Quality attributes and quality models for ambient assisted living software systems: A systematic mapping

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Abstract

Context: Ambient Assisted Living (AAL) has become an essential, multi-disciplinary research topic, aiming at providing software systems and services that assist people in their everyday life activities. Considering the critical nature of AAL systems, several initiatives have already contributed to the improvement of their quality, by mainly focusing on their non-functional requirements. Despite the importance of quality assurance in AAL systems, there is a lack of a comprehensive analysis on how quality assurance is performed in such systems. This fact might in turn lead to an absence of standardization with regard to the quality assurance process of these systems.

Objective: We provide a broad, detailed panorama about the state of the art on quality models (QMs) and quality attributes (QAs) that are important for the AAL domain.

Method: We performed a Systematic Mapping (SM). We used six publication databases to cover all published material pertinent for our SM. We initially obtained 287 studies that were filtered based on a set of well-defined inclusion/exclusion criteria, resulting into a set of 27 studies that were used for

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exploring QAs for AAL systems.

Results: The most common QAs used in the development of AAL systems were identified and defined. We also characterized important critical attributes for software systems in the AAL domain. Additionally, QAs for some AAL sub-domains were defined. Furthermore, we investigated how QM&QA have been defined, evaluated, and used in that domain. Finally, we offered an analysis of the maturity of the studies identified in our SM.

Conclusion: It is necessary to develop a complete QM that: (i) defines all common QAs for AAL systems; (ii) considers variability of QAs among AAL sub-domains; (iii) analyses dependences among QAs; (iv) offers indicators or metrics to measure QAs; and (v) offers means to assess and predict quality of AAL systems.

Keywords: Quality Attribute, Quality Model, Ambient Assisted Living, Systematic Mapping, ISO/IEC 25010

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1. Introduction

Ambient Assisted Living (AAL) constitutes a fundamental research domain that has recently received significant attention, mainly in Europe and North America. AAL has arisen as a philosophy that includes methods, products, services, and AAL systems to support the everyday lives of disabled and elderly people, promoting mainly their independence and dignity [1].

The development of AAL systems is considered quite complex, since [1]: (i) such systems sometimes involve different technologies, like actuators, sensors, communication technologies, and software systems of related domains (e.g., eHealth or smart homes); (ii) they must be personalizable, adaptive, and anticipatory; and (iii) they must be non-invasive (or invisible) and must be developed to fit different circumstances, e.g., use at home or at work, or through mobile support.

AAL systems can be considered as embedded ones, in the sense that they refer to computational systems designed to perform one or several dedicated specific functions, sometimes, as part of a complete device including hardware and mechanical parts [2]. Moreover, AAL systems are critical due to the fact that, in case of failure, they may cause serious damage to human lives [3]. Furthermore, AAL systems exhibit hard constraints on critical quality attributes, such as dependability, safety, performance, and security [3]. In this perspective, the assurance of quality requirements should be considered a key concern during the development of AAL software systems. In the current literature, one can identify several initiatives, intending to improve and to some extent guarantee the quality of such systems. These initiatives have mainly discussed on the use of general quality models (QMs) and the definition of quality attributes (QAs). However, to the best of our knowledge, there is a lack of a complete, detailed panorama on how quality is being treated in AAL systems. Additionally, the state of the art lacks reporting a consensus on which are the most relevant QAs, critical attributes, or QMs that could be more fitting for AAL systems. Moreover, there is an absence of a broad analysis on the strategies used to establish quality requirements of AAL systems (i.e., target QAs).

Motivated by the aforementioned shortcomings in the state of the art, the main contribution of this article is to provide a broad, detailed panorama on QAs that are important in the AAL domain. For this, we have applied the Systematic Mapping (SM) technique [4], which enables researchers to conduct a complete and fair evaluation of a topic of interest. Important points of contribution expected are: (i) the identification and analysis of approaches utilized to define, evaluate and use the QAs and QMs found in the literature; (ii) the identification of the most important QAs for AAL systems; and (iii) the proposal of research topics that should be investigated. In parallel, we also intend to initiate a broader research area that promotes the development of quality-based AAL systems, centered mainly on the welfare of elderly and disabled people.

The remainder of this work is organized as follows. Section 2 presents a background on quality in software systems, focusing in QAs and QMs; this section also presents a background on the AAL domain. Section 3 provides an overview of related works. Section 4 presents the planning and conduction of our SM. Section 5 reports results of our mapping and the quality assessment of these results. Section 6 provides a discussion on the main findings and identifies perspectives of future research. Section 7 discusses threats to validity of our mapping. Finally, Section 8 presents our conclusion and future work.

2. Background

In this section, we briefly present the context in which our SM is placed. To achieve this, we briefly present a background on quality assessment of software systems, including QMs and QAs. Moreover, we discuss the objectives, the sub-domains, and the most important characteristics of AAL systems.

2.1. Quality of software systems

Over the years, a variety of models has been proposed aiming to support the software development, through the description, assessment, and/or prediction of software quality [5]. Such QMs allow the identifation of QAs that can be used so as to orient the design of software systems. Through this perspective, it is possible to find three types of QMs [6]: definition QMs, assessment QMs, and prediction QMs, which are detailed as follows.

Definition QMs: Models that provide taxonomies or hierarchical decompositions of QAs. Shortly, a QA[1] is a characteristic of software that specifies the degree of an attribute that affects the required software quality [7]. Definition QMs aim at decomposing quality down to a level that allows to measure and evaluate the software quality. Important definition quality models have been established during the last decades. The QM proposed by McCall et al. [8] is considered as the precursor of the modern QMs. McCall's model established three major perspectives for defining and identifying the quality of a software product: product revision, product transition, and product operations. Each of these perspectives describes a set of QAs that refers to the ability of a software

[1]Quality attribute is a generic term to quality factors, quality subfactors, or metric values [7]

system to undergo changes, to adapt to new requirements, and to adequately perform its functionalities. Similarly, the QM established by Boehm et al. [9] attempts to qualitatively define software quality by a given set of attributes and metrics.

Moreover, the ISO (International Organisation for Standardization) and the IEC (International Electrotechnical Commission) proposed the international standard ISO/IEC 9126 [10] in 1991 and, as its successor, in 2011, the set of international standards denominated ISO/IEC 25000:SQuaRE (Systems and software Quality Requirements and Evaluation) [11]. SQuaRE defines the ISO/IEC 25010 [11] and the ISO/IEC 25012 [12] standards that establish QMs for computer systems and software products, quality in use, and data. Specifically, ISO/IEC 25010 standard defines: (i) a "software product quality model" composed of eight characteristics (i.e., functional suitability, reliability, performance efficiency, usability, maintainability, security, compatibility, and portability), which are further subdivided into subcharacteristics measured internally or externally; (ii) a "system quality in use model" composed of five characteristics (i.e., satisfaction, effectiveness, freedom from risk, efficiency, and context coverage), which are further subdivided into subcharacteristics measured when a product is used in a realistic context of use.

Assessment QMs: These models evaluate QAs detailed in the definition QMs. Examples are the metric-based models such as Maintainability Index (MI) [13] that organizes the software factors to determine or influence maintainability into a hierarchical structure of measurable attributes, and for each attribute, a consistent metric definition is established. MI is comprised of weighted Halstead metrics (effort or volume), McCabe's Cyclomatic Complexity, lines of code (LOC), and number of comments [14]. Another example is Qualixo [15], a factor-criteria-metrics QM that uses measurements to assess software quality. These measurements cover a number of specification accuracy, programming rules, and test coverage [15]. Goyal and Joshi [16] developed a model based on the QMOOD (Quality Model for Object Oriented Design) [17] to assess QAs of design properties of Java programs (e.g., reusability, functionality, effectiveness, understandability, extensibility, and flexibility).

Prediction QMs: These models are usually based on source code metrics or past defect detection data to estimate the number of systems defects, mean times between failures, repair times, and maintenance efforts [6]. Good examples of these models are the Software-Reliability Growth Models (SRGM), which attempt at modelling processes associated with software failures, using various assumptions related to the test procedures. Discussion of the earlier SRGM was presented by Zeephongsekul et al. [18]. One of the most recent SRGM was proposed by Ahmad [19], which established a stochastic model as a counting process to represent the number of failures experienced in a given period of time by the system.

2.2. Ambient Assisted Living

Aiming at enhancing the quality of life for everyone, the Ambient Assisted Living (AAL) domain emerged in the 1990s, and by the middle of the 2000s, it starts to receive more attention. AAL is a relatively new field and has become an increasingly important, multidisciplinary research topic for both medical and 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 people) in all stages of their life [1]. AAL is primarily concerned with the individual in his/her immediate environment (e.g., home or work) by offering user-friendly interfaces for all sorts of equipment in the home and outside, by taking into account that many older people have impairments in vision, hearing, mobility, or dexterity [20]. To achieve these goals, AAL interlinks, improves, and proposes solutions that combine ICT (Information and Communication Technologies) and social environments.

AAL systems have been developed in the last years for a variety of subdomains. In Table 1 we present a classification of AAL sub-domains proposed by Afsarmanesh [21] as result of the BRAID project [22]. This classification is focused on four different sub-domains that correspond to the main areas of persons life [22]: (i) Independent Living: assists daily life activities (e.g., medical reminders, living status monitoring) and supports people mobility (e.g., shopping assistance, smart wheelchairs); (ii) Health and Care in Life: assists patients in health-related activities, e.g., remote health monitoring, emergency assistance, exercise assistance; (iii) Occupation in Life: supports elders to continue their professional activities; and (iv) Recreation in Life: facilitates socialization and participation of ageing citizens in social, leisure, learning, and in cultural and political activities.

Table 1: Classification of AAL sub-domains. Adapted from Afsarmanesh [21].

