created by 14.3% (i.e., 2/14) of RA&RM (i.e., S3 and S10), and ontologies were used in 14.3%

[4] Complete list about QAs addressed by RA&RM is available in `https://www.dropbox.com/s/h92ouypn68z8usf/Quality_Attributes_List.xlsx`

[5] `http://www.oasis-project.eu/docs/OFFICIAL_DELIVERABLES/SP2/D2.1.1/OASIS_D2_1_1_v3.0.pdf`

[6] `http://universaal.org/images/stories/deliverables/d1.1-d.pdf`

(i.e., 2/14) of studies (i.e., S8 and S11).

Table 5: Elements defined in RAModel

Group	Element	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Domain	Legislations, standards, and regulations									X					X
	Quality Attributes		X	X			X		X	X	X	X	X		
	System compliance									X					X
Application	Constraints	X		X		X	X		X	X					
	Domain data	X		X	X	X	X		X	X		X	X	X	
	Functional requirements		X	X	X	X	X		X	X	X	X	X	X	
	Goal & needs		X	X	X	X	X		X	X	X	X	X	X	
	Limitations		X	X	X	X	X				X		X	X	
	Risks						X								
	Scope		X	X	X	X	X	X	X	X	X	X	X	X	
Infrastructure	Best practices and guidelines						X		X	X	X	X			
	General structure	X	X	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	X	
Crosscutting elements	Decisions		X		X	X	X		X	X	X				X
	Domain terminology	X		X	X	X	X	X	X	X	X	X		X	X
	External communication	X					X			X		X	X		X
	Internal communication	X	X	X		X	X		X	X	X	X			

5.2.4. Crosscutting elements:

Description of decisions, alternatives, rationale, and tradeoffs, was reported in 57.1% (i.e., 8/14) of studies.

Domain terminology was described by 85.7% (i.e., 12/14) of studies. In this context, we identified some common domain concepts of the RA&RM, such, sensor, actuator, perception, Human Machine Interface (HMI), autonomous behaviour, context data, situation-awareness, medical health records, monitoring, Activity of Daily Lives (ADL), AAL space, and Body Signal Sensors (BSS), that were defined in the majority of RA&RM.

External communication was defined by 35.7% (i.e., 5/14) of studies. RA&RM define communication with external systems using network interfaces (i.e., S1 and S6), external service integrators (i.e., called as uaaltools in S11), information source services (i.e., S12), and using the publish-subscribe style (i.e., S14).

Internal communication was specified by 64.3% (i.e., 9/14) of studies, using internal monitoring and control components (i.e., S1), gateways (i.e., S2), interfaces between layers (i.e., S3 and S5), interfaces for each component (i.e., S6 and S9), web services interfaces (i.e., S8 and S11), and event-based & call-based communication (i.e., S10).

5.3. RQ3: Congruency of RA&RM

This research question investigates the congruency of the RA&RM for AAL software systems. In short, RA&RM are congruent if their goals are relevant for the context of the RA&RM and their design reflects their goals and context. For this, we applied the Angelov's framework (Angelov et al. , 2009) for each RA&RM found in this review. Results are presented in Table 6.

Table 6: Application of Angelov's framework Angelov et al. (2009)

