



International Journal of  
**Design Sciences  
& Technology**

**Volume 22 Number 1**

Peruzzini M Germani M  
Papetti A and Iualè M  
(2015) Design of  
sustainable smart homes  
for elderly, *International  
Journal of Design Sciences  
and Technology*, 22:1 7-26

Editor-in-Chief:  
**Edwin Dado**  
**Khaldoun Zreik**

Editors:  
**Reza Beheshti**  
**Daniel Estevez**  
**Mithra Zahedi**

Guest Editors:  
**Regine Vroom**  
**Imre Horváth**

ISSN 1630 - 7267

**europia**

**ISSN 1630 - 7267**

© europa Productions, 2015

15, avenue de Ségur,

75007 Paris, France.

Tel (Fr) 01 45 51 26 07 - (Int.) +33 1 45 51 26 07

Fax (Fr) 01 45 51 26 32- (Int.) +33 1 45 51 26 32

E-mail: [ijdst@europa.org](mailto:ijdst@europa.org)

<http://www.europa.org/ijdst>

*International Journal of*  
***Design Sciences and Technology***

*Volume 22 Number 1*

ISSN 1630 - 7267



*International Journal of Design Sciences and Technology*

**Editor-in-Chief:** **Reza Beheshti**, Design Research Foundation, Netherlands

**Khaldoun Zreik**, University of Paris 8, France

**Editors:** **Daniel Estevez**, Toulouse University, France

**Edwin Dado**, NLDA, Netherlands

**Mithra Zahedi**, University of Montreal, Canada

**Editorial Board:**

**ACHTEN**, Henri (Czech Technical University, Prague, Czech Republic)

**AMOR**, Robert (University of Auckland, New Zealand)

**AOUAD**, Ghassan (Gulf University for Science and Technology, Kuwait)

**BAX**, Thijs (Eindhoven University of Technology, Netherlands)

**BECUE**, Vincent (Université de Mons, Belgium)

**BEHESHTI**, Reza (Design Research Foundation, Netherlands)

**BONNARDEL**, Nathalie (Université d'Aix Marseille, France)

**BOUDON**, Philippe (EAPLV, France)

**BRANGIER**, Eric (Université de Lorraine, France)

**CARRARA**, Gianfranco (Università di Roma La Sapienza, Italy)

**DADO**, Edwin (NLDA, Netherlands)

**EDER**, W. Ernst (Royal Military College, Canada)

**ESTEVEZ**, Daniel (Toulouse University, France)

**FARINHA**, Fátima (University of Algarve, Portugal)

**FINDELI**, Alain (Université de Nîmes, France)

**GERO**, John (George Mason University and University of North Carolina at Charlotte, USA)

**GUENA**, François (ARIAM-LAREA, ENSA de Paris la Villette, France)

**HASSAN**, Tarek (Loughborough University Of Technology, UK)

**HENSEL**, Michael (Oslo School of Architecture and Design, Norway)

**HORVATH**, Imre (Delft University of Technology, Netherlands)

**KATRANUSCHKOV**, Peter (Dresden University of Technology, Germany)

**KAZI**, Sami (VTT, Finland)

**KHOSROSHAHI**, Farzad (University of Leeds, UK)

**KUILEN**, Jan-Willem van de (Munich University of Technology, Germany)

**LAUDATI**, Patrizia (Université de Valenciennes et du Hainaut Cambrésis, France)

**LECLERCQ**, Pierre (University of Liège, Belgium)

**LEEUEWEN**, Jos van (Haagse Hogeschool, The Netherlands)

**MONTARAS**, Lopez de Ramon (ILIA, Spain)

**NEWTON**, Sid (University of New South Wales, Australia)

**PAOLI**, Giovanni de (Université de Montréal, Canada)

**REBOLJ**, Daniel (University of Maribor, Slovenia)

**ROBERTSON**, Alec (4D Design Futures Philosopher, UK)

**RUITENBEEK**, Martinus van de (Delft University of Technology, Netherlands)

**SARIYILDIZ**, Sevil (Delft University of Technology, Netherlands)

**SCHERER**, Raimar (Dresden University of Technology, Germany)

**SCHMITT**, Gerhard (ETH Zurich, Switzerland)

**SCIAMMA**, Dominique (Strate Collège, France)

**SMITH**, Ian (EPFL, Switzerland)

**TROUSSE**, Brigitte (INRIA – Sophia Antipolis, France)

**TURK**, Žiga (University of Ljubljana, Slovenia)

**ZAHEDI**, Mithra (University of Montreal, Canada)

**ZARLI**, Alan (CSTB, France)

**ZREIK**, Khaldoun (University of Paris 8, France)

## **Design of sustainable smart homes for elderly**

**Margherita Peruzzini<sup>1</sup>, Michele Germani<sup>2</sup>, Alessandra Papetti<sup>3</sup> and Matteo Iualè<sup>4</sup>**

<sup>1</sup> Department of Engineering, University of Modena and Reggio Emilia, Modena, Italy. Email: margherita.peruzzini@unimore.it

<sup>2</sup> Industrial Engineering & Mathematical Sciences, Polytechnic University of Marche, Ancona, Italy. Email: m.germani@univpm.it