First level	**Second level**	**Third level**
Independent living	Daily life assistance	Home safety and care
		Personal activity management
	Supporting physical mobility	Localization/positioning assistance
		Mobility and transportation
Health and care	Monitoring	Chronic diseases
		Sensorial supervision

Continued on next page

Table 1 – *Continued from previous page*

First level	Second level	Third level
Health and care	Rehabilitation and disabilities compensation	Physical compensation
		Neuro-cognitive compensation
		Rehabilitation
	Caring and intervention	Healthcare management
		Healthy lifestyle intervention
		Medication assistance
Occupation in life	Ageing at work	Inter-generational relations
		Adjusted working space
	Extending professional life	Keeping links former employers
		Freelancing & entrepreneurship
		Professional communities
Recreation in life	Socialization	Social events management
		Virtual communities
	Learning	Remote learning
		Experiences exchanging
	Entertainment	Recreation activities
		Cultural activities
		Gamming

Moreover, in terms of functionality, AAL software systems must be [1]: 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. Additionally, according to EvAAL [23][2], AAL systems must present the following core functionalities:

- *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);
- *Reasoning*: aggregation, processing, and analysis of data to either infer new data or deduce actions to be performed;
- *Acting*: automatic control of the environment through actuators;

[2]EValuating AAL systems through competitive benchmarking EvAAL [23]

- *Communicating*: communications among sensors, reasoning systems, and actuators, where all these components can be connected dynamically; and
- *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) has 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 to appropriately develop AAL systems.

3. Related Work

Due to the lack of directly related work (i.e., secondary studies on the quality assessment of AAL systems), in this section we present works (i.e., systematic reviews, surveys, and experience reports) that analyse QAs in application domains similar to AAL, i.e., embedded and healthcare systems.

Firstly, starting with the most generic type of systems in which AAL can be classified, Oliveira et al. [24] presented a detailed state of the art about QMs and QAs for embedded systems. The findings of that systematic literature review suggested that the most important QAs for embedded systems are understandability, reliability, security, safety, functionality, efficiency, portability, and testability.

Regarding the healthcare domain, Mairiza et al. [25] provided a catalog of non-functional requirements (NFRs) and highlighted several NFRs (i.e., communicativeness, confidentiality, integrity, performance, privacy, reliability, safety, security, traceability, and usability) as the most frequently considered in this domain. In a similar effort, Wangenheim et al. [26] established a model to meet quality requirements for asynchronous store-and-forward telemedicine systems.

In this work, they defined context completeness, flexibility, time behavior, resource utilization, capacity, co-existence, and interoperability as the most important attributes that such systems must have. Concerning mobile health systems, Akter et al. [27] identified reliability, availability, efficiency, and privacy as the prominent quality characteristics for health services provided over mobile platforms.

Recently, Domínguez-Mayo et al. [28] identified the most studied and used quality characteristics in e-Health systems, following a two-step process. First, they selected two categories of quality characteristics from the ISO/IEC 9126 standard, i.e., external/internal quality and quality in use characteristics.: Second, they conducted a systematic literature review to identify the level of importance of each quality characteristic in such systems. As a result, functionality, effectiveness, and safety were identified as the most used to develop e-Health systems.

A similar research was made by Aghazadeh et al. [29], who evaluated the effects of software quality characteristics and sub-characteristics on the healthcare indicators: user satisfaction, quality of patient care, clinical workflow and efficiency, care providers communication and information exchange, patient satisfaction, and care costs. The most important health quality indicators in relation to software quality characteristics were established based on a literature review. As contribution, the study of Aghazadeh et al. proposed a model based on ISO/IEC 9126 standard that establishes relations between software quality characteristics and health quality indicators. Relations were evaluated through expert opinion analysis. Some important findings were: (i) software functionality affects directly the quality of patient care; (ii) clinical workflow is influenced by the software efficiency; (iii) communication is affected by software maintainability; (iv) usability and efficiency influence on patient satisfaction; and (v) care costs are affected by software maintainability, efficiency, and reliability.

Finally, we can observe that the identification of the state of the art on QMs and QAs for the AAL domain is interesting in order to complement the previous studies conducting until now.

4. Systematic Mapping Process

In order to conduct our SM, we followed the process proposed by Kitchenham and Charters [4], as showed in Figure 1. Sections 4.1, 4.2 and 5 present in details, the planning, conducting and reporting phases, respectively.

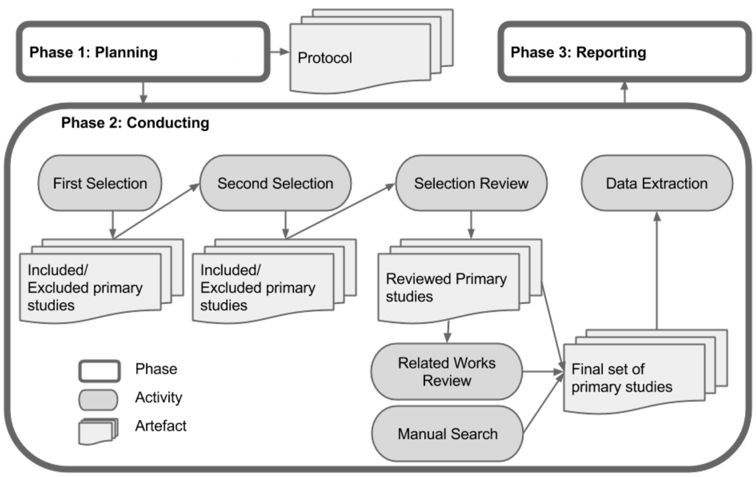


Figure 1: Systematic Mapping Process. Adapted from [4]

4.1. Planning

In this phase, the research objectives and the SM protocol were defined. This protocol contains: (i) research objectives and research questions; (ii) search strategy; (iii) selection criteria (i.e., inclusion and exclusion criteria); (iv) procedures for the studies selection; and (v) data extraction and synthesis method.

4.1.1. Research Objectives & Research Questions

In order to guide the planning of our SM, we adopted the Goal-Question-Metrics (GQM) approach [30], which is considered one of the most powerful approaches for research planning. This approach involves three elements: (i) the goal to be achieved; (ii) a set of questions that must be answered to achieve the goal; and (iii) a set of metrics needed to answer the questions.

Regarding our SM, the goal is to provide a broad, detailed state of the art on the existing QMs and QAs for AAL software systems, focused on: (i) which QMs and QAs are the prominent ones in the AAL domain; (ii) how they have been established; and (iii) how they have been evaluated. Based on this goal, three research questions, four subquestions, and related metrics were established, as presented in Table 2.

Table 2: Research Questions and Metrics

Research Questions	Metrics
RQ_1: Which are the QMs or QAs proposed for AAL software systems?	(1) QMs or QAs found for AAL software systems; (2) Number of occurrences of each QM or QA found;
$RQ_{1.1}$: Which are the critical QAs (e.g., safety, security, performance, and dependability) proposed for AAL software systems?	(1) QAs that are critical for AAL software systems; (2) Number of occurrences of each critical QA.
$RQ_{1.2}$: Which are the AAL sub-domains that present QMs or QAs?	(1) AAL sub-domains that present QMs or QAs; (2) Number of occurrences of each QM or QA in each AAL sub-domain; (3) Differences in QMs or QAs across AAL sub-domains.
RQ_2: How have QMs or QAs for AAL software systems been established?	(1) Approaches used to establish QMs or QAs; (2) Number of occurrences of each approach.
$RQ_{2.1}$: Which are the information sources (e.g., personal experience, existing systems or architectures) used to define QMs or QAs for AAL software systems?	(1) Information sources used to define QMs or QAs; (2) Number of occurrences of each information source; (3) The most important information sources.
$RQ_{2.2}$: Are the QMs or QAs presented in a prescriptive (i.e., how quality should be addressed) or descriptive (i.e., how quality has been addressed) manner?	(1) Approach used for presenting QMs or QAs; (2) Number of occurrences of each approach.
RQ_3: How have QMs or QAs for AAL software systems been evaluated?	(1) Approach used (e.g., no evaluation, toy example, case study, experiment, and evaluation in industry); (2) Number of occurrences of each approach ; (3) Technological Teadiness Level (TRL).

4.1.2. Search strategy

To establish the search strategy for answering the research questions, we initially established the Population (i.e., AAL systems) and the Intervention (i.e., quality of AAL systems) of our SM. Hence, we identified two main keywords: "Ambient Assisted Living" and "Quality Attribute". Subsequently, we identified terms related to these keywords and we considered the plural form of all keywords and related terms. Afterwards, we used the Boolean operator OR to link the main term and their synonyms; furthermore, all these terms were combined using the Boolean operator AND, resulting in the following search string:

("Ambient Assisted Living" OR "ambient assisted" OR "ambient assistance" OR "assisted environment" OR "assistive environment" OR "AAL environment" OR "independent living" OR "assisted life" OR "intelligent living" OR "pervasive living" OR "assistive environments" OR "AAL environments" OR "assisted environments")

AND

("quality model" OR "quality attribute" OR "non-functional property" OR "non-functional requirement" OR "quality requirement" OR "quality models" OR "quality attributes" OR "non-functional properties" OR "non-functional requirements" OR "quality requirements")

To validate our search string, we defined a control group for our SM. We used two previously known studies (Antonino et al. [31] and Omerovic et al. [32]) that were suggested by an AAL expert. They were our baseline to check whether our search string was properly defined, i.e., if our string was able to find these studies in the publication databases.

With the purpose of selecting the most adequate databases for our search, we considered the criteria discussed by Dieste and Padua [33]. We selected six databases (namely ACM Digital Library, IEEE Xplore, ScienceDirect, Scopus, Springer, and Web of Science). According to Dyba et al. [34] and Kitchenham and Charters [4], these publication databases are the most relevant sources in the computer science area.

4.1.3. Selection criteria

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

- IC_1: The primary study introduces one or more QMs for AAL systems.
- IC_2: The primary study presents one or more QAs that have been reported as important while specifying AAL systems.
- EC_1: The study is a previous version of a more complete one on the same research, of the same authors.
- EC_2: The primary study is a table of contents, short course description, or summary of a conference/workshop.
- EC_3: The primary study is written in a language other than English.
- EC_4: The primary study does not present an abstract or its full text is not available.
- EC_5: The primary study is out of the SM objective.

4.1.4. Procedure for study selection

In our SM, the selection and evaluation of primary studies were performed in five activities, such as illustrated in Figure 1, previously presented.