Study	Goal	Context			Design				Type
		C1	C2	C3	D1	D2	D3	D4	
S1	S	M.O	R.C	Classical	Components	Aggregated	Abstract	Informal	-
S2	F	M.O	R.C	Classical	Components	Aggregated	Abstract	Informal	-
S3	S	M.O	R.C	Classical	Components & Interfaces	Semi-detailed	Abstract	Informal	-
S4	F	M.O	R.C	Classical	Components	Semi-detailed	Semi-concrete	Informal	-
S5	F	M.O	R.C	Preliminary	Components & Algorithms	Semi-detailed	Abstract	Informal	-
S6	F	M.O	S.O, U.O, & R.C	Preliminary	Components, Interfaces, & Guidelines	Semi-detailed	Abstract	Informal	-
S7	F	M.O	R.C	Classical	Components	Semi-detailed	Abstract	Informal	-
S8	F	M.O	S.O, U.O, & R.C	Preliminary	Components & Algorithms	Detailed	Abstract	Formal	Type 5
S9	S	M.O	S.O, U.O, R.C & Std.O	Classical	Components, Interfaces, Guidelines & Protocols	Semi-detailed	Abstract	Formal	Type 1
S10	F	M.O	S.O & R.C	Classical	Components, Interfaces, Guidelines & Protocols	Semi-detailed	Concrete	Semi-formal	Type 3
S11	S	M.O	S.O & R.C	Classical	Components & Interfaces	Detailed	Abstract	Formal	-
S12	F	M.O	S.O, U.O, & R.C	Classical	Components	Aggregated	Abstract	Informal	-
S13	F	M.O	S.O & R.C	Preliminary	Components	Aggregated	Abstract	Semi-formal	Type 5
S14	F	M.O	R.C	Preliminary	Components	Aggregated	Abstract	Formal	Type 5

The main observations derived from Table 6 are:

- *Goal of the RA&RM:*
  - 36.4% (i.e., 4/11) of RA aim at standardization (i.e., S) of AAL software systems.
  - 63.6% (i.e., 7/11) of RA, and 100% of RM aim at facilitating (i.e., F) the design of concrete architectures for AAL domain.
- *C1 - Scope of the RA&RM:*
  - 100% of RA&RM were established to be used in multiple organizations (i.e., M.O).
- *C2 - Organizations that designed the RA&RM:*
  - 100% of RA&RM had the participation of research centers (i.e., R.C).
  - 45.5% of RA (i.e., 5/11) and 66.6% (i.e., 2/3) of RM had support of software organizations (i.e., S.O).
  - 27.3% (i.e., 3/11) of RA and 33.3% (i.e., 1/3) of RM had the contribution of user organizations (i.e., U.O).
  - 9.1% (i.e., 1/11) of RA had the support of standardization organizations (i.e., Std.O).
- *C3 - Timing of RA&RM definition:*
  - 72.7% (i.e., 8/11) of RA and 33.3% (i.e., 1/3) of RM are classical (i.e., designed after experience from commercial application has already been accumulated)
  - 27.3% (i.e., 3/11) of RA and 66.6% (i.e., 2/3) of RM are preliminary (i.e., defined before there exist significant practical experiences with the design of concrete architectures).
- *D1 - Design elements:*
  - 100% or RA&RM defined components,
  - 45.4% (i.e., 5/11) of RA established interfaces,
  - 18.2% (i.e., 2/11) of RA described algorithms,

  - 27.3% (i.e., 3/11) of RA specified guidelines, and
  - 18.2% (i.e., 2/11) of RA determined protocols.

- *D2 - Levels of detail for RA&RM elements:*
  - 18.2% (i.e., 2/11) of RA and 100% of RM and have an *aggregated* detail level for its components.
  - 63.3% (i.e., 7/11) of RA have a *semi-detailed* description of its design elements.
  - 18.2% (i.e., 2/11) of RA (i.e., S8 and S11) have a *detailed* representation level of components.

- *D3 - Level of abstraction of RA&RM:*
  - 81.8% of RA (i.e., 9/11) and 100% of RM are *abstract*,
  - 9.1% of RA (i.e., 1/11) are *semi-concrete*, and
  - 9.1% of RA (i.e., 1/11) are *concrete*.

- *D4 - Representation of RA&RM:*
  - 63.6% (e.g., 7/11) of RA and 66.6% (e.g., 2/3) of RM were informally represented,
  - 27.3% (e.g., 3/11) of RA were formally represented (e.g., using UML), and
  - 9.1% (e.g., 1/11) of RA and 33.3% (e.g., 1/3) of RM were semiformally represented.

Based on the aforementioned dimensions (i.e., goal, context, and design dimensions), and on the five types of reference architecture given by Angelov's framework (Angelov et al. , 2009), we were able to classify the RA&RM for AAL domain, as follows:

- 27.3% (i.e., 3/11) of RA and 66.6% of RM (i.e., 2/3) matched in one of the RA types proposed in the Angelov's framework.
- S8, S13, and S14 were classified as Type 5, this is, RA&RM that were designed to facilitate the design of architectures of systems that will become needed in the future.

