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A novel reference model for ambient assisted living systems' architectures

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Abstract
AAL (Ambient Assisted Living) is lacking a RM (Reference Model) to serve as an abstraction of the domain. Therefore, to help implement new architectures established on the prior experiences of the designer's expertise and former competences, in this paper, we propose a novel approach of an AAL RM. Our objective is to handle the resolution of conflicts that appear between the developers, and give an overview of the basis for implementing concrete software architectures for different families of AAL applications. Our proposed RM is a standardized clarification for developers to apply in the process of the design and implementation. We illuminate the AAL domain fundamental dimensions and we established a formal RM with an infrastructure that could survive the domain's progression. To achieve integrated system-of-systems composed of systems, subsystems and components, our RM describes a standard and regulated structure to be established. High-level elements, essential properties and characteristics that must appear in the application's design are described and illustrated in this work.

Keywords Reference model, AAL, Standardization, Abstraction
Paper type Original Article

1. Introduction

New challenges are raised in software engineering due to the complexity of the AAL field. To cope with the specific characteristics and the individuality of demands of ambient intelligence, new approaches are required to be adopted [20]. These systems are demanding in

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matters of performance, time and quality as they answer to the elderly needs. Moreover, they acquire awareness of the stakeholder's environment, the adjustability to its needs and the diversity of the provided services. Using a RM to design AAL applications would simplify the integration of multiple systems [34]. Which will minimize the cost and insure advances in the performance. The system will be enforced by solid and flexible background that encourages and strengthen the adjustments and the maintainability of the system.

Additionally, as the interoperability has become a major issue in software development [25], standardization has emerged to manifest the compatibility between the software components. As of our knowledge, there is a lack of formulations, guidelines, rules and specifications in the context of AAL to guide the achievement of a common and optimum use of the architectural elements. Engineers have a passion for diversity and variety to deliver a wide range of choices for manufacturers and stakeholders. However, to mandate the quality and ensure a consistency in the process of the development, standards gathering all the interesting aspects of the field are required to be available and considered.

All the above is in the objective of maximizing reusability and quality, thus concentrate on providing individual, self-contained components that would be useful for banding a global and efficient system. Moreover, it allows mixing and matching components of the systems to align with the specific needs of each user to promote adjustability.

In this paper, we aim to propose a RM, which helps performing the establishment of an AAL system within a specified structure. It defines the basic features to enforce a level of uniformity in the model designs. This facilitates the merge and acquisitions of diverse components into one consolidated, corporate and compatible system. We aim also to optimize and abstract the designs to balance between the varieties of technologies and lack of patterns. Our concern is to clarify the path ahead of the engineers for establishing qualified AAL systems and to improve the performance of existing ones. The proposed RM facilitates technical interchangeability between all the contributors of the system's establishment.

The remainder of this paper is organized as follows: In the next chapter, we discuss the work that has been done in the same axis of research. In Section 3, we investigate the fundamental dimensions of the AAL field and we illustrated the process of adopting them. The process of standardization and the principles respected in the development of the RM are represented in Section 4. Section 5 is devoted to the illustration and description of the proposed RM. Finally, Section 6 concludes with a summary.

2. Related work

Creating models and architectures for AAL systems has been the core interest of a number of EU projects like PERSONA [36], UniversAAL [12], OASIS [16], AALIANCE [38], AAL 4 ALL [15], and many others. UniversAAL was itself based on many input projects, as it describes five different concepts of the AAL field [29]. OASIS extended to seven different elements that, from its point of view, are the roots for creating an AAL system. AALIANCE has presented a roadmap to the AAL environments, discussing suitable solutions appropriate for each individual's requirements. Where others had focused on discussing the ontology [19]. The most interesting approach to this issue has been the ones introducing architectures such as MPOWER [23], AmIRA [21] and Continua [39].

While investigating these works, we conducted a review for evaluating the AAL system's architectures and models. The results have revealed the weakness in each of the presented models. Although UniversAAL seem to be a complete RM, it neglected all the aspects of components and connectors, which are vital to the AAL environments. According to [7] any possibility of extending this model into another suitable version would require too much effort in matter of time, cost and resources, which we judge very unsuitable for a field that is evolving rapidly such as AAL. The project Continua has presented a technology-based architecture, for that it cannot be considered reference as it does not answer to the uniformity nor to the standardization issues. Projects such as AAL 4 ALL has focused on the user's experience in AAL space, ignoring other fundamental concepts such as the infrastructure requirements and the sources of the data, which narrowed the vision of the project. Feelgood was a promising project; unfortunately, it did focus only on targeted groups of AAL in Finland. The project was dedicated to their needs. Moreover, it specifies all the technologies associated to each of the described components.