First selection. The search string was customized and applied to the selected publication databases. For this, time limits were not placed, and filters on title, abstract, or keywords were also not used in the search. As a result, a set of primary studies possibly related to the research topic was obtained. Based on this set, the title, abstract, and keywords of each primary study was read and the inclusion and exclusion criteria were applied. The introduction and the conclusion sections of each primary study were also considered when necessary. As a result, a set of primary studies potentially relevant was selected.

Second selection. Each primary study selected was read in full and analysed again considering the inclusion and exclusion criteria. If the decision about the inclusion or exclusion of a study was not clear, this study was analysed by two reviewers. When a disagreement occured, discussions were conducted.

Selection Review. We tested the reliability of our selection by applying a Visual Text Mining (VTM) technique in our SM, as proposed by Felizardo et al. [35]. This technique supports the exploration and analysis of the set of primary studies selected to ensure that relevant studies were not initially eliminated. This technique offers clues about what studies need to be doubly reviewed for inclusion or exclusion, replacing the random choice strategy defined by Kitchenham and Charters [4]. To apply VTM, we used Revis (Systematic Literature Review Supported by Visual Analytics) tool [36], which enables several VTM capabilities to analyse a set of primary studies. The VTM functionalities of Revis that we used were: (i) the creation of content map, i.e., a visual representation of the primary studies that enables to investigate content and similarity relationships among these studies; (ii) the application of clustering algorithms in order to create primary studies clusters and their respective topics; and (iii) the representation of the studies status, i.e., included or excluded. For instance, Figure 2 shows four clusters of studies with similarities in the title, keywords, and abstract contents. Clusters 2 and 3 contain both included (represented as white circles) and excluded studies (represented as black circles), which means that the four studies into such clusters need to be reviewed to verify the applied selection criteria.

Related works review. We used the snowball technique [37] intending to cover the whole research area. This technique allowed us to identify and examine works cited in the studies selected in the two previous activities (i.e., in the second selection and selection review activities).

Manual search:. We used the "Google Scholar" search engine to identify possible studies that were not found neither in publication databases nor in the works

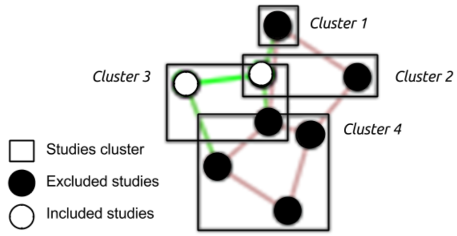


Figure 2: Clusters of studies using the Revis tool

cited by the primary studied selected previously.

As result of these five activities, a set of primary studies that can answer our research questions were obtained.

4.1.5. Quality Assessment

To analyse the quality of each included primary study, we established a checklist containing seven questions (or quality criteria), based on the quality assessment of primary studies proposed by Kitchenham and Charters [4]:

- Q1: Is there a rationale for why the study was undertaken?
- Q2: Is an overview about the state of the art of the area in which the study is developed presented?
- Q3: Is there an adequate description of the context in which the work was carried out?
- Q4: Is a clear justification about the methods used during the study provided?
- Q5: Are there a clear statement of contributions and sufficient data to support them?
- Q6: Are the credibility and limitations of their findings explicitly discussed?
- Q7: Are the perspectives of future works discussed?

For each question, the following scale-point was applied: (i) the study fully meets a given quality criterion (1 point); (ii) the study meets the quality criterion to some extent (0.5 point); and (iii) the study does not meet this quality criterion (0 point). The total quality score of each study can fell into the range between: 0 - 1.0 (very poor); 1.1 - 2.0 (poor); 2.1 - 3.0 (fair); 3.1 - 4.0 (average), 4.1 - 5.0 (good), 5.1 - 6.0 (very good), and 6.1 - 7.0 (excellent). Studies with score above or equal to 3.0 (fair) were considered for the data extraction.

4.1.6. Data extraction & synthesis strategy

The selected primary studies were underwent through data extraction. More specifically, we used a data extraction form for each primary study. This form also contains data related to each research question. The form can be consulted in [38]. The dataset gathered from these forms supported the synthesis of the results. During the data extraction, data of each primary study was extracted by one researcher involved in this SM. In case of doubt, discussions with other researchers were conducted. To draw conclusions and answer our research questions, we performed qualitative analysis. The mapping between metrics and research questions has already been presented in Table 2; therefore, it is omitted in this sub-section.

4.2. Conducting the Systematic Mapping

Our SM was conducted from August to December 2015. During the conducting phase, primary studies were identified, selected, and evaluated using the inclusion and exclusion criteria. For each selected study, data were extracted and synthetized according to the protocol presented in Section 4.1. Figure 3 shows the results for each activity previously described in Section 4.1.4.

4.2.1. First selection

We adapted the search string established during the planning to each publication database, as detailed in [38]. We obtained 302 primary studies and removed duplicate ones (i.e., 15 studies), remaining 287 studies for analysis. To support the management of the primary studies, we used Mendeley [39],

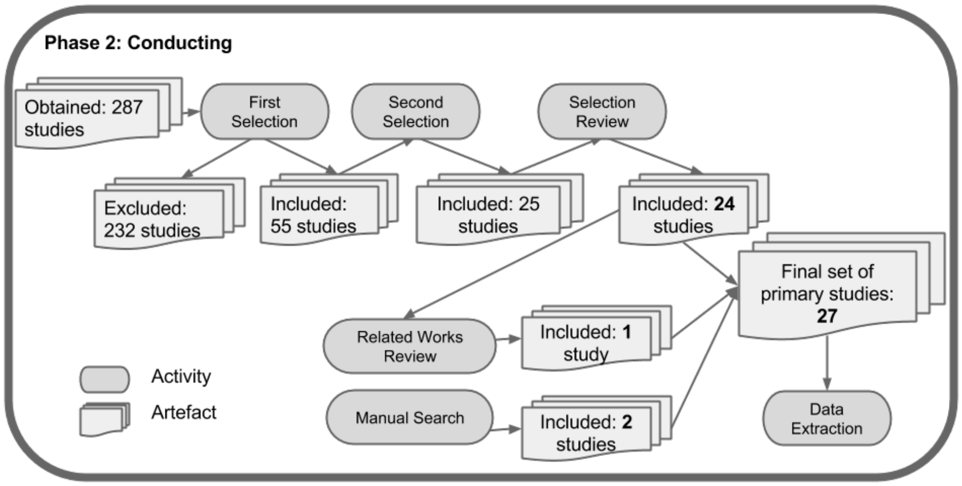


Figure 3: Search conduction results

a reference management tool that allows storing information on the primary studies (e.g., title, authors, book title, and abstract), as well as the set the exclusion/exclusion criteria applied to select each primary study. As result of this first selection activity, a total of 55 studies were included for detailed inspection, as illustrated in Figure 3.

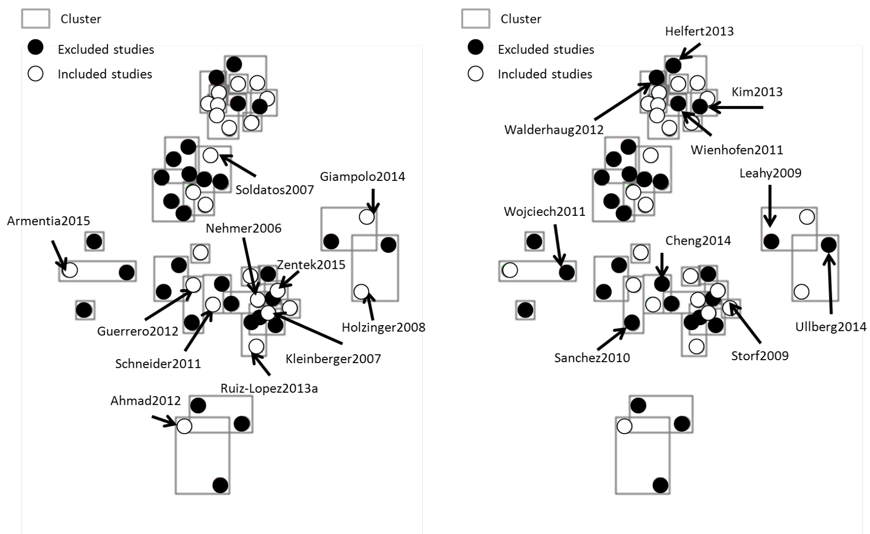
4.2.2. Second selection

The full text of the 55 primary studies was read and the selection criteria were again applied. As a result, 25 primary studies were included and 30 studies were excluded, as shown in Figure 3.

4.2.3. Selection review

To verify the reliability of the results of the second selection activity (i.e., 25 studies included and 30 excluded), we applied VTM techniques in our SM. Specifically, we used the Revis tool [36] to identify if important primary studies were excluded or if irrelevant ones were included.

A content map was created, as showed in Figure 4, containing 30 clusters (represented by rectangles) with the 25 studies included (represented as white



(a) Primary studies reviewed for possible exclusion

(b) Primary studies reviewed for possible inclusion

Figure 4: Content map with 30 clusters of primary studies using Revis tool.

circles) and the 30 studies excluded (represented as black circles). Clusters with mixed studies (i.e., included and excluded studies) were observed. Figure 4(b) and Figure 4(a) highlight the studies that we reviewed again for possible inclusion or exclusion, respectively. Observe that primary studies that were reviewed are in clusters where there are mixed studies (i.e., included and excluded studies). Hence, we reviewed again ten primary studies, which were initially excluded, but possible could be included (See Figure 4(b)). Similarly, we also reviewed other eleven primary studies, which were previously included, but possibly could be excluded, as detailed in Figure 4(a). For instance, Leahy and Dolan [40] is found in a cluster with other included studies (see right side of Figure 4(b)). Hence, it could be possible included; therefore, it was again reviewed. The same strategy was applied to all other studies.

After reviewing the 21 primary studies (11 studies for a possible exclusion, and 10 studies for a possible inclusion), we concluded that one study should be included (Sánchez-Pi and Molina [41]) and two studies should be excluded (

Schneider et al. [42] and Soldatos et al. [43]). As a result, 24 primary studies remained for the data extraction.