<sup>3</sup> Industrial Engineering & Mathematical Sciences, Polytechnic University of Marche, Ancona, Italy. Email: a.papetti@univpm.it

<sup>4</sup> Industrial Engineering & Mathematical Sciences, Polytechnic University of Marche, Ancona, Italy. Email: m.iuale@univpm.it

*Designing sustainable systems is challenging since economic, environmental and social factors must be considered. It is particularly hard when heavy interaction with humans take place. The smart home is an example: it is finalized to increase the comfort of dwellings and optimize the devices' behaviour as well as the consumed resources in relation to the users' habits. Elderly represent a special category of users characterized by specific needs: therefore, the design of a smart home is particularly critical since elderly require support in their everyday activities, control of their own lifestyle monitoring, and consciousness about the devices' behaviours. As a consequence, smart home are usually complicated, expensive and not suitable for elderly. This paper defines a methodology to design sustainable smart home systems for elderly. An intelligent network monitoring the users' wellbeing and assuring a controlled use of objects and resources is defined and verified on a case study.*

*Keywords: smart home, sustainability, smart objects, distributed information management, assistive technologies*

### **1 Introduction**

Although numerous research works addressed sustainability issues and many enterprises focused their business on sustainability, developing sustainable systems is still challenging because of the broad range of economic, environmental and social factors that need to be considered across system lifecycle. Alternative definitions of sustainability abound, but for system design purposes the following definition can be provided: “a product, process, or service contributes to sustainability if it constrains environmental resource consumption and waste generation to an acceptable level [32] and, at the same time, supports the satisfaction of important human needs and provides enduring economic value to the business enterprise [3]”. In this context, the home represents a special system and got our attention for two main reasons: firstly, the residential sector has been proved to be one of the most energy-intensive [6]; secondly research focuses on smart device connectivity and information management [23], but they lack of a real user-centred perspective. As a consequence, there is still much to do in terms of sustainability.

As far as smart home system sustainability is concerned, a smart home should be designed according to not only the devices' technological features, but also the needs and skills of home dwellings [28]. Indeed, the majority of the existing systems are usually strongly technology-oriented and focused on the single sub-system potentialities [10]. Consequently they usually focus on the implementation of a specific technology instead of the achievement of the expected benefits for the final users. However, the diffusion of intelligent objects also in private homes makes numerous smart devices available at low cost and enables new functionalities to achieve sustainability. Indeed, the adoption of such objects easily allows monitoring the home environment and the behaviour of its dwellings as well as controlling and supporting the devices' performance. Under these circumstances, the adoption of an interoperable network of smart objects can be exploited to benefit on sustainability in terms of devices' resources control, cost reduction and higher user satisfaction [17].

The notion of Smart Object (SO) describes technology-enhanced everyday objects or devices, which are equipped with sensors, memory and communication capabilities [16]. Hence, they are able to capture information about their surroundings, communicate with each other, react according to previously defined rules and act according to predefined rules on behalf of the user needs [47]. Through the capability to interact with humans directly, they can support users to accomplish their tasks in an intuitive way, monitor the users' state and actions as well as control home performances as well as resources consumption [7].