Although they have indicated the relationships between the AAL space, services, network artifacts and the interactions, little attention has been paid to the quality attributes and to the general structure of the systems. Another key limitation of these researches is that they are focusing on specific needs with a fixed objective and particular stakeholders to serve and respond to definitive purposes. All the above presented models and architectures were projects with limited objectives, time and interests. Where the creativity that have been presented was neglected by the end of the projects. Furthermore, many of them were not technology-independent, where the design of others, such as Feelgood and SOPRANOO, was not formalized and they did not offer an overview of the AAL field's essential concepts. As the main purpose of a RM is the abstraction and standardization, none of the presented RMs can be considered mature enough to be declared as a reference one according to [7].

By comparing these models and architectures, we can emphasize that: cost and data flow are absent in OASIS, AALIANCE and AAL 4 ALL. Only RAFAALS and UniversAAL support interoperability. RAFAALS [8] and OpenAAL are the only ones whom could be implemented [9]. Neither of them addresses scalability nor the possibility of adjustments and modifications. SOPRANOO and Feelgood are the ones whom supported facilitation as their objective.

However, to the best of our knowledge, very few publications have addressed the standardization issue. None of the available resources has investigated the needs for a RM to regulate the establishment of AAL applications, where the benefits of facilitating the integration and providing comprehensive directions for architects and developers appear while following the directions when creating such systems. We can confirm that the field of AAL is still lacking a complete, dedicated and reliable RM.

In this paper, we propose a RM that is standard, classic and mature. We aim to emphasize an arrangement to be applied by designers in the determination of coordinating with all other participants of the AAL system creation. The possibility of the evolution, the tolerance to all the technologies and the adjustability to all kinds of AAL applications are the leading factors of our vision.

3. AAL fundamental dimensions

A RM presents the high-level ideas of a field. It also proposes abstract entities and an interpretation of the relationship between them. Besides, it presents the heavy concepts that any related system of a specific field has to adopt [4]. Knowing the complexity of the AAL field, a RM is a crucial element to describe all the entities that the applications must hold.

To be able to propose a RM for the AAL field we examined the AAL scenarios and common ontologies [8]. We adapted a projection of the RAModel [26] into our field of research. Which is a reliable RM for RA (Reference Architecture). We took in consideration all the basic concepts of RMs proposed by RAModel to serve as an infrastructure for our vision.

In the process of selecting the fundamental dimensions of the AAL domain, we investigated several publications [7,29,40]. Moreover, we examined the ontology and terminology of AAL presented in [24,6,17]. We extracted decisive dimensions to be evaluated whether as abstract values or context related ones. In the case where the dimension was context related, we proceeded with an abstraction methodology to extract knowledge. We examined attributes of the abstract value to select the major ones as illustrated in Figure 1. This process helped us to consider only abstract, essential elements, and exclude irrelevant or obscure dimensions for the AAL RM. To decide the relevance of the attributes we studied the ontologies presented in [30]. First, the number of the redundancies of an attribute reveals its connection to the dimension. Its accuracy was judged by answering to three questions: does the attribute appears correct? Does it influence the completeness of the dimension? Can the dimension survive the abstraction criteria if we added this attribute? Uniqueness is also a criterion that eases the selection of the attributes. In addition, does the attribute depend on his own, or is it resulted from another one? These are the questions we answered to affirm the importance of an attribute.

While expanding our vision to the followed RM, we pursued the arrangement of model versions and variants presented in [3]. Although, the adaptation has known some complexity, we modified several aspects to come up with the ideal ones. The investigation process highlighted the object model of the essential elements presented in the model.

4. The process of standardization

The diversity of dimensions in AAL ontology promotes a complexity in extracting the fundamental and common ones. This selection emerges in order to satisfy the uniformity of the systems, likewise to preserve the variety of services and objectives to reach. Furthermore, to promote a background for designers in the assembling process to support a wide range of use cases [32].

We intend to:

1. Promote interchangeability where the systems can serve as a component of other systems to fulfill a relevant requirement.