4.2.4. Related works review

We applied the snowball technique [37] looking for works cited in the 24 selected primary studies. Among all works evaluated, we selected one relevant primary study (Ras et al. [44]), which had not been previously identified.

4.2.5. Manual search

Moreover, we made a search using Google scholar search engine and we identified two relevant primary studies, Schneider et al. [45] and Queirós et al. [46].

Finally, a set of 27 studies, presented in Table 3, was selected as the relevant ones for our SM. Column "Type" indicates if the primary study was published as a Journal Article (JA), Chapter of Book (CB), Conference Paper (CP), or Web Page (WP). Column "IC" describes the criterion used to include the studies. Column "DL" shows the database where each study was obtained: ACM (ACM), IEEE Xplore (IE), Science Direct (SD), Scopus (Sc), Springer (Sp), Web of Science (WS), and Google Scholar (GS). Moreover, reference search (RS) indicates that we found the study by applying the snowball technique.

Table 3: Final list of primary studies selected to data extraction

ID	Title	Reference	Type	IC	DL
S1	Living Assistance Systems: An Ambient Intelligence Approach.	Nehmer et al. (2006) [47]	CP	IC2	ACM
S2	Ambient Intelligence in Assisted Living: Enable Elderly People to Handle Future Interfaces	Kleinberger et al. (2007) [48]	CB	IC2	Sp
S3	Engineering Tele-Health Solutions in the Ambient Assisted Living Lab	Ras et al. (2007) [44]	CP	IC2	RS
S4	Investigating Usability Metrics for the Design and Development of Applications for the Elderly	Holzinger et al. (2008) [49]	CB	IC2	Sp

Continued on next page

Table 3 – *Continued from previous page*

ID	Title	Reference	Type	IC	DL
S5	Adaptation of an Evaluation System for e-Health Environments	Sánchez-Pi and Molina (2010) [41]	CB	IC2	Sp
S6	Evaluation of AAL Platforms According to Architecture-Based Quality Attributes	Antonino et al.(2011) [31]	CB	IC2	Sc Sp WS
S7	Modeling and Assessing Quality of Information in Multisensor Multimedia Monitoring Systems	Hossain et al. (2011) [51]	JA	IC2	ACM
S8	Using RELAX, SysML and KAOS for Ambient Systems Requirements Modeling	Ahmad et al. (2012) [50]	CP	IC2	WS
S9	An Indoor Navigation System for the Visually Impaired	Guerrero et al. (2012)[52]	JA	IC2	Sc
S10	Data and Information Quality Issues in Ambient Assisted Living Systems	McNaull et al. (2012) [53]	JA	IC2	ACM
S11	Towards a Reusable Design of a Positioning System for AAL Environments	Ruiz-López et al. (2012) [54]	CB	IC2	Sc Sp WS
S12	OptimAAL Quality Model	Schneider et al. (2012) [45]	WP	IC1	GS
S13	Elicitation of Quality Characteristics for AAL Systems and Services	Omerovic et al. (2013) [32]	JA	IC2	Sc Sp
S14	Usability, Accessibility and Ambient Assisted Living: A Systematic Literature Review	Queirós et al. (2013) [46]	JA	IC2	GS
S15	Requirements Systematization through Pattern Application in Ubiquitous Systems	Ruiz-López et al. (2013a) [55]	JA	IC2	Sc
S16	Critical Design Issues for the Development of Smart Home Technologies	Solaimani et al. (2013) [56]	JA	IC2	Sc
S17	Ambient Assisted Living Healthcare Frameworks, Platforms, Standards, and Quality Attributes.	Memon et al. (2014) [57]	JA	IC2	Sc
S18	The Challenges Behind Independent Living Support Systems	Giampaolo et al. (2014) [58]	CB	IC2	Sp
S19	A framework for Evaluating Ambient Assisted Living Technologies and the Experience of the universAAL Project	Salvi et al. (2014) [59]	JA	IC2	Sc
S20	Flexibility Support for Homecare Applications Based on Models and Multi-Agent Technology	Armentia et al. (2015) [60]	JA	IC2	Sc

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Table 3 – *Continued from previous page*

ID	Title	Reference	Type	IC	DL
S21	"Get that Camera Out of My House!" Conjoint Measurement of Preferences for Video-Based Healthcare Monitoring Systems in Private and Public Places.	Arning et al. (2015) [61]	CB	IC2	Sp
S22	Data Quality Oriented Taxonomy of Ambient Assisted Living Systems	Beevi et al. (2015) [62]	CP	IC2	IE
S23	A Semantic Approach for Designing Assistive Software Recommender Systems	Gómez-Martínez et al. (2015) [63]	JA	IC2	Sc
S24	Exploring the Critical Quality Attributes and Models of Smart Homes	Luor et al. (2015) [64]	JA	IC2	Sc
S25	Bridge: Mutual Reassurance for Autonomous and Independent Living	Mangano et al. (2015) [65]	JA	IC2	Sc
S26	Towards the Deployment of Open Platform AAL Services in Real Life-Advantages and Lessons Learned uSmAAL: A Case Study for Implementing Intelligent AAL Services in Real Life based on the Open Platform universAAL	Stengler et al. (2015) [66]	CP	IC2	Sc
S27	Which AAL Middleware Matches my Requirements? An Analysis of Current Middleware Systems and a Framework for Decision-Support	Zentek et al. (2015) [67]	CB	IC2	Sp

It is important to notice that we just found one study (S12) that proposed a QM for AAL systems, i.e., included by IC1. The majority of studies (96,3%, 26/27) provide sets of QAs for AAL systems, i.e., studies included by IC2. Moreover, all studies were published in the last ten years, which might indicate an increasing interest for this research topic.

4.3. Quality Assessment

For each study, we calculated the quality score answering questions presented in Section 4.1.5. Details about scores obtained by each primary study can be consulted in [38]. Nineteen out of 27 studies present good quality, i.e., S9, S13, S16, S19, S20, and S21 can be categorized with excellent quality; S7, S11, S12, S14, S22, S23, S24, S25, and S26 have very good quality; and S2, S6, S17, and

S27 have good quality. Moreover, five studies (S3, S4, S5, S8, and S10) have average quality, and three studies (S1, S15 and S18) can be considered as having fair quality. Therefore, we considered all 27 studies to extract information to answer our research questions.

5. Reporting the Mapping

This section presents the results for each research question defined for our SM. For each question, we provide tables that summarize the collected data, and we present qualitative analysis for this data.

5.1. RQ_1. Quality attributes for AAL software systems

This research question investigates the QAs that are important for AAL software systems, based on their occurrence frequency in the selected primary studies. Besides, this question allows to identify the AAL sub-domains in which QAs have been explored. We also discuss if critical attributes were addressed by these studies.

Initially, we identified 97 attributes from selected studies[3]. To establish a standardized set of QA, we defined and conducted the process presented in Figure 5. This process aims to map the 97 QAs into quality characteristics or sub-characteristics specified by the ISO/IEC 25010 standard. For each QA, QA_i, its definition $cdef_i$ is extracted based on the primary studies that address QA_i. Next, $cdef_i$ is compared to definitions of quality characteristics $qchar[j]$ or sub-characteristics $qschar[k]$ provided by ISO/IEC 25010. If $cdef_i$ matches (or it is similar) to a definition of $qchar[j]$ or $qschar[k]$, QA_i is considered as part of ISO/IEC 25010 standard. Otherwise, $cdef_i$ is compared to definitions of quality characteristics $qchar2[x]$ or sub-characteristics $qschar2[y]$ provided by ISO/IEC 9126. If there is a direct match between the $cdef_i$ and $qchar2[x]$ or

[3]List with all QAs found in this mapping is available in `http://start.icmc.usp.br/files/GarcesLM/FinalListQA-AAL.pdf`

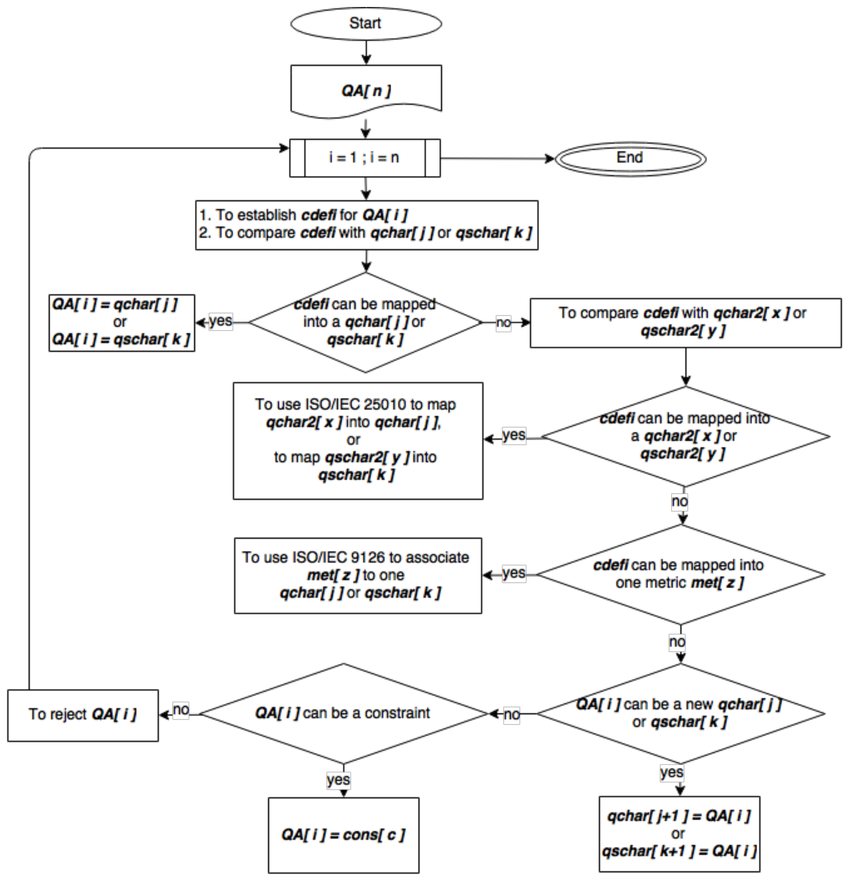

Figure 5: Process to adapt QAs to the standard ISO/IEC 2510

$qschar2[y]$, the Annex A[4] of ISO/IEC 25010 is used to map quality characteristics of ISO/IEC 9126-1 into ISO/IEC 25010. If the $cdef_i$ is not considered as characteristic or sub-characteristic of any of the standards, $cdef_i$ is compared to metrics $met[z]$ for characteristics or sub-characteristics of ISO/IEC 9126. If QA_i is considered as metric $met[z]$, Annex A is used again to associate $met[z]$ to the correspondent characteristic or sub-characteristic into the ISO/IEC 25010. In

[4]Section 3.7 - Relationship between the models. Online: `https://www.iso.org/obp/ui/#iso:std:iso-iec:25010:ed-1:v1:en`

any other case, QA_i is considered as a new quality characteristic $qchar[j+1]$ or sub-characteristic $qschar[k+1]$. Finally, if QA_i is not considered as characteristic, sub-characteristic, or metric of ISO/IEC 25010 nor as a new characteristic or sub-characteristic, it is checked if QA_i can be classified as a constraint. Otherwise, QA_i is not considered as a QA relevant to the AAL domain.