The concept of Smart Home System (SHS) arises when different SOs are connected to the same network and exchange information each other [45]. A SHS has been defined as a special place where different devices are interconnected to allow the users improving safety, comfort and quality of life, saving energy and reducing the operating costs [39]. As a consequence, it implies creating a distributed network with many entities working together and managing the interrelations between different sub-systems (i.e. home automation, digital entertainment, assistive computing, healthcare, surveillance, energy management). Hence the smart home is a special house that allows highly advanced automatism for controlling and monitoring their functions (e.g. lighting, temperature control, multi-media, security, window and door operations, etc.).

As a result, a SHS made up of a set of SOs can support people in acting and living within their environment through their smart objects, and can control and monitor the users' behaviours and conditions thanks to communication and interoperability functions. In a broader sense SOs can be considered as assistive technologies since they can offer assistance to fragile users, for instance elderly people, which require support to their independent living and real-time feedback about their conditions, even when they are still active and in good health conditions [14].

The present paper focuses on SHS sustainability for elderly. It means that those technologies must be sustainable in terms of their applicability, costs and performances specifically for older people. In this context the present research proposes a methodology to design sustainable smart home networks able to satisfy the needs of elderly. It exploits a set of correlation matrices to elicit the specific needs of elderly, translate them into functional requirements, and selecting the most proper SOs on the basis of the significant information to be managed to realize the desired functionalities. It finally considers the technological constraints to identify the appropriate sustainability-enhancing network architecture.

The remainder of the paper is organized as follows: Section 2 provides an overview about the available SOs for supporting wellbeing and independent living of elderly and information management in the smart home environment; Section 3 describes the approach and the methodology steps to define a smart home; Section 4 illustrates the case study regarding the definition of a sustainable SHS for elderly in the Marche Region.

## **2 smart home for elderly**

### **2.1 Challenges in homecare for elderly**

Smart home are good candidates for supporting elderly people mainly due to the recent challenges in healthcare. Indeed, the quantity of over-65 people is quickly increasing worldwide. According to the UN's population projections, today there are around 600 million of people aged 65 or older alive (representing 8% of the total population); such a group will increase up to 1.1 billion people by 2035 (corresponding to 13% of the total population [46]. Meanwhile, more and more elderly are affected by chronic conditions that need long term and on-going healthcare, preferably at home, and this trend will continue more dramatically among fast developing countries [45]. Generally speaking, elderly consumes three times healthcare resources as much as than other groups [34]. From an economic viewpoint, the healthcare sector is under

great pressure due to limited financial resources and manpower resources, lack of qualified doctors, nurses, and home healthcare staffs.

Against this background, there is a growing concern about sustainability. The current healthcare systems deal with mainly short and episodic treatments, like infection treatment by hospitalization. When elderly care moves at home, problems of the current healthcare system relate to poor continuity, lack of interoperability, and knowledge sharing among those care-providers. After seeing the doctor, patients are discharged from hospital, and the hospital normally doesn't communicate with home health providers. There is no one within the care providers to ensure care at home is appropriate and meshes well with the broader plan of care for that individual [26]. In this context, technological advances in Information and Communication Technologies (ICT) related to biomedical technologies have pushed the frontiers of healthcare into home settings until the so-called "homecare" [13]. Using ICT devices, the diagnosis and treatment information can be shared instantly between patients and doctors, nurses, caregivers, as well the patients' families. During the whole treatment process, information concerning the patients' symptoms, the treatment solutions applied or the effectiveness of solutions can be shared among different medical establishment. Furthermore, instant communication technology can also combine the control of home devices (i.e. household appliances, personal devices) with biomedical devices, or affect their behaviours on the basis of the users' conditions monitored by the medical equipment [30]. Such premises open up to the creation of intelligent smart home for an effective and sustainable elderly care.

## **2.2 Sustainable smart homes for elderly**

The modern sustainable thinking considers three main area of interest: environment, economics and social wellbeing [1]. As far as elderly are concerned, the present research assumes that being sustainable means to be: socially advanced by supporting users in executing their tasks, monitoring their actions and status and guaranteeing usability; economically sustainable in terms of both purchasing and operative costs since usually elderly people have limited monetary resources; eco-friendly in terms of reduced use of material and energy resources and limited infrastructural impact.