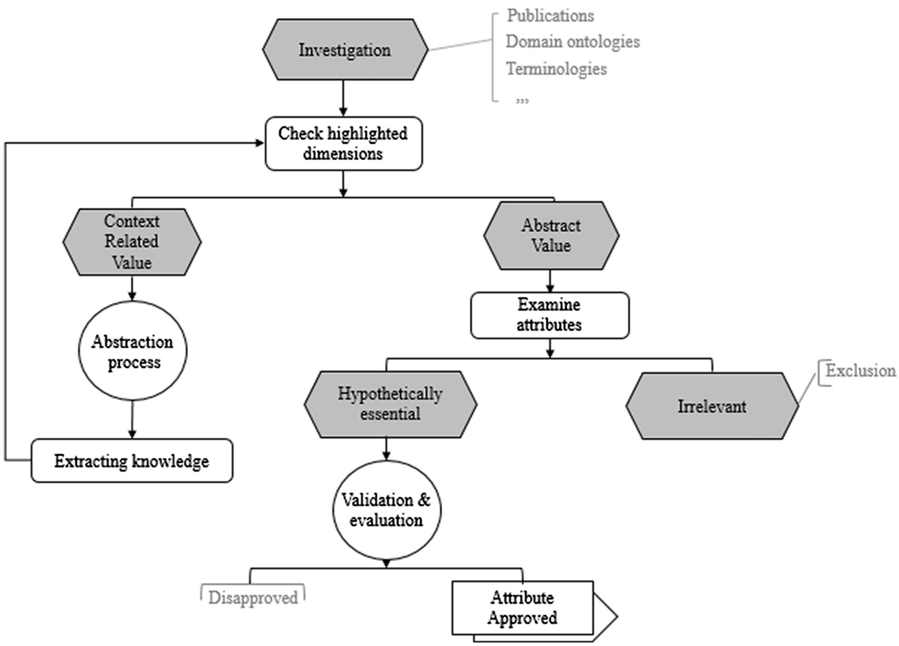

Figure 1. Illustration of the process pursued to select fundamental AAL dimensions.

2. Ensure compatibility. The created system will be suitable for the reutilization as a portion of other systems under specific conditions to fulfill relevant objectives, without causing unnecessary interaction.
3. Improve utilization of resources. The RM helps in the achievement of maximum overall economy through better utilization of existing systems [27].
4. Enhanced communication and understanding in the case of transferring the systems.
5. Ameliorate adaptability. Because of standardization, the RM promotes flexibility for quick adaptations and modifications to suite the diversity of stakeholders and adjust to each one's needs.

In the purpose of preserving legitimacy and AAL relevance to the standards, we proceeded in several steps as illustrated in Figure 2. First, we investigated the existing models in the field of AAL using our previous published researches, in order to have an overview of the proposed models and elements used to justify their value. Second, we made a preliminary examination of the common axioms related to the contexts and concepts of AAL. As a result, we approved the repetitive and frequently used elements in the systems environments. The next step was the extraction and the allocation of attributes according to the relevant aspects of the field. We scanned the influencing factors on each selected element. Finally, we considered the relationships between the axioms and we illustrated these relationships in a concept map graph.

We started with a draft proposal as the first version then we used the return cycle for the modifications to regulate new versions for the ambition of accomplishing a flawless one. In each iteration, we selected a RM to explore the axioms adapted and we adjust them into abstract concepts. We did an inspection for the relevant aspects of the field and we converted them into flexible ones, in the goal of embracing them. In this procedure, we respected the basics of the process of standardization along with the consideration of its following five principles.

4.1 Consistency

The accepted axioms had to be approved by several models. The RM illustrates how general dimensions and attributes are related to each other in an AAL context [5]. To achieve consistency, systems developers, engineers, researchers, stakeholders and end-users are considered. Software systems, publications and AAL ontologies are all selected and investigated. Complete possibilities of processes and activities that could be supported by the systems are also examined. The consistency approved the ability of synchronizing different families of services into a federation capable of responding to the particular needs of each user [10].