Figure 6 illustrates the QAs found in this work mapped into the standard ISO/IEC 25010. It is interesting to said that we did not find evidence for the use of several QAs defined by the standard ISO/IEC 25010 in the AAL domain (represented as white boxes in Figure 6). Moreover, we identified one QA (i.e., Adaptivity represented as a dashed line box in Figure 6) that is not defined by the standard, but it seems to be relevant for AAL software systems. Represented by gray boxes, most of the QAs defined by the standard ISO/IEC 25010 are considered important to develop software systems for the AAL domain. Table 4 presents the final set of QAs, the primary studies where each QAs was found, and the amount and percentage of studies referring each QA.

Figure 7 illustrates the amount of studies that address each QA. Security, freedom for risk[5], usability, reliability, and adaptivity were considered by at least 40.7% (i.e., 11/27) of studies, as the most important QAs for AAL systems. These QAs are aligned to the nature of AAL software systems that brings assistance to elders and disabled persons in their daily life, protecting their healthcare information, and preserving their health. Discussions on the importance of each QA for the AAL domain are provided in Section 6.

[5]Freedom for risk is referred by the standard ISO/IEC 9126 as safety.

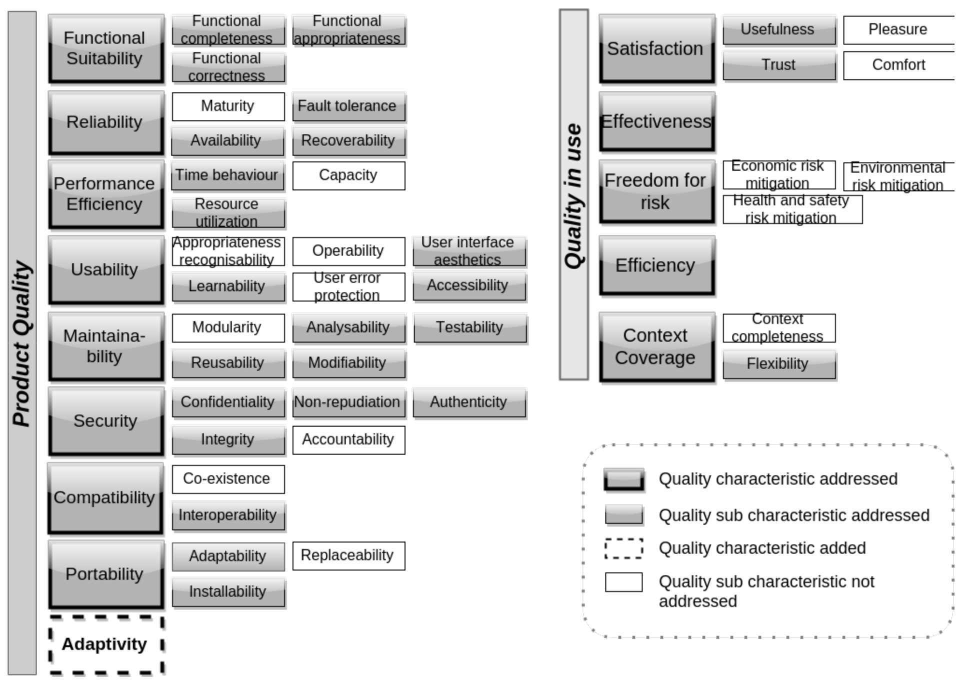

Figure 6: Taxonomical representation of QAs for AAL software systems. Result of mapping to the standard ISO/IEC 25010.

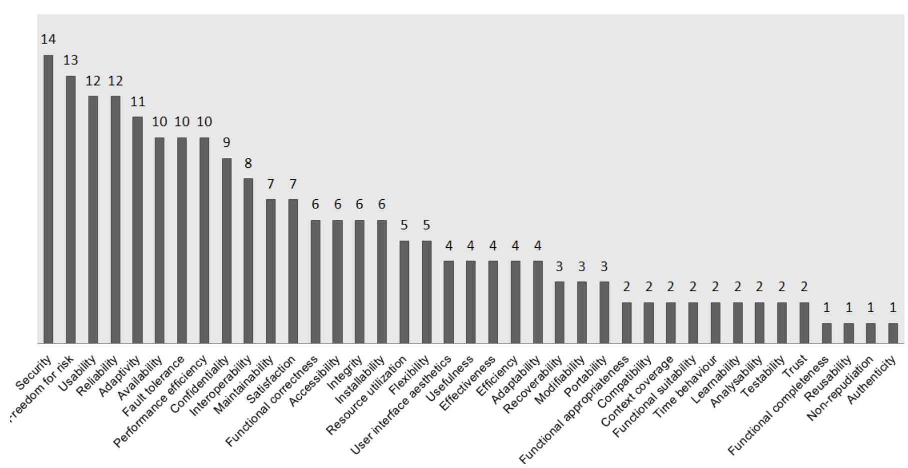

Figure 7: Amount of studies addressing QAs

Table 4: Quality attributes for the AAL systems

Charact.	Sub-charact.	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26	S27	#	%
	Product quality																													
Functional suitability	Functional suitability													x						x									2	7.40
	Functional completeness										x																		1	3.70
	Functional correctness							x		x	x	x				x		x											6	22.2
	Functional appropria.		x							x																			2	7.40
Reliability	Reliability					x	x				x			x		x	x	x		x				x		x	x	x	12	44.4
	Availability	x		x					x	x	x	x	x					x			x						x		10	37.0
	Fault tolerance	x		x		x			x			x				x	x			x							x	x	10	37.0
	Recoverability						x											x		x									3	11.1
Performance efficiency	Performance efficiency			x	x	x	x						x	x				x			x			x				x	10	37.0
	Time behavior												x							x									2	7.40
	Resource utilization	x					x						x					x		x									5	18.5
Usability	Usability	x	x		x					x				x	x	x	x	x		x						x		x	12	44.4
	Learnability				x															x									2	7.40
	User interface aesthetic	x	x	x																								x	4	14.8
	Accessibility		x		x										x			x						x		x			6	22.2
Maintainability	Maintainability						x						x	x			x	x		x								x	7	25.9
	Reusability																x												1	3.70
	Analysability												x							x									2	7.40
	Modifiability						x						x							x									3	11.1
	Testability												x							x									2	7.40
Security	Security	x		x	x	x	x		x				x			x		x	x	x	x		x			x			14	51.8
	Confidentiality						x	x	x		x		x						x		x	x	x						9	33.3

Continued on next page

Table 4 – *Continued from previous page*

Charact.	**Sub-charact.**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**S17**	**S18**	**S19**	**S20**	**S21**	**S22**	**S23**	**S24**	**S25**	**S26**	**S27**	**#**	**%**
Security	Integrity								x		x		x					x			x		x						6	22.2
	Non-repudiation					x																							1	3.70
	Authenticity										x																		1	3.70
Compatibility	Compatibility															x	x												2	7.40
	Interoperability		x	x													x	x		x			x			x	x		8	29.6
Portability	Portability													x			x			x									3	11.1
	Adaptability																			x	x					x	x		4	14.8
	Installability						x					x						x		x				x				x	6	22.2
Adaptivity		x	x	x												x	x	x		x	x	x				x	x		11	40.7
	Quality in use																													
Satisfaction	Satisfaction				x									x						x		x			x	x	x		7	25.9
	Usefulness				x					x							x								x				4	14.8
	Trust				x																				x				2	7.40
Effectiveness					x	x								x						x									4	14.8
Freedom for risk		x		x	x		x						x	x		x	x	x	x		x	x			x				13	48.1
Efficiency					x								x	x						x									4	14.8
Context coverage	Context coverage										x							x											2	7.40
	Flexibility		x														x				x			x				x	5	18.5
		8	6	7	11	6	10	2	5	5	8	4	13	10	2	8	12	16	3	21	9	4	4	5	4	8	7	8		

5.1.1. $RQ_{1.1}$. *Critical QAs proposed for AAL systems*

In this section, we consider critical QAs as those QAs that need to be successfully addressed to avoid environmental damages, harm to human life or health, or non-recoverable material and financial losses. The QAs of dependability, freedom of risk, performance efficiency, reliability, and security have been considered as critical QAs in diverse systems, e.g., critical embedded systems, System-of-Systems, safety-critical systems, and mission-critical systems [68, 69].

In our SM we identify that four QAs (i.e., security, freedom for risk, reliability, and performance efficiency) are also considered critical when developing AAL systems. In Table 4, we note that 85.2% of the primary studies (i.e., 24/27) considered at least one of such critical attributes. Only two studies (S6 and S17) addressed all four critical QAs, and 26% of studies (i.e., 7/27) addressed simultaneously three of such attributes. Moreover, from Table 4 and Figure 7, we can observe that security, freedom of risk, reliability, and performance efficiency, besides to be considered critical QAs, they are among the five QAs more addressed by the primary studies. Hence, such QAs must be contemplated since the inception of AAL systems.