- S10 was classified as Type 3 reference architecture, designed to promote a software product of the designing organization by describing its main components and interfaces, and providing guidelines for their implementation.
- S9 was classified as Type 1, a classical, standardization reference architecture designed to be implemented in multiple organizations.

Quality Assessment

In order to analyse the quality of the included primary studies, based on the quality assessment created by Kitchenham and Charters Kitchenham and Charters (2007), we developed a checklist containing ten questions. For each question in the checklist, the following scale-point was applied[7]: the study fully meets a given quality criterion (1 point), the study meets the quality criterion in some extent (0.5 point), and the study does not meet this quality criterion (0 point). Thus, the total quality score fell into the range between: 0 - 2.0 (poor); 2.1 - 4.0 (fair); 4.1 - 6.0 (average); 6.1 - 8.0 (good), and 8.1 - 10.0 (excellent). As result of quality assessment, three RA (e.g., S8, S9, and S11) have an excellent quality, followed by the RM S13 that obtained a good quality. Average quality was assigned to RA S3, S6, and S10, and fair quality was established to S2 and S14, both RM. Others RA (e.g., S1, S4, S5, S7, and S12) obtained a poor quality.

6. Discussion

As main outcome of this study, it is possible to conclude that there is a lack of RA&RM that promote reuse of design expertise and facilitate the development, standardization, and evolution for important AAL sub-domains, such as, **D1.A.c** Support for care givers and care organizations (e.g., reasoning systems on all available data); **D1.D** Biorobotic systems (e.g., operational machine or exoskeleton-like machines for rehabilitation); and **D3.** AAL for work to assure environmental working conditions, and to prevent diseases and injuries. Moreover, we believe that there is a need for a RA specialized for AAL ecosystems (D6), i.e., a recent and complex sub-domain. In short, an AAL ecosystem could be seen as a System of Systems (SoS),

[7]Questions and scores assigned for each RA&RM are available in `https://www.dropbox.com/s/92vng9fx8l3m5fx/Quality_Assessment_SLR_RA\%26RM_AAL.xlsx`

this is, large-scale integrated systems that are heterogeneous and independently operable on their own, but are networked together for a common goal (Jamshidi , 2009). Furthermore, there is a lack of RA&RM supporting AAL software systems using, simultaneously eHealth & AmI & and Smart Home technologies (e.g., situation awareness home, or supportive home systems).

Moreover, we found that interoperability, security, and scalability are the most important quality attributes considered by RA&RM for AAL domain. Such quality attributes were considered, at least, by 50% (i.e., 4/8) of studies that defined QAs. Additionally, another finding is that Continua (Wartena et al. , 2010) and UniversAAL (Hanke et al. , 2011) are the only reference architectures that address critical attributes (i.e., performance, availability, dependability, safety, security, reliability, and integrity). This result suggests that the majority of RA&RM must consider the aforementioned critical attributes to support the development of AAL software systems leading with situations with high potential of emergency (e.g., a hearth attack situation). Furthermore, our results sugest that standardization organizations do not have an active participation in the construction of RA&RM for AAL domain. Moreover, the fact that just 27.3% (i.e., 3/11) of RA and 33.3% (i.e., 1/3) of RM, had support from user organizations, research centers, and software organizations, indicates that the majority of proposed RA&RM for AAL domain, are research-oriented instead of user, community, and commercial oriented. This result seems to be consistent with the fact that only four RA are oriented to standardization.

Additionally, this review allowed us to identify and point out, based on the RAModel (Nakagawa et al., 2012), that the most complete reference architectures for AAL software systems are OASIS (Kehagias et al. , 2010), Continua (Wartena et al. , 2010), and UniversAAL (Hanke et al. , 2011), followed by PERSONA (Tazari et al. , 2010), AmIRA (Berger et al. , 2007), and FeelGood (Hietala et al. , 2009). Moreover, the aplication of Angelov's framework, permitted the classification of OASIS, Continua, and PERSONA as congruent RA, that could be instantiated for developing effective, and with high success probability, AAL software systems. Table 7 presents possible improvements for each one of this reference architectures.