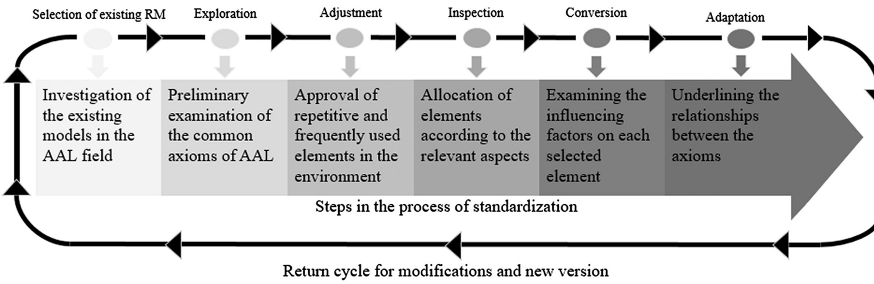

Figure 2.
Steps in the process of standardization.

4.2 Globalizing the objectives
The stakeholders have particular and specific criteria in matter of interacting with the system. Therefore, the adjustability is a demanding quality attribute. Nevertheless, there will be no tolerance to the oblivion of any reference element. Each of the possible systems may have distinguished objectives; still the awareness of the users' presence, sense and response are the general objectives of any AAL system. A common RA based on a RM, a set of reference use cases and functionalities eases the determinations of the goals. Also, it serves as an explanation to non-specialist about the nature of the field.

4.3 Openness
The practices of designing AAL systems are largely informal and unconstrained [14,13]. This has the consequence of weakening the effectiveness of the systems and weakens the background of communication between designers and developers. The openness of the RM will break down problems of understanding and emphasizing other systems. The models will be understood, tackled, and refined so that developers who are new to a particular set of problems can quickly learn what the different dilemmas are, and can focus on the problems that they are being asked to solve [35].

4.4 Tolerance to change
The system model should be dynamic and acceptable to the changes. Proposing several versions and the ability to add and remove elements is the key factor of using a RM while designing. Starting with a formal description, processing with a list of conditions and finalizing the model gives a clear image to other contributors [37]. The description of the behavior between the components, the connectors and the process of possible scenarios highlights the changes that have to be made before accepting the end version.

4.5 Balance
As the RM abstracts away implementation details, it focuses on the elements that influence the software's quality. It serves as a standard constitution that supports the reuse concept. Our proposal of a RM promotes the balance between respecting critical attributes and adopting the quality characteristics. It endorses the harmony between all the major concepts of AAL systems. Furthermore, it illustrates the elements of each dimension and the flow of knowledge accomplished by the investigation of the related publication to the field [7,33].

To respect these principles while processing, we organized as follows: For example, to achieve consistency, we highlighted the coherent elements in each of the investigated models. We eliminated the redundant axis in the preliminary examination phase. We checked the flexibility while approving the elements. Consistency was also checked while allocating the elements, as we tuned each of them to the suitable placement. For globalizing the objectives, we eliminated the details in the investigation step. We ignored the minor effect of some individual attributes in the phase of examining the influencing factors. Furthermore, we adopted only major relationships and we ignored the humble effects among some others to reach the globalization. We followed the same approach for each of the principles all the way of standardizing, as we believe its effectiveness in building a coherent, dynamic and adaptive RM for AAL RAs. In each step, we verified the respectfulness of the extracted results to each of the presented principles.

5. AAL reference model
In fact, good engineering demands standards and regulations to follow [11]. In our perception, an AAL system adapting our standard, regulated, RM would consider validating the

dimensions and the attributes we selected in the following RM. We formulated the concepts that govern the variety selected while the investigation, which essentially defines the structure of knowledge in the domain.

We illustrated the first version of the model and we followed several evaluation processes in order to purify the content and improve the quality of the attributes. In this phase, the level of the details was consciously restricted. Finally, this evolution had ended up by the presented version.

We have built a knowledge base on the elements of the AAL environments using the known ontology and the extracted terminology. In this model, we use the AAL system as a root as illustrated in Figure 3, and we describe the formal concepts, as well as the attributes related to each one of them. We define the axioms of the field and the relations between them. Each dimension can be further extended with a set of attributes where their endorsement justifies the quality of the AAL system design. The standard characteristics associated with the dimensions are mandatory. The absence of any critical attribute may cause failures in the system. On the other hand, the quality characteristics have to be supported to guaranty that the system matches the domain's specifications. The absence of a quality characteristic does not apply the failure of the system rather than increasing the chances of rejection from the AAL community. As for example, the security of the individuals among the AAL environment would suggest more attention paid to the actions accorded to the actuators embedded in the AAL space. For instance, this aspect is mandatory for the AAL community, but it is not for the software engineers whom would privilege the security of the system than the physical security and safety of the users.