5.1.2. $RQ_{1.2}$. *AAL sub-domains that present QM or QA*

Based on the classification of the AAL sub-domains previously presented in Table 1, we identified that the studies proposed/studied QM or QAs for three sub-domains, namely, home safety and care systems (SD1), monitoring systems (SD2), and localization/positioning assistance systems (SD3). Moreover, QAs for Ambient Intelligent (AmI) based AAL systems (SD4) were also found. Table 5 exhibits the number of studies that presents each quality characteristic and sub-characteristic considering each sub-domain.

Table 5: Taxonomy of quality attributes by category of AAL sub-domains

Characteristic	**Sub-characteristics**	**SD1**	**SD2**	**SD3**	**SD4**
	Product quality				
	Functional suitability				
Functional suitability					

Continued on next page

Table 5 – *Continued from previous page*

Characteristic	**Sub-characteristics**	**SD1**	**SD2**	**SD3**	**SD4**
	Functional completeness				
	Functional correctness		1	2	1
	Functional appropriateness	1		1	
Reliability	Reliability	4			1
	Availability	2	1	2	1
	Fault tolerance	3	1	1	2
	Recoverability				
Performance efficiency	Performance efficiency	4			
	Time behavior				
	Resource utilization				1
Usability	Usability	3		1	2
	Learnability				
	User interface aesthetics	2			1
	Accessibility	3			
Maintainability	Maintainability	1			
	Reusability	1			
	Analysability				
	Modifiability				
	Testability				
Security	Security	5	2		2
	Confidentiality	1	4		
	Integrity	1	2		
	Non-repudiation	1			
	Authenticity				
Compatibility	Compatibility	1			1
	Interoperability	4	1		
Portability	Portability	1			
	Adaptability	2			
	Installability	1		1	
Adaptivity		3			2
Quality in use					
Satisfaction	Satisfaction	2	1		
	Usefulness	2		1	
	Trust	1			
Context coverage	Context coverage				
	Flexibility	4			

Continued on next page

Table 5 – *Continued from previous page*

Characteristic	Sub-characteristics	SD1	SD2	SD3	SD4
Effectiveness		1			
Freedom for risk		5	1		2
Efficiency					
Total of QA addressed by each sub-domain		26	9	7	11

SD1. Home Safety and Care (HSC) systems: This sub-domain includes systems installed in residences that assist persons in normal daily life activities at home. Smart Homes and Home Care Systems (HCS) are representative systems for this sub-domain. Shortly, a Smart Home contains computing and information technology that anticipates and responds to the needs of people, working to promote their comfort, convenience, security and entertainment through the management of technology within the home and connections to the world beyond [56]; and HCS is a smart home that provides health assistance services to elder or disable people. Nine studies relate to this sub-domain: i.e., S2, S3, S5, S16, S18, S20, S23, S24, and S25.

Moreover, 26 QAs found for the AAL domain refer to HSC sub-domain (see Table 5). Important QAs for HSC systems are security and freedom for risk found in five studies. Other QAs addressed for these systems are reliability, performance efficiency, interoperability, and flexibility, which were found in four studies. The remainder QAs showed in Table 5 were found in at least one study. There are also two QAs (namely, reusability and non-repudiation) which are only related to HSC systems.

SD2. Monitoring systems: Systems in this sub-domain aim to monitor people's health condition, through sensorial information, looking for anomalies or out of pattern behaviors. The monitoring can be performed either at home or outdoors. Four studies were classified in this sub-domain: S7, S8, S21 and S22.

Nine QAs found for the AAL domain are associated to these systems, as showed in Table 5. All four studies indicate that confidentiality is a QA that must be considered by monitoring systems. Other QAs identified for SD2 are security, availability, fault tolerance, functional correctness, integrity, interoperability and satisfaction.

SD3. Localization/Positioning assistance systems: These systems aim to support physical mobility at walking, driving, and traveling. Moreover, these systems provide information, both indoor and outdoor, about persons position, obstacles location, and road paths. Two studies were placed in this sub-domain: S9 and S11.

Seven QAs for AAL systems were identified for this sub-domain. Availability and functional correctness were considered by both S9 and S1 studies (see Table 5), while other attributes (namely, usability, fault tolerance, installability, usefulness, and functional appropriateness) were addressed by only one study.

SD4. Ambient Intelligent (AmI) based systems: AmI systems bring intelligence to the environments, both indoor or outdoor, and make those environments sensitive to persons [70]. These systems are [70]: (i) invisible/ transparent (being embedded in things like clothes, watches, or glasses); (ii) mobile (being carried around); (iii) context-aware (providing knowledge about the context of the environment); (iv) adaptive (being capable of reacting to situations); (v) sensitive (perceiving the state of the environments); (vi) ubiquitous/pervasive (spreading widely throughout an area or a group of people); and (vii) responsive (modeling user behavior). Two studies address AmI systems: S1 and S15.

Eleven of the QAs found for the AAL domain address AmI based systems. Usability, security, freedom for risk, and performance efficiency were found in both studies S1 and S15 (See Table 5). Other attributes are availability, reliability, functional correctness, resource utilization, adaptivity, user interface aesthetics, and compatibility.

From Table 5, it is possible to highlight that availability and fault-tolerance are addressed by all four sub-domains. Usability, security, functional correctness, and freedom for risk are relevant in three sub-domains. The remainder QAs are related to at most one sub-domain. Additionally, we identified QAs defined for the entire AAL domain that were not associated for a specific sub-domain. These QAs are time behavior, efficiency, and authenticity.

5.2. RQ_2. Information sources and approaches to define QA for AAL software systems

This RQ aims at understanding how QA for AAL systems have been identified, established, and defined. To answer it, we investigated which sources of information are mostly used to identify the QAs and whether they have been defined using a descriptive or prescriptive approach. Table 6 summarizes the sources of information and the aproaches used to define the QAs.

Table 6: Information sources and approaches used to define QA

	Source				**Approach**	
Study	Software documentation	Literature review	Expert opinion	Standards & regulations	Prescriptive	Descriptive
S1	x					x
S2	x		x		x	
S3	x					x
S4	x	x		x		x
S5	x					x
S6	x		x	x		x
S7	x	x				x
S8	x		x		x	
S9	x	x	x			x
S10	x					x
S11	x					x
S12	x		x	x	x	
S13	x		x	x	x	
S14		x				x
S15	x		x			x
S16		x			x	
S17		x	x			x
S18	x		x			x
S19	x		x	x	x	
S20	x					x
S21			x			x
S22	x	x	x		x	
S23	x					x
S24	x		x		x	
S25	x					x
S26	x					x
S27	x	x	x		x	
Total	23	8	14	5	9	18

An important percentage of QAs for AAL systems (85.2% or 23/27 of the studies) were determined from documentation of software systems, e.g., requirements document, software architecture documentation, or source code. Expert opinion obtained from interviews, questionnaires, and related experiences were used by 51.8% (14/27) of studies to define QAs for those systems. Literature reviews also were sources of information in 29.6% (8/27) of the studies. Standards and regulations were considered in 18.5% (5/27) of the studies. Regarding standards, five studies (i.e., S4, S6, S12, S13, and S19) reported the use of ISO/IEC 9126, and two of such studies (i.e., S6 and S12) also used the standard ISO/IEC 25010 [11] to define QA for AAL systems.

Furthermore, there is a predominance of descriptive studies (66.6% or 18/27 of the studies) over prescriptive ones (33.3% or 9/27 of the studies). Descriptive studies detail the set of QAs considered to analyse, design, and develop AAL systems in the past, whilst, prescriptive studies give recommendations, procedures, or guidelines based in accumulated experience to orient the correct identification of QAs for future AAL systems. The reduced number of prescriptive studies may be explained due to AAL is a relatively novel domain with no more of 10 years. Additionally, 89% (8/9) of prescriptive studies (S2, S8, S12, S13, S19, S22, S24, and S27) have been based, simultaneously, on the documentation of existing software systems and expert opinions. Hence, these information sources could be used to create guidelines for engineering future AAL systems.

5.3. RQ_3. Evaluation and use of QAs for AAL software systems

This RQ explores how primary studies evaluated the QAs that were proposed for AAL systems. The following evaluation approaches were considered: (i) industrial use, i.e., actual use of the QAs in industry; (ii) industrial studies, i,e., QAs defined in the industry; (iii) academic studies, i.e., QAs obtained/evaluated from controlled lab experiments or evidence based results; (iv) expert opinions or observations, i.e., QAs defined as result of interviewing experts; (v) demonstration or working out toy examples, i.e., QAs assessed through prototyping; and (vi) no evidence. Moreover, RQ3 investigates if exists evidence of the practical use of such QAs. Furthermore, we used the Technology Readiness Level (TRL) method [71] to assess the maturity level of the QAs proposed by the primary studies. There are nine readiness levels, being TRL 1 the lowest and TRL 9 the highest. For each primary study, a TRL rating was assigned considering the approach used to evaluate the QAs [71]:

- *TRL 1. Basic principles observed and reported:* Studies reporting QAs of AAL systems based on empirical evidence, e.g., literature reviews or surveys;
- *TRL 2. Technology concept formulated:* Studies that describe practical applications of QAs in AAL systems, e.g., using scenarios description or experts opinions. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Description of technological feasibility can be presented;
- *TRL 3. Experimental proof of concept:* Laboratory-scale studies to validate AAL systems regarding their QAs, through modeling and simulation;
- *TRL 4. Technology validated in lab:* QAs in AAL systems are assessed by testing the systems in a laboratory environment;
- *TRL 5. Technology validated in user environment:* Studies assessing QAs of AAL systems deployed in a user environment, connected to the broader technological infrastructure;
- *TRL 6. Technology demonstrated in relevant environment:* Studies evaluating QAs of AAL systems tested in operating environment, which closely represents the final operating environment;
- *TRL 7. Full-scale system demonstrated in relevant environment:* Studies assessing QAs of AAL systems in the final operating environment;
- *TRL 8. Final system completed and qualified:* Studies presenting QAs addressed by a final version of an AAL system operating under expected conditions; and

- *TRL 9. Final system proven in operational environment:* Studies detailing QAs of AAL systems in their final version, operating under the full range of mission conditions.