In the last years, some studies explored the use of SOs for monitoring people lifestyle and supporting independent living [24]. In this context, SOs represent new opportunities for creating intelligent systems by coping with the limited interaction capabilities of users and exploring context information to provide a more natural interaction and tailored features. For instance, a large variety of wearable SOs for activity monitoring and mobility control has been developed [9]; at the same time, telemedicine systems are increasingly widespread [42] and a large amount of SOs can today assure high performances in terms of stability, accuracy and human interaction, and is available at low costs. In literature, several studies reviewed the existing smart technologies and their benefits, barriers, and drivers. Table 1 summarizes the most recent research works in this context; it highlights the type of technologies they refer to and which aspects they mainly pay attention to.

Furthermore, an in-depth analysis of commercial SOs has been conducted focusing on data and functionalities that they are able to provide. As far as elderly people are concerned, four categories have been defined depending of the aspect monitored: vital signs, lifestyle, mobility and falls detection, and domestic environment. The vital signs monitoring category (1) comprises medical devices (e.g. glucometer, sphygmomanometer, etc.) able to check the user's level of physical functioning (e.g. heart rate, oxygen saturation, ECG, blood pressure, Blood glucose and spirometer values). They usually allow also data storing and sharing, real-time consulting, sending alerts, and other accessory functions. Lifestyle monitoring category (2) involves devices like clothing accessories (e.g. bracelets, pedometers, etc.), personal care products (e.g. scales) and sleep sensors (e.g. bed accessories), able to observe the user's daily behaviour,

monitor his/her sleep quality and control his/her activity (i.e. eating habits, hygiene care, physical exercise, etc.). Usually they have associated apps to enhance user's awareness and encourage the lifestyle improvement by setting goals and providing useful advises. Mobility and falls monitoring category (3) comprises monitoring devices (e.g. video cameras, fall detection systems) able to monitor indoor user mobility, detect possible intrusion or dangerous situations, generate an alert, and help user to stay connected with his/her family and caregivers in order to improve people safety and security. Finally, domestic environment monitoring category (4) refers to sensors able to monitor and control the internal environment by regulating the environmental parameters (e.g. temperature, humidity, water flood, CO2 level).

Table 1 Literary review about smart home for elderly

Authors	Research topics	Attention to user needs	Analysis of impact	Interoperability
Chan et al [8]	Smart home technologies	YES, elderly / disabled people	Social, Economic	NO
Chan et al [9]	Smart wearable systems for activity and health monitoring	NO	Social, Economic	YES
Torunski et al [40]	Energy saving systems	NO	NO	NO
Van den Berg et al [42]	Telemedicine systems review	YES, elderly people	NO	NO
Chidzambwa [11]	Social aspects related to the home telecare	YES, generally	Social	NO
Ghaffarian Hoseini et al [19]	Smart house	YES, generally	Environmental, Social, Economic	NO
Mubashir et al [27]	Fall detection system	NO	NO	NO
Rocha et al [33]	Complete ambient assisted living system	YES, elderly people	NO	YES
Lowe & Ólaighin [24]	Behaviour monitoring systems	NO	NO	NO
Shaikh et al [36]	Intelligent control systems for energy and comfort management	NO	Environmental	NO
Beaudin & Zareipour [5]	Home energy management systems	NO	NO	NO

Subsequently, a survey involving experts from medical and health centres as well as home-care organizations allowed identifying the potential benefits for elderly people due to the adoption of smart home technologies. The survey has pointed out the following key functions:

- *Monitoring physiological and biomedical parameters*: elderly needs to be monitored frequently about their specific diseases, so their vital parameters have to be acquired and checked to control the user's physical functioning (e.g. heart and breathing rate, core and skin temperature, blood pressure, blood glucose level);
- *Monitoring people behaviour and activity*: elderly generally have to follow medical prescriptions and guidelines, so the SOs can control their activities (gait, taking medicines, etc.) with the purpose to detect dangerous situations and potential risks, and can control of their habits (eating habits, hygiene care, physical exercise, etc.)
- *Providing medical assistance*: elderly can feel more secure and quiet thanks to a direct communication with experts available at home. It can be useful to periodically check-up the health conditions and provide consultations in risky situation
- *Supporting sociality*: elderly frequently live alone or spend a lot of time alone, so they need assistance in everyday activities and direct relationships with other elderly people, family members as well as caregivers. It helps them to age less and better
- *Surveillance and security*: elderly people living alone are usually afraid to be hit by thieves and not to receive help in case of danger. Technologies can monitor users' at home, detect risky situations and generate alert when needed, and monitor the domestic environment conditions (temperature, humidity, CO2 level, etc.)
- *Training for a healthy lifestyle*: elderly people can be trained to use SOs to improve their quality of life by setting goals and providing best practices