5.1 Critical attributes

In the critical attributes dimension, we proposed properties and characteristics that should be within an appropriate limit or range to ensure the desired systems quality. To identify the

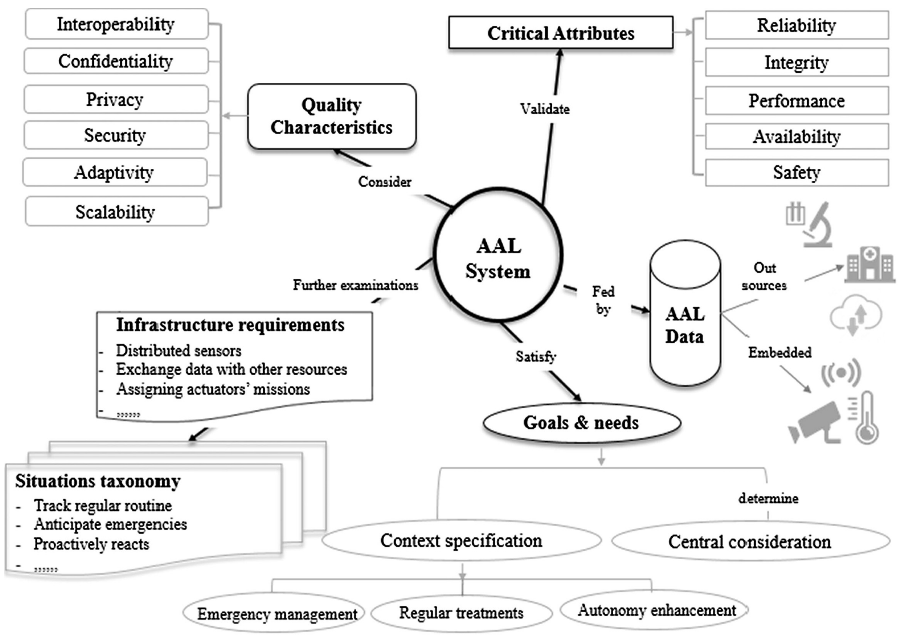

Figure 3.
A scope of the proposed AAL reference model.

critical attributes we considered all the attributes, identifications, content, and elements presented in the AAL literature [7]. We embrace the important ones based on the severity of problems that would result from its absence.

The model of the system should validate a number of attributes. The system has to meet the requirements of the users by being intuitive and easy. Yet, it should result in a good overall user experience. Developers have to take in consideration the assurance for the stakeholders. The system has to remain operational over time. The model will have to face criteria's where the failure of performance is much reduced, which will insure the reliability.

Integrity is mandatory in the term of defining the consistency and coherence of the overall design. This includes the way that components are designed, as well as, factors such as interoperability and completeness [2]. The number of functionalities and services provided by the system has to be taken in consideration to enhance the performance. Simultaneously, attention has to be paid to the complication of emergency services while the design conception.

The system has to be available for legitimate use. Availability represent a critical attribute due to the importance of managing failure scenarios and its associated consequences. The delivery of the services is a major concern for the designers. Specially that we are dealing with a sensitive field related to many critical situations such as emergencies and urgent intervention. The system should be safe for the stakeholders to use. Generally, we are dealing with people with physical and/or mental disorders. The system has to be secure. Yet, it has to be invulnerable and preserved.

5.2 Quality characteristics

AAL systems support the fundamental qualities of confidentiality, privacy, security and many others [28]. Quality characteristics have a greater impact on the reliability of the AAL system model. Any laps on its parameters reduces the ability of the system to evolve and confront the maintainability and scalability issues.

Communicating and exchanging information between the system elements is a mandatory characteristic for the AAL systems. The ability to embrace new sensors as well as actuators, and operate successfully is imperative. The interoperability is the key factor for a successful design capable of embracing new technologies, systems and new devices internally.

The physical privacy of the stakeholders as well as the informational privacy has to be a major concern of any designer. The physical space of the system as well as the identifiable information are very critical. This privacy is strongly connected to other values such as integrity [22]. Yet the privacy by design approach is highly recommended [18], And the 7 foundational principles of it has to be applied while the design creation [31].

