Intelligent Environments 2018
I. Chatzigiannakis et al. (Eds.)

doi:10.3233/978-1-61499-874-7-57

Engineering Intelligent Environments: Preliminary Findings of a Systematic Review

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Abstract. Intelligent environments are complex systems that may require a diverse set of hardware devices, software libraries, networking and human computer interactions. New tools and techniques that can facilitate the engineering of such systems are thus critical. However, given the size and heterogeneity of the literature and in the light of, to our knowledge, there being only informal surveys restricted to specific issues have been conducted, we have seen the need to organise and synthesise the existent research corpus to obtain a clear idea on the main approaches that have been utilised for the development of IEs. To address this research gap, this systematic literature review was carried out. This paper presents the review's preliminary findings that are expected to provide avenues for further research in this area. We find that there are different approaches for developing IEs and the development cycle consists of several phases. However, not all phases have received equal consideration. An evaluation framework which could offer guidance on the choice of the most suitable techniques per phase should also be the target of research efforts.

Keywords. Intelligent Environments, engineering, systems development lifecycle

1. Introduction

An Intelligent Environment (IE) consists of a range of embedded devices, sensors, network architectures and middleware, intelligent algorithms, and diverse human computer interactions amongst others [4]. The underlying theories for IEs are from pervasive/ubiquitous computing, smart environments and ambient intelligence. An IE builds on concepts from these key areas by integrating smart environments with ambient intelligence and is based on the pervasive/ubiquitous availability of services. In simpler terms, this is how an intelligent environment is able to acquire and apply knowledge about its occupants and their surroundings in order to improve their experience by providing better comfort, security, efficiency and productivity. The engineering of IEs is therefore a complex undertaking since it involves a wide range of multidisciplinary areas. This, in tum, is driving the need for new tools and techniques that can facilitate the design, implementation and management of such advanced systems.

However, research in this field has been technology driven to a large extent [13]. A lot of focus has also been placed on the development of applications for IEs rather than

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on the engineering of such complex systems [35]. In the context of IEs, where quality, reliability, and safety of users are some of the key requirements, use of suitable techniques is thus essential [4]. Therefore, it is imperative to study the various processes and techniques involved in effectively conceptualising, designing and implementing Intelligent Environments. There is the need to organise and synthesise the existent research corpus to obtain a clear idea on the main approaches that have been utilized for the development of IEs, what issues they addressed and what open issues still need to be tackled. To address the research gap, this systematic literature review seeks to identify, synthesize, and present the findings reported about engineering of Intelligent Environments to date.

This paper consists of the following sections. In section 2, we explain the systematic review process. Section 3 discusses the results of the review with a brief discussion of the researchable issues on this topic. Section 4 concludes the paper.

2. Systematic review process

According to [25], "*A systematic review is a means of identifying, evaluating and interpreting all available research relevant to a particular research question, or topic area, or phenomenon of interest*." The review process consists of several activities such as the development of review protocol, the identification and selection of primary studies, the data extraction and synthesis, and reporting the results. We followed all these steps for the reported study as described in the following sections of this paper.

2.1. Definition of research questions

With the objective of developing an understanding of the state of research regarding engineering of IEs, this study has been driven by the following research questions:

RQ1: How are IEs engineered from a systems development perspective?
RQ2: What are the stages of IE development process that have been mainly considered?
RQ3: What are the techniques which are mainly adopted during each stage of the development lifecycle for IEs?
RQ4: What are the open issues to be further investigated with respect to development of IEs?

2.2. Data sources and search strategies

The search process was performed using automatic and manual search of specific conference proceedings and journal papers since 2000. We only selected papers that are written in English and available online. The search strategy included electronic databases and manual searches of conference proceedings. The following electronic databases were used.

- IEEEXplore (www.ieeexplore.ieee.org/Xplore/)
- Scopus, Elsevier Science Direct (https://www.elsevier.com/solutions/scopus /)
- ACM Digital library (https://dl.acm.org/)
- Google Scholar (http://scholar.google.com/)

- SpringerLink (www.springerlink.com)
- Web of Science (https://webofknowledge.com/)

We also searched the following conference proceedings:

- International Conference on Intelligent Environments
- International Conference on Ambient Assisted Living Technologies
- International Conference on Pervasive Computing and Communications
- International Conference on Cyber-Physical Systems

Different kinds of papers were considered for this study: industry experience reports, theoretical, empirical and experimental academic papers. The review process proceeded in four stages. In stage 1, the electronic databases were searched using every possible combination of search items listed in Table 1. The Boolean "AND" operator was used to combine the search items from Category 1 and 2. This resulted in a total of 4210 publications.