Table 7 presents our results for each primary study, detailing its TRL, the study's identificator, and the approach used to evaluate the proposed QAs. Moreover, the last column of Table 7 reports if the QAs presented by each study were used to develop new AAL systems. If no information about their use was reported, the study is marked as NR.

Table 7: Overview of the evaluation approach, use, and maturity level of studies

TRL	**Study**	**Evaluation approach**	**Used**
1	S14	Academic study - SLR	Yes
1	S16	Academic study - Literature survey	NR
1	S17	Academic study - Literature survey	NR
2	S4	Academic study - Qualitative analysis	NR
2	S6	Academic study - Qualitative analysis	Yes
2	S8	Academic study - Qualitative analysis	NR
2	S15	Academic study - Qualitative analysis	NR
2	S21	Academic study - Qualitative analysis	NR
2	S27	Academic study - Qualitative analysis	NR
2	S1	Expert opinion and observations	NR
2	S5	Expert opinion and observations	NR
2	S10	Expert opinion and observations	NR
2	S13	Expert opinion and observations	NR
3	S25	Industrial study - case study	NR
4	S2	Academic study - Lab experiment	Yes
4	S3	Academic study - Lab experiment	Yes
4	S22	Academic study - Lab experiment	Yes
4	S24	Academic study - Lab experiment	NR
5	S7	Demonstration or working out toy examples	NR
5	S9	Demonstration or working out toy examples	NR
5	S11	Demonstration or working out toy examples	Yes
5	S12	Demonstration or working out toy examples	Yes
5	S18	Demonstration or working out toy examples	NR
5	S20	Demonstration or working out toy examples	NR
5	S23	Demonstration or working out toy examples	NR
5	S26	Demonstration or working out toy examples	NR
6	S19	Industrial use	Yes

Only two studies (S19 and S25) have evaluated QAs based on industrial studies/evidence. Most of the studies that propose or use QAs for the AAL domain come from academic context, including systematic literature review (S14), literature surveys (S16 and S17), qualitative analysis (S4, S6, S8, S15, S21 and S27), and laboratory experiments (S2, S3, S22 and S24). Four studies were evaluated using expert opinions (S1, S5, S10, and S13). Eight studies used demonstrations or worked with toy examples (S7, S9, S11, S12, S18, S20, S23 and S26) to evaluate their QAs. Moreover, only eight studies reported the use of the proposed QAs in real systems (S1, S2, S3, S6, S11, S12, S19, and S22). Regarding the maturity level of the studies that proposed QAs, we classified these studies only in the first six readiness levels. No evidence of AAL systems with maturity levels from TRL7 to TRL9 was found.

6. Discussion of Results

In this section, we present analysis and synthesis on QAs, QMs in the AAL domain. Moreover, critical QAs for AAL sub-domains are also examined.

6.1. Quality attributes definition for AAL systems

To clarify the way that the QAs are used/defined in the AAL domain, we discuss in details the fourteen quality characteristics and their more important sub-characteristics found through our SM, which were previously presented in Figure 6. For each QA, we provide a definition according to ISO/IEC 25010 and a discussion about its use in the domain.

- **Functional suitability** describes the degree to which a product or system provides functions that meet stated and implied needs when used under specified conditions [11]. We identified that all quality sub-characteristics of functional suitability are important at developing AAL software systems. Hence, AAL software systems must address *functional completeness*, since the data gathered by the system is used to determine what has ocurred in the environment (e.g., home or work office) (e.g., study S10 addresses such sub-characteristic). Moreover, AAL systems must address *functional correctness*, since it is needed to provide the correct results with a degree of precision, e.g., the system must provide accurate information about user movement and location to support the navigation of blind persons in a safe way (as presented in S9). Additionally, AAL systems must address *functional appropriateness*, since these systems must facilitate the accomplishment of specified tasks and objectives, e.g., in assistive robotics applications, where robots are configured to execute a determined set of tasks such as opening doors or moving walls to facilitate blind persons navigation (as reported in S2 and S9).

- **Reliability** is the degree to which a system, product or component performs specified functions under specified conditions for a specified period of time [11]. For this quality characteristic, we found three sub-characteristics as important for AAL systems. Hence, these systems must address the *availability* attribute, since they must meet all warranted characteristics of the described environmental conditions at any time and error free (as documented in S12), independently of the environment (as presented in S9), when occurring crash of hardware components, shortage of hardware resources and other exceptional conditions (as stated in S1 and S3), to deliver accurate information to health professionals or care providers that are monitoring the AAL system (as described in S10). Moreover, AAL systems must be *fault tolerant*, since it is required to be robust against all kinds of misuse and errors of elders or health practitioners, who could leave to a system malfunction or crash (S1, S3). In addition, these systems must address the *recoverability* attribute. If a failure occurs, it is needed that the system recovers its last status in a short time (S6) to avoid injuries to elders or wrong diagnostics by healthcare professionals.

- **Performance efficiency** is related to the amount of resources used under stated conditions [11]. We identified two quality sub-characteristics related to performance efficiency (i.e., time behavior and resource utilization). Hence, AAL systems must address the *time behavior* attribute, since they need to accomplish response times at processing requests of final users (e.g., navigation services must consider walking speed to assist users at avoiding obstacles in real time) (as defined in S19). Furthermore, AAL systems must consider *resource utilization*, since it is necessary an affordable price of the systems, and the realization of heterogeneous, distributed, highly integrated, and autonomous sensor nodes with a high endurance (i.e., that is of particular interest if sensor nodes are mobile) (as discussed in S6).

- **Usability** is the degree to which a product or system can be used by specified users to achieve specific goals with effectiveness, efficiency and user satisfaction in a specified context of use [11]. The *Learnability* sub-characteristic was identified as an important one when using AAL systems by elders (as reported in S4), who need a good understanding of the functionalities offered by the applications, principally at monitoring chronic diseases of elders in their home. *User interface aesthetics* must also be considered when developing those systems, since they provide human interfaces for three final users: the assisted persons (e.g., elders or disabled), the medical personnel, and the maintenance personnel. Each of them has different requirements for interacting with the system (e.g., the human interface for the handicapped and elderly persons must be based on voice, gesture, and visual animation, and avoid any kind of particular skills) (as discussed in S1, S2 and S3). Moreover, *accessibility* through anticipatory interfaces, which proactively contact health professionals or family members in certain emergency situations, are considered mandatory (also discussed in S2).

- **Maintainability** is the degree of effectiveness and efficiency with which a product or system can be modified by the intended maintainers [11]. For this quality characteristic, all its sub-characteristics must be considered to develop AAL systems. Those systems must consider *reusability* of their software components to decrease the cost for final users (as presented in S16). *Analysability* must also be considered to diagnose deficiencies or causes of failure, or to determine changes in the system (as reported in S12). Similarly, the *modifiability* attribute has been addressed due to AAL systems must present facilities for self-maintaining after deployment, executing improvements, troubleshooting or adapting to environmental changes (as established in S12), and/or downloading and releasing new updates automatically from a remote service center (as described in S19). Additionally, the *testability* attribute must be contemplated when software modifications are made, aiming to optimize the time required to test the modified software (as stated in S12).

- **Security** is the degree to which a product or system protects information and data so that persons or other products or systems have the degree of data access appropriate to their types and levels of authorization [11]. *Confidentiality* is considered as an important quality sub-characteristic, since it protects sensible information ensuring a well defined degree of privacy for patients (as reported in S6). The privacy rules must be precisely formulated and verified (as described in S1 and S3). The *integrity* attribute is also important for these systems, since it prevents processing data corrupted or incorrect (as stated in S12) caused by the fact that sensors in the environment are susceptible to vibrations, humidity, and other environmental conditions (as presented in S10). Moreover, the *non-repudiation* sub-characteristic must be addressed in the AAL systems to validate actions or events when diagnosis are made by health professionals (as established in S5). The *authenticity* attribute must be considered, since an AAL system must be able to unequivocally identify the users (as defined in S9), information should only be processed by the system, and information can not be changed by external sources (as disclosed in S10).

- **Compatibility** is the degree to which a product, system or component can exchange information with other products, systems or components, and/or perform its required functions, while sharing the same hardware or software environment [11]. The *interoperability* sub-characteristic must be addressed, since AAL systems integrate several subsystems (e.g., components or electronic devices) provided by different manufacturers and it is needed to preserve subsystems integration in a seamless way (as reported in S2 and S3).

- **Portability** is the degree of effectiveness and efficiency with which a system, product or component can be transferred from one hardware, software or other operational or usage environment to another [11]. AAL systems must address *adaptability*, since they must provide adaptation mechanisms to achieve wide variety of user needs, and must support the personalisation of new software, hardware and service (as stated in S19 and S20). To measure the adaptability attribute, the *reaction time* metric can be used (as defined in S12). Moreover, *installability* must be addressed, since both people with and without technical knowledge should be able to add new services and devices to the systems, as well as mechanisms for assuring that external dependencies will be automatically downloaded to assure proper (re)installation of the system (as described in S6).

- **Adaptivity** is the software capability to modify its own behavior in response to changes in its operating environment (i.e., anything observable by the software system, such as end-user input, external hardware devices and sensors, or program instrumentation) [72]. AAL systems must able to adapt themselves at runtime [73]. Adaptivity on different levels and scales is considered one outstanding characteristic of AAL systems. To support this, systems must monitor themselves, the users, and their environment, reason on required adaptations and execute them in a quality-preserving way (as stated in S1, S2 and S3), e.g., to reduce the user interface complexity in case of emergencies (as proposed in S2). Becker [73] exposed, based on his experience, that AAL systems can perform:

  - *self-configuration*, which denotes the ability of the system to dynamically integrate new software components and remove existing ones not needed anymore;

  - *self-healing*, which denotes the ability to detect problems of components and take appropriate countermeasures;

  - *self-optimization*, which denotes the ability of the system to adapt its algorithmic behavior to change needs of the applications; and

  - *self-protection*, which denotes the ability of the system to protect itself against misuse.