While designing the system architecture, the security measurements and the resistance to unauthorized use are indispensable. The capacity of preventing a malicious or accidental action outside of the designed usage is mandatory to prevent the loss of critical information. Access to, or modification of, data and services has to be restricted as we are dealing with personal health issues. Tracking activities within the system is also a demanding service.

One of the major quality attributes of AAL system model is trustability. Mainly because the end-users have no technical expertise in handling different devices, applications, network equipment, gateways, and other infrastructural components. The system model has to consider all the expectations to secure the equipment included in the end users' environments [20].

An AAL system is dedicated to particular stakeholders where each one of them has special needs. A standard system will not fulfill all the expected needs and aspirations of these users. Therfore, adaptivity is mandatory. Adjusting the functionalities will expand the system's cost-effectiveness and reduce the resource consumption.

The major element that we seek to improve by using this RM is scalability. The standardization objective is to introduce systems suitable to be integrated to interoperate in the favor of producing a system-of-systems. The coordination between the systems established under the same guidelines will offer the possibility of the assemblage of existing elements into producing new high-performance ones. The capability of the system to be reused will minimize the duplication of development and will save the most precious value: time.

Reusability is a mandatory quality by which the system would be suitable for use by other systems and would tolerate new elements as well as new devices.

5.3 AAL data

Data in the AAL field is very sensitive in matters of confidentiality. Unauthorized access would disqualify the system integrity. In AAL systems, the enormous, different and far away collected data, the treatments necessarily done to feed the systems, the different backgrounds, architectures and families of the integrated sensors, etc. are all challenging factors for the design of a suitable AAL environment. This makes integrating data a fundamental concern. Nevertheless, the processing time represents a key factor to produce a satisfactory action in an explicit moment.

Both external and internal factors may have a direct effect on the quality of the data collected depending on the distance, the acquisition process and the transmission protocols. Tolerance for different types of data sources, including large, dynamic and heterogeneous ones is to be taken into consideration while the design process [13]. Other problems may appear due to the deluge of data from distant places. The slowness of collecting may cause multiple complications in event triggering. How to precisely determine the value of the data is also a dilemma because of its impact on the quality of the produced knowledge.

The bigness of the collected information means more than simply larger storage requirements; it is also a symptom of scalability issues. In addition, the data collected from sensors can cause an inflection point between the costs and benefits associated with using it. For example, sensors should be able to collect data in 24/7 yet not all these data is suitable nor profitable for the system. Which is a factor to considerate in order to prevent the damages caused by the processing delayed in case of urgent situations.

5.4 Goals & needs

The main interest of the model conception is to be able to determine the goals and the needs out of the establishment of such systems, in the purpose of promoting their scalability and maintainability. In our approach, we consider two major purposes. A system might be a context specific one, which means the general objective of its creation is to help in emergency management or in the urgent situations. Another possibility is to be specified in regulating daily treatment and taking measurements for the end-users as an autonomy enhancement system. Otherwise, the system should have a central consideration specified by the developers and highlighted in the establishment process. The needs have to be described before the determination of the goals, so the developers would not be confused nor the system would be overwhelmed by multiple functionalities that does not help with the main goals.

5.5 Infrastructure requirements & the situation taxonomy

Many further examinations have to be studied. The infrastructure requirements have to be specified and situation taxonomy has to be considered. Customizing predictions and reactions for each stakeholder is a major concern. The AAL system should have a standard data-analyzing layer, working independently, unrelated to the sources of collection, capable of producing knowledge and transferring it to the different processes. Situations treated by the system have to be clearly identified and strongly studied.

The RM for AAL systems represents the first step in producing coherent, common and easily integrated systems. It is considered as the fundamental elements in creating RAs, which simplify the design of concrete architectures in fusion with the design patterns [7,1].

6. Conclusion

RMs in its standard and formal way have been recognized as the backbone to the success of any architectural design of software systems. The standardization of the RM qualified the reuse of the systems into creating a system-of-systems. In this paper, we investigated the process of standardizing models in which we use in assembling the represented one. We examined the domain and we extracted the essential dimensions and their significant attributes.

Based on the promising findings presented in this paper, our next vision intended to concentrate on investigating architectural requirements with the objective of developing a new approach of a RA for AAL systems. Work on context classifications, goal determination and the design elements of the RA are continuing, and will be presented in future papers.

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