Table 1. Search terms used in the review process

Type	Category	Keywords
1	Primary term	Intelligent Environment, ambient assisted living, smart environment, pervasive system, cyber- physical system
2	Secondary term	Engineering, development, development methodologies, development lifecycle

2.3. Screening papers

The titles of the articles were carefully examined in the second stage. Any title which was clearly outside the scope of the review was removed from any further consideration. Articles that address editorials, prefaces, discussion comments, news, summary of tutorials, workshops, panels and poster sessions were also excluded. During the third stage, each abstract of the remaining 608 articles from the previous stage was investigated by the researcher. At the end of stage 3, 217 papers were left for stage 4 of the selection process.

Finally during the last screening, the whole paper was read to determine its relevancy. The following inclusion (I) and exclusion (E) criteria were applied:

I1: The paper should have some focus on the engineering of IEs; individual phase or lifecycle.
I2: Does the paper discuss application of a systems development methodology or approach for IEs?
E1: Posters, panels, abstracts, presentations and article summaries
E2: Publishing source not relevant

70 papers out of the 217 articles were selected by carrying out the quality assessment based on these four screening criteria. In order to extract significant data from the list of articles obtained, a data extraction form was created using Microsoft

Excel, as shown in Table 2. The design of this form was motivated by [25]. The items bibliographic references, approach identifier and approach aims allowed us to answer RQ1. Items phase in development cycle informed us about RQ2. Items phase in development cycle, technique identifier and technique aims were aimed towards answering RQ3. Finally, to answer RQ4, each paper was carefully scrutinised to gather about limitations and future work as highlighted by its author(s).

Table 2. Data extraction form

General Concern	Specific data
Study	Paper identifier
	Date of data extraction
	Bibliographic reference: Author, year, title, source
	Type of article
Approach	Approach identifier
	Approach aims
	Phase in development cycle
	Technique identifier
	Technique aims
	Limitations
	Future work

3. Results and discussion

3.1. Overview of studies

In the following section, we present the main findings of our study. To begin with, we synthesized the data by identifying themes emanating from the findings reported in each of the reports reviewed in this study. Figure 1 shows the publication frequency of the selected papers from 2000 until 2017. The majority of the studies are from conference proceedings (54%) from 31 different conferences. Journals had 45% of the studies from 18 different journals. Whilst the last couple of years may have seen a statistical decrease in papers, over the decade there has been an 'increasing trend.' This could indicate an interest among researchers to consider applying some methodology for development of IEs.

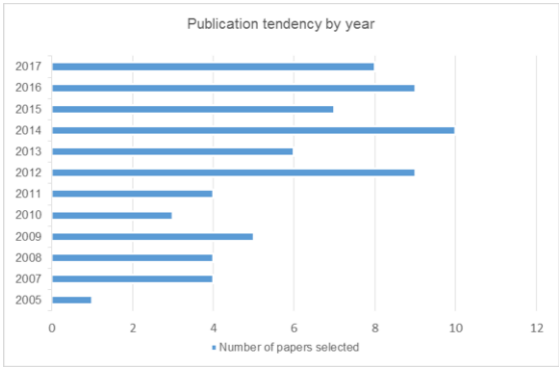

Figure 1: Publication tendency by year

3.2. How are IEs engineered from a systems development perspective (RQ1)?

As shown in Figure 2, a total of 15 distinct approaches were identified for engineering IEs. However, we also noted adoption of mixed approaches in certain projects. Overall, the user driven approach [1; 6; 9; 10; 14; 15; 17; 19; 23; 32; 34; 41] appeared more frequently than the rest.