- **Satisfaction** is the degree to which user needs are satisfied when a product or system is used in a specified context of use [11]. *Usefulness* is relevant for AAL systems, since final user must be satisfied with results and consequences obtained from using the systems. For example, for blind people, the information delivered by the system must be useful and allow them to properly navigate indoor environments, even if they are visiting those spaces for the first time (as stated in S9). Additionally, AAL systems ought address *trust* requirements, since elders, disabled persons, healthcare professionals, and others stakeholders must have high confidence that the system is behaving properly. For instance, biosignals must be sensed and transferred accurately avoiding to add noise signals that influence diagnostics made by healthcare professionals of possible critical conditions (as described in S4).

- **Effectiveness** is the accuracy and completeness with which users achieve goals [11]. AAL systems must ensure that required tasks by final user are met successfully to bring an adequate assistance by healthcare organizations and professionals.

- **Freedom of risk** is the degree to which a product or system mitigates the potential risk to economic status, human life, health, or the environment [11]. This quality characteristic is of utmost importance, since AAL systems are directly related to health status of final users. For this, faulty system components and exceptions must never result in system misbehavior and injuries to elders or disabled persons.

- **Efficiency** is perceived as the resources expended in relation to the accuracy and completeness with which users achieve goals [11]. This quality characteristic needs to be considered to develop AAL software systems, due to the limited capacity of devices and the necessity to obtain accurate and reliable results in an economic way, e.g., algorithms used to infer possible critical situation of elders with multiple chronic conditions need to continuously process all biomedical signals. For systems running at the patients home, such algorithms are sometimes processed using a set-top-box that at the same time can be used by other applications (as stated in S12).

- **Context coverage** is the degree to which a product or system can be used with effectiveness, efficiency, freedom from risk and satisfaction in both specified contexts of use and in contexts beyond those initially explicitly identified [11]. AAL systems ought consider *flexibility* requirements, e.g., mobile health telemonitoring systems must measure biomedical data in both indoor (e.g., home or work place) and outdoor (e.g., shopping center) environments (as proposed in S16).

Security, freedom of risk, usability, reliability, and adaptivity were the QAs most considered by the primary studies of this SM, since at least 40.7% (i.e., 11/27) of studies reported their use to build AAL systems. Hence, software engineers should think in considering at least these five QAs since first stages of AAL systems development, intending to improve the quality of such systems.

6.2. Quality models in the AAL domain

In our SM, we found only one QM: the OptimAAL (S12). OptimAAL model was based on the standards ISO/IEC 9126 and 25010, as part of the OptimAAL project founded by the European Commission. Such model establishes reliability as one of the most important QAs for AAL systems. This QM presents the reliability attribute as dependent from other attributes: availability, safety (or freedom for risk in the standard ISO/IEC 25010), integrity, and maintainability. Hence, OptimAAL states that a reliable AAL systems must be: (i) available, in other words, prepared to be used when they are needed; (ii) reliable, to ensure adequate continuity in the provision of their services; (iii) safe, in terms of possible catastrophic consequences in the use of the systems; (iv) integer, to ensure that there are no unacceptable system changes; and (v) maintainable, easy to make adjustments and repairs. Moreover, OptimAAL details metrics to measure the quality of AAL systems regarding those four quality attributes. In this way, it is observed that other important QAs are not considered by OptimAAL (e.g., usability and adaptivity). Besides, OptimAAL is oriented to provide only a structured overview of the relevant QAs for AAL systems. In this context, it does not allow the assessment neither the prediction of software quality for the AAL domain. Therefore, more efforts are needed to establish a complete QM to define, assess, and predict the quality of software systems in the AAL domain. Definitions provided by OptimAAL, and results of our SM can be used as a basis to create a more exhaustive and detailed QM, which supports the following phases of the AAL systems life cycle: (i) Requirement analysis, formalizing quality-related requirements and improving communication among stakeholders; (ii) Design and implementation, offering suitable measures to verify the required quality; (iii) System integration, validating gradual integration of system components against appropriate quality requirements; and (iv) Installation, maintenance, and evolution, ensuring that modifications or future versions of the software address the quality requirements. Moreover, the QM must consider variabilities in QAs regarding AAL sub-domains, because, as presented in Section 5.1.2, each sub-domain has specific QAs that need to be satisfied.

In this scenario, the development of QMs for AAL sub-domains and guidelines about how quality should be addressed can be considered as a promising topics of research, and results of this mapping can be used as a starting point.

6.3. Critical quality attributes and AAL sub-domains

This subsection gives details about which of the critical QAs found for the entire AAL domain (i.e., security, freedom of risk, reliability and performance efficiency) have been considered in the AAL sub-domains identified in Section 5.1.2: (SD1) Home Safety and Care (HSC) systems, (SD2) Monitoring systems, (SD3) Localization/Positioning assistance systems, and (SD4) AmI-based AAL systems.

Systems in the HSC sub-domain must address the critical QAs of: (i) freedom for risk, since its failure can result in misdiagnosis, affecting the patient's health status; (ii) security, since patient's information must be confidential, and medical diagnosis need to be verified and authenticated; (iii) reliability, since information obtained from home environment must be reliable to be used in medical diagnosis, and to predict possible emergency situations in the patient's health status; and (iv) performance efficiency, since continuous monitoring of patient's health status must be carried on using embedded systems, such as set-top-boxes, sensor networks (namely, body sensor networks, internet of things, wireless sensor networks), or smart TVs, with limited computational resources.

Monitoring systems must ensure security for the users' information. Hence, users' authentication, encrypting users' information, and guarantee the integrity of those information are mandatory quality requirements for those systems. Moreover, diverse network technologies also must be considered to design these systems.

For AmI-based systems in the AAL domain, security and freedom for risk attributes are critical QAs. Security is extremely important for those systems, since they are executed in heterogeneous environments (e.g., home, work places, shopping malls, smart buildings, and streets) using diverse networks technologies (namely, wireless, 4G, bluetooth, zigbee, or even ad-hoc). In this context, those systems must guarantee users' information protection, independently of the users' environment. Additionally, AmI-based systems must be executed in a safe way, avoiding possible risks for the final users and their environments.

Otherwise, no evidence was found to relate critical QAs to the localization/positioning assistance systems. We consider that freedom of risk and reliability could be contemplated for those systems, since they support physical mobility at driving to avoid possible accidents. However, a deeper analysis must be conducted to characterize critical QAs for systems in this sub-domain.

Finally, more efforts must be made to identify QAs and critical QAs for other important AAL sub-domains, such as rehabilitation and disabilities compensation, caring and intervention, assistance in the work place, learning, recreation, and other presented in Section 2.2. Despite we have made a broad search of QAs for AAL systems, those sub-domains were not identified in this SM. Hence, results of our SM could be improved with opinions of experts in these sub-domains.

7. Threats to Validity

The main threats identified to the validity of this SM are described as follows:

7.1. Missing of important primary studies

The search for QM&QA for AAL software systems was conducted in six publication databases. According to Dyba et al. [34] and Kitchenham and Charters [4], the publication databases are the most relevant sources in software engineering area. In addition, we wanted to be as inclusive as possible; thus, no limits were placed on date of publication and we avoided imposing restrictions (i.e., filters by title, abstract, and keywords) on the primary study selection. Aiming at not missing any important evidence, we also conducted the snowball technique [37] using the reference list of the selected primary studies. A manual search using "Google scholar" search engine was also made, since we wanted a broad overview of the research area. During the search, conference papers, journals articles, technical reports, and chapter of books were considered. In spite of our effort to include all relevant evidence in this mapping, it is possible that primary studies were missed.

7.2. Selection reliability

Aimed at ensuring an unbiased selection process, we defined research questions in advance, and devised inclusion and exclusion criteria. We believe that the questions and criteria are detailed enough to provide an assessment of how the final set of primary studies was obtained. Moreover, aiming to increase the reliability of our SM, we used the Revis tool [35] to select the final set of primary studies. However, it might be possible that studies proposing QM&QA for AAL systems were excluded in first stage due to their lack of important information in the title, abstract, keywords introduction and conclusions sections.

7.3. Data extraction

Another threat to this mapping refers to how the data were extracted from the primary studies, since not all the information were obvious to answer the research questions and some data had to be interpreted. Moreover, in the event of a disagreement between reviewers, a discussion was conducted to ensure that a full agreement was reached.

7.4. Quality assessment

Aiming to assess the quality of primary studies we defined seven criteria. We evaluated each primary study using such criteria and we considered that all studies had enough quality to be considered in our mapping. However, it is possible that the assignment of scores has been influenced by the opinion of the reviewers.

8. Conclusion and Future Work

AAL systems have become increasingly complex embracing multiple, critical sub-domains, e.g., health care monitoring, physical mobility supporting, people rehabilitation, and work assistance. Moreover, sometimes executing closely to chronic patients or disabled people, they must prevent failures that could cause injuries to final users or financial lost to health organizations. Despite important contributions of the AAL community to develop innovative AAL systems (e,g., systems constituted by smart home, ambient intelligence, e-Health, sensor networks, and robotics technologies) in the last ten years, more efforts must be still destined to enhance the quality of such systems and to overcome, in a middle time, the challenges imposed by the population ageing.

The adoption of QMs and identification of the most important QAs can contribute to the improvement of the quality of AAL software systems. In this perspective, the main contribution of this work was to present a detailed panorama containing the state of the art on the QMs and QAs, which can orient the development of these critical systems. We also presented the major QAs addressed currently for AAL, the way they were defined and evaluated, and the AAL sub-domains where they were proposed. For this, we conducted the steps of an SM. The main result found in this SM showed that more industry involvement is still required in the AAL systems engineering to mainly establish a QM and its associated QAs that could be considered essential for any AAL system. As a consequence, high-quality systems could be made available, impacting directly the life of the final users.

As future work, we intent to make a more specific investigation of this research topic, for instance, identifying metrics associated to each QA, and characterizing the QAs addressed in current reference architectures in the AAL domain. Furthermore, the results of this SM intend to support the consolidation of a more complete QM for the AAL domain, aiming at contributing to a more effective development of successful AAL software systems.

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