Table 7: Possible improvements for RA&RM

RA&RM	Description	Improvements
OASIS	Futuristic reference architecture, defined for facilitating the development, for multiple organizations, of service oriented software systems for multiple AAL subdomains. Due to this characteristics, OASIS has a high level of generality.	It is needed to dedicate efforts in establishing domain (e.g., legislation, standards, regulations, and system compliance), application (e.g., limitations and risks), and infrastructure (e.g., external communication) elements.
Continua	Standardization reference architecture, designed to be implemented in multiple organizations for eHealth applications. The level of generality of Continua is high.	Are required specifications about the limitation and risks, when used this RA in the development of AAL software systems.
UniversAAL	The level of generality of UniversAAL is high, due to it intends to cope software systems for all AAL domain. It not matched within the types RA offers by Angelov's framework.	This RA needs support of user & standardization organizations, to be considered as a standardization reference architecture. Additionally, is necessary the definition of important elements such as, legislation, domain standards, regulations, system compliance, and risks.
PERSONA	Facilitation reference architecture , designed to be implemented in multiple organizations and for multiple AAL applications, making it to have a high level of generality.	It is necessary the definition of legislations, standards, regulations, system compliance, constraints, risks, domain data, and external communication elements.
AmIRA	It aims to be a standardization reference architecture for AmI technologies applied in AAL software systems.	It is required the stablishment of legislation, standards, regulations, system compliance, risks, decisions, and external communication elements. Moreover, to be considered as a standardization RA, AmIRA needs involving software, users, and standardization organizations, and also, requires the adoption of a formal representation.
FeelGood	It intends to be a facilitation reference architecture for eHealth software systems.	This RA needs to define protocols and system compliance to be considered as a facilitation and futuristic reference architecture. Additionally, this RA requires the adoption of a formal representation.

7. Threads to validity

In this section, we present possible threats to the validity of our study, specifically, we discuss about: (a) construct validity threats, (b) internal validity threats, and (c) threats to conclusions validity.

Construct threats to validity. Concerning our search process, to be as inclusive as possible, no limits were placed on date of publication and we avoided imposing restrictions (such as, filters by title, abstract, and keywords) on primary study selection, since we wanted a broad overview of the research area. Additionally, by performing a global search on indexing systems such as Scopus, Engnineering Village, and Web of Science, we aimed to include as many as possible of papers. Moreover, related works presented in the reference list of the selected primary studies also were considered. However, it is possible we have missed some papers.

Internal validity threats. Due to the extensiveness of information needed to apply the RAModel and the Angelov's framework, it was needed to search additional information, apart of the provided by the selected digital libraries, about primary studies. For this, we used the search engine of the Cordis[8] system, which indexes technical reports of projects supported by European Commission. In this perspective, for such projects we realized a more complete analysis, and possibly they had better results, than projects for which we not found additional information.

Threats to conclusions validity. In the case of our study, factors that could lead to incorrect conclusions, are related to identification of primary studies, i.e., missing studies that should have been included in the review, and incorrect data extraction. Both these threats were discussed in detail in the previous paragraphs.

8. Conclusion and Future Work

The main contribution of this systematic literature review, was the identification of current RA&RM for AAL software systems. For evaluation reasons the identified RA&RM were analysed using the RAModel (Nakagawa et al., 2012), aiming to understand the information (e.g., domain, application, infrastructure, and crosscutting elements) contained in them, and to identify which information is missing in order to propose needed improvements to RA&RM for AAL software systems. Also, RA&RM were classified using Angelov's framework (Angelov et al. , 2009), with the aim of establishing the level of success for AAL concrete architectures based on such RA&RM. With this information, software architects can have a starting point when deciding about which RA or RM will guide their AAL concrete architectures in a sucessful way.

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[8]http://cordis.europa.eu/

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