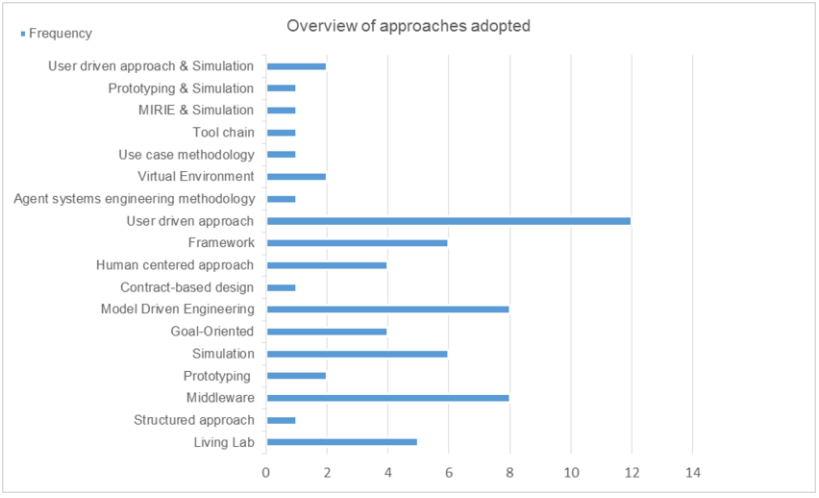

Figure 2: Approaches for development of IEs

3.3. What are the stages of IE development process that have been mainly considered (RQ2)?

According to the study findings in Figure 3, requirements engineering as well as analysis and design phases occupy the major share of attention compared to the other three phases. However, the maintenance stage seems to have been largely overlooked. Only one project [37] briefly mentioned about maintenance phase without offering any mechanism or guidelines on change management for IEs.

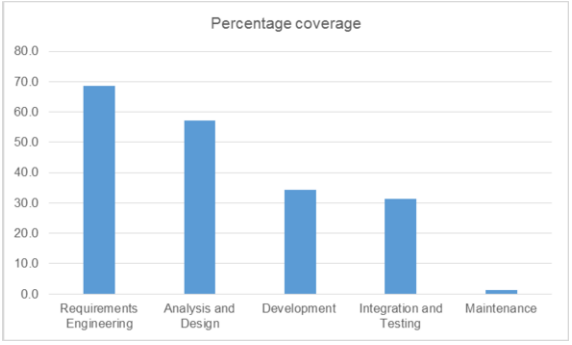

Figure 3: Systems development phase discussed in the papers

3.4. What are the techniques which are mainly adopted during each stage of the development lifecycle for IEs (RQ3)?

Requirements engineering is a key process in systems development methodologies as it defines what a customer or user expects from a new or modified product [40]. A closer scrutiny of the selected papers has uncovered a multitude of techniques for gathering requirements, as shown in Figure 4. However, two of the most prominent approaches are the use of focus groups [6; 10; 15; 16; 18; 19; 21; 22; 31; 34] and scenarios [1; 2; 5; 30; 33; 36; 37; 38; 42; 43].

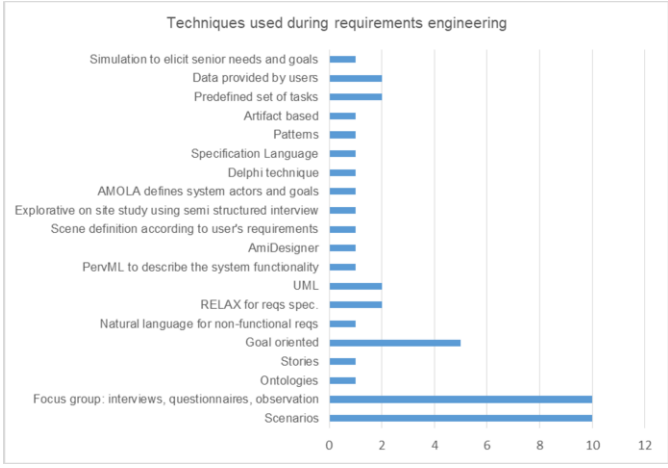

Figure 4: Techniques used during requirements phase

The list of Systems Analysis and Design (SAD) techniques identified in the reports is presented in Figure 5. We gathered that model based techniques were more often utilized during this phase. Some examples are [2; 5; 11; 12; 26; 27; 32; 37; 38; 44].

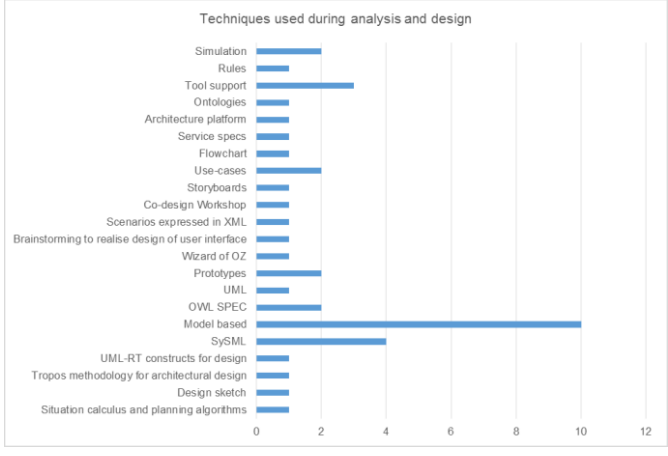

Figure 5: Techniques used during analysis and design phase

As far as the development of IEs is concerned, we found a number of techniques as shown in Figure 6. Although tool support [3; 8; 28; 29; 30; 43] appeared more frequently, it is closely followed by techniques such as prototyping, simulations and middleware.

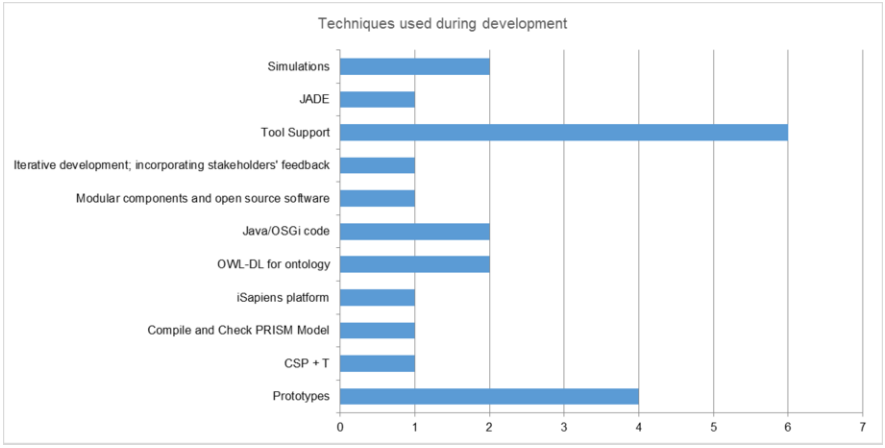

Figure 6: Techniques used during development phase

Figure 7 represents the list of techniques during integration and testing phase. Conventional techniques such as unit and integration testing [6; 12; 34] were quite popular. However, simulations [28; 37; 38] are also gaining in popularity. They enable regulation of the environment, which appears to be relatively difficult in real situations. They also offer the possibility of evaluating user interactions and algorithmic behavior in a safer test environment before actual deployment to the real world [37].

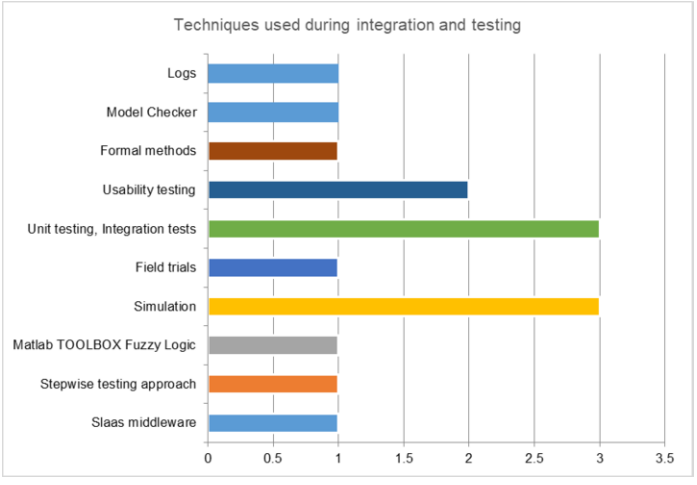

Figure 7: Techniques used during integration and testing phase

3.5. What are the open issues to be further investigated with respect to development of IEs (RQ4)?

For sake of brevity, we are only presenting the main themes which we have uncovered from the study findings. The following papers [1; 10; 11; 24; 26; 27; 31] have emphasized on the need for more real-world applications of IEs for more realistic evaluation of IEs. Some authors have identified addressing usability issues and improving tools which would allow end-users to develop their own IEs [18; 37; 43] as priority. Consolidated efforts aiming to bridge the communication gaps between end-users and designers of IEs were highlighted in the following papers [28; 33; 36; 43].

3.6. Discussion

The review has provided further insights into the techniques which are used by researchers during each phase of the development cycle. However, the limitations of the approaches are still open for further investigation. We note that, for the most part, the IEs were developed in an ad hoc manner. Maintenance appears to be one of the least considered phase. There are no perfect systems and bug fixes or upgrades will always form part of a system life cycle [39; 40]. The review also raises the questions why there is no consensus upon techniques used during a project's phase and there is not yet a standard systems development methodology for IEs. Current research effort is looking towards developing an evaluation framework [20] which could offer guidance on the choice of the most suitable techniques for engineering of IEs.

4. Conclusion

The main motivation for this study was to carry out a systematic literature review on how Intelligent Environments are engineered. We largely followed the guidelines by [26]. The initial search resulted in 4210 papers, out of which 70 were selected for extraction. This report provides preliminary findings of our study.

In terms of an overall methodology, a user driven approach was found to be quite prominent. However, not all phases in the development cycle have received equal consideration. Focus groups seem to be the most accepted method for gathering requirements followed by scenarios. For analysis and design, model based approaches are quite popular. Tool support and prototyping are mostly used during development. Unit and integration tests along with simulations are more frequent during integration and testing. However, the results show that maintenance phase has been largely overlooked.

It is also quite evident from these initial findings that there is no consensus upon techniques used during a project's life-cycle and there is not yet a standard systems development methodology for IEs. Development of an evaluation framework which could offer guidance on the choice of the most suitable techniques for engineering of IEs is in the pipeline.

References

[1] M. Amiribesheli and A. Bouchachia, Towards Dementia-Friendly Smart Homes, *2016 IEEE 40th Annual Computer Software and Applications Conference (COMPSAC)*, **1** (2016), pp. 638-647

[2] A. Ariani, S.J. Redmond, D. Chang and N.H. Lovell, Simulation of a smart home environment, *2013 3rd International Conference on Instrumentation, Communications, Information Technology, and Biomedical Engineering (ICICI-BME)*, 2013

[3] J.C. Augusto, Increasing Reliability in the Development of Intelligent Environments, *Intelligent Environments 2009*, 2009, pp. 134-141

[4] J. Augusto, V. Callaghan, A. Kameas, D. Cook, I. Satoh, Intelligent Environments: a manifesto. *Human - centric Computing and Information Sciences*, 3:12, 2013. Springer.

[5] J.C. Augusto and M.J. Hornos, Software simulation and verification to increase the reliability of Intelligent Environments, *Advances in Engineering Software*, **58** (2013), pp. 18 – 34

[6] J. Augusto, D. Kramer, U. Alegre, A. Covaci and A. Santokhee, Co-creation of Smart Technology with (and for) People with Special Needs, *Proceedings of the 7th International Conference on Software Development and Technologies for Enhancing Accessibility and Fighting Info-exclusion*, 2016, pp. 39—46

[7] K. Bouchard, B. Bouchard and A. Bouzouane, Guidelines to Efficient Smart Home Design for Rapid AI Prototyping: A Case Study, *Proceedings of the 5th International Conference on PErvasive Technologies Related to Assistive Environments*, 2012, pp. 29:1--29:8

[8] F. Cabitza, D. Fogli, R. Lanzilotti and A. Piccinno, End-User Development in Ambient Intelligence: A User Study, *Proceedings of the 11th Biannual Conference on Italian SIGCHI Chapter*, 2015, pp. 146—153

[9] N. Castelli, C. Ogonowski, T. Jakobi, M. Stein, G. Stevens and V. Wulf, What Happened in My Home?: An End-User Development Approach for Smart Home Data Visualization, *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, 2017, pp. 853—866

[10] S. Ceccacci and M. Mengoni, Designing Smart Home Interfaces: Traditional vs Virtual Prototyping, *Proceedings of the 10th International Conference on PErvasive Technologies Related to Assistive Environments*, 2017, pp. 67—74

[11] F. Cicirelli, G. Fortino, A. Guerrieri, G. Spezzano and A. Vinci, Metamodeling of Smart Environments: from design to implementation, *Advanced Engineering Informatics*, **33** (2017), pp. 274 – 284

[12] J.M. Conejero, P.J. Clemente, R. Rodríguez-Echeverría, J. Hernández and F. Sánchez-Figueroa, A Model-driven Approach for Reusing Tests in Smart Home Systems, *Personal Ubiquitous Comput*., **15(4)** (2011), pp. 317—327

[13] F. Corno, E. Guercio, L. De Russis, E. Gargiulo, Designing for user confidence in intelligent environments. *Journal of Reliable Intelligent Environments*. Springer International Publishing Switzerland 2015.

[14] C. Evans, L. Brodie and J. C. Augusto, Requirements Engineering for Intelligent Environments, *2014 International Conference on Intelligent Environments,* 2014, pp. 154-161

[15] R.J. Davies, C.D. Nugent, M.P. Donnelly, M. Hettinga, F.J. Meiland, F. Moelaert, M.D. Mulvenna, J.E. Bengtsson, D. Craig and R.M. Dröes, A user driven approach to develop a cognitive prosthetic to address the unmet needs of people with mild dementia, *Pervasive and Mobile Computing*, **5(3)** (2009), pp. 253 – 267

[16] C. Diamantini, A. Freddi, S. Longhi, D. Potena and E. Storti, A goal-oriented, ontology-based methodology to support the design of AAL environments, *Expert Systems with Applications*, **64** (2016), pp.117 – 131

[17] B. Guo, D. Zhang and M. Imai, Enabling user-oriented management for ubiquitous computing: The meta-design approach ,*Computer Networks*, **54(16)** (2010), pp. 2840 – 2855

[18] S. Hammer, A. Seiderer, E. Andre, T. Rist, S. Kastrinaki, C. Hondrou, A. Raouzaiou, K. Karpouzis and S. Kollias, Design of a Lifestyle Recommender System for the Elderly: Requirement Gatherings in Germany and Greece, *Proceedings of the 8th ACM International Conference on PErvasive Technologies Related to Assistive Environments*, 2015, pp. 80:1--80:8

[19] N. Hendrich, H. Bistry, B. Adler and J. Zhang, User-driven Software Design for an Elderly Care Service Robot, *Proceedings of the 8th International Conference on Pervasive Computing Technologies for Healthcare*, 2014, pp. 142—149

[20] S. Hesari, H. Mashayekhi, R. Raman, Towards a General Framework for evaluating Software Development Methodologies. Proc. IEEE 34th Annual Computer Software and Applications Conference, 2010

[21] M. Hilia, A. Chibani and K. Djouani, Trends and Challenges in Formal Specification and Verification of Services Composition in Ambient Assisted Living Applications, Procedia Computer Science, **19** (2013), pp. 540 – 547

[22] W. Hlauschek, P. Panek and W.L. Zagler, Involvement of Elderly Citizens As Potential End Users of Assistive Technologies in the Living Lab Schwechat, *Proceedings of the 2Nd International Conference on PErvasive Technologies Related to Assistive Environments*, 2009, pp. 55:1--55:4
[23] S. Kartakis and C. Stephanidis, A design-and-play approach to accessible user interface development in Ambient Intelligence environments, *Computers in Industry*, **61(4)** (2010), pp. 318 – 328
[24] J.A. Kientz, S.N. Patel, B. Jones, E. Price, E.D. Mynatt, and G.D. Abowd, The Georgia Tech Aware Home, *CHI '08 Extended Abstracts on Human Factors in Computing Systems*, 2008, pp. 3675—3680
[25] B. Kitchenham, P. Brereton, A systematic review of systematic review process research in software engineering. *Inf. Softw. Technol.*, 55 (12) (2013), pp. 2049–2075
[26] W. Kurschl, S. Mitsch and J. Schönböck, Modeling Situation-Aware Ambient Assisted Living Systems for Eldercare, *2009 Sixth International Conference on Information Technology: New Generations*, 2009, pp. 1214-1219
[27] C. Lampasona, P. Diebold, J. Eckhardt, and R. Schneider, Evaluation in Practice: Artifact-based Requirements Engineering and Scenarios in Smart Mobility Domains, *Proceedings of the 8th ACM/IEEE International Symposium on Empirical Software Engineering and Measurement*, 2014, pp. 20:1--20:8
[28] J. Lertlakkhanakul, W.C. Jin and M.Y. Kim, Building data model and simulation platform for spatial interaction management in smart home, *Automation in Construction*, **17(8)**, 2008, pp. 948-957
[29] T.V. Nguyen, J.G. Kim and D. Choi, ISS: The Interactive Smart home Simulator, *2009 11th International Conference on Advanced Communication Technology*, 2009, pp. 1828-1833
[30] J. Park, M. Moon, S. Hwang and K. Yeom, Development of Simulation System for Validating Contextual Rule in Smart Home, *The 9th International Conference on Advanced Communication Technology*, 2007, pp. 1143-1146
[31] M. Peruzzini and M. Germani, Designing a user-centred ICT platform for active aging, *2014 IEEE/ASME 10th International Conference on Mechatronic and Embedded Systems and Applications (MESA)*, 2014, pp. 1-6
[32] M. Peruzzini and M. Pellicciari, A framework to design a human-centred adaptive manufacturing system for aging workers, *Advanced Engineering Informatics*, **33** (2017), pp. 330 – 349
[33] R. Phull, R. Liscano and A. Mihailidis, Comparative Analysis of Prominent Middleware Platforms in the Domain of Ambient Assisted Living (AAL) for an Older Adults with Dementia (OAwD) Scenario, *Procedia Computer Science*, **83** (2016), pp. 537 – 544
[34] F. Portet, M. Vacher, C. Golanski, C. Roux, Camille and B. Meillon, Design and Evaluation of a Smart Home Voice Interface for the Elderly: Acceptability and Objection Aspects, *Personal Ubiquitous Comput.*, **17(1)** (2013), pp. 127—144
[35] D. Preuveneers, P. Novais, A survey of software engineering best practices for the development of smart applications in Ambient Intelligence. *Journal of Ambient Intelligence and Smart Environments 4:3 (2012), (149-162).*
[36] A. Queirós, M. Cerqueira, A.I. Martins, A.G. Silva, J. Alvarelhão, A. Teixeira and N. P. Rocha, Inspired Personas to Improve Development for Usability and Accessibility in Ambient Assisted Living, *Procedia Computer Science*, **27** (2014), pp. 409 – 418
[37] L. Roalter, A. Moller, S. Diewald, M. Kranz, Developing intelligent environments: A development tool chain for creation, testing and simulation of smart and intelligent environments. In *Intelligent Environments (IE), 2011 7th International Conference on* (pp. 214-221). IEEE.
[38] G.N. Rodrigues, V. Alves, R. Silveira and L.A. Laranjeira, Dependability analysis in the Ambient Assisted Living Domain: An exploratory case study, *Journal of Systems and Software*, **85(1)** (2012), pp. 112 – 131
[39] J. Rushby, Formal methods and critical systems in the real world. *Formal Methods for Trustworthy Computer Systems (FM89)*, 1989, pp.121-125.
[40] I. Sommerville, *Software Engineering*, Addison-Wesley Publishing Company, 2010.
[41] V. Tzeremes and H. Gomaa, A Software Product Line Approach for End User Development of Smart Spaces, *2015 IEEE/ACM 5th International Workshop on Product Line Approaches in Software Engineering*, 2015, pp. 23-26
[42] C.L. Wu and L.C. Fu, Design and Realization of a Framework for Human #x2013;System Interaction in Smart Homes, *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, 42 (2012), pp. 15-31
[43] A. Vasilateanu, I.A. Popescu, A.S. Cergan and N. Goga, Smart home simulation system, *2016 IEEE International Symposium on Systems Engineering (ISSE)*, 2016, pp. 1-5
[44] G.M. Youngblood, D.J. Cook and L.B. Holder, Managing Adaptive Versatile environments, *Pervasive and Mobile Computing*, **1(4)** (2005), pp. 373 – 403