However, while SHS engineering proposed numerous solutions for home building automation and interoperability according to different standards, from Ethernet, to Transport Control Protocol (TCP), User Datagram Protocol (UDP), Address Resolution Protocol (ARP) Internet Protocol (IP/IPv6) and syntactic interoperability (OSI model) [2, 22, 29], the definition of private smart houses tailored on satisfy specific users' requirements is still challenging. It is due to several reasons: on the technological side, the huge quantity of smart objects available, the variety of adopted communication protocols and data model schemas ([8]; on the functional side, the lack of an analytic classification of SOs and smart home functions and the absence of structured methodologies to select SO addressing specific needs. Indeed, although some companies started to care about devices' remote control [4], real interoperability within a smart home is still far to be implemented due. As a consequence, even if the idea of smart appliances connected within a home network is not new, efficient smart home management has still numerous open issues.

### **3 Designing a smart home system for elderly**

#### **3.1 Research questions and goals**

The present research aims at defining a methodology to design a sustainable smart home for elderly according to their specific needs. The main questions are:

- Which information should be managed to support the user needs for the specific context of application?
- Which is the most suitable set of SOs to support the specific user needs?
- Which are the necessary functions to realize by means of the selected SOs?
- How to create the necessary functions? Which is the most appropriate system architecture?
- How to assess the system performances?

In order to answer these questions, the research adopted a Quality Functional Deployment (QFD) approach to define the design of the sustainable SHS. Such an approach adopts a set of Houses of Quality (HoQ) to progressively correlate the most significant aspects at each stage of the analysis [12], starting from the user needs and arriving to the system architecture. Such an approach is strongly user-centred and commonly used to put the users in the centre of the design process. It allows easily correlating needs and available technologies according to a predefined set of drivers. In our case, drivers are represented by sustainability goals in terms of reduced environmental, economic and social impact. Finally, the research approach supports the definition of the best technologies to create a sustainable system in terms of their applicability, costs and performances specifically for elderly.

In this context, applying a structured methodology for technology selection is the starting point to realize an efficient system [31]. For instance, we classify SOs into homogenous classes, identify a set of significant information categories for the specific purposes, and define a proper information management model. Such a model elicits the relations between SOs, information and functions and the rules to be applied by the network intelligence, like in Papetti et al [28].

The approach starts with a deep phase of analysis of user needs and scenarios focused specifically on elderly. Users are involved by participatory design techniques such as brainstorming, workshops and focus groups. At the same time, experts objectify their impressions and feedbacks in order to carry out the QFD analysis. Matrix correlation allows creating a general and flexible model, and contemporary addressing specific tasks. The adoption of QFD technique to explore the user needs and identify the critical design factors has been successfully adopted also by recent researches: for instance, it has been used to define home system architecture in other field by Germani et al [18], to map the functionalities of an ICT-based assistive platform for fragile old users according to their needs by Peruzzini and Germani [30], and to define a patient-centred medical home model by Singh and Lillran [38].

The research goal is overcoming the theoretical perspective adopted by the majority of the research works in this field by adopting a pragmatic methodology able to rigorously handle the information flows among the SOs and map the correlation between SOs and the needs of elderly people. A lot of previous studies focused on energy-related aspects about the smart home. For instance, Beaudin et al [5] analysed different energy models (e.g., consumer well-being, multi-objectivity scheduling, etc.) and established a common baseline for evaluating new models, but is not appropriate to select technologies; differently, Wong and Li, [44] proposed a set of selection criteria with different weightings for the intelligent building systems, but it is too general and not correlated to the user's needs. Indeed, existing methods mainly focused on specific technological aspects like technical performances, costs or interoperability, without a holistic approach. For instance, Lowe and ÓLaighin [24] focused on the devices' technical characteristics and cost; Chan et al [9] focused on benefits, current barriers, and future perspectives; Van den Berg et al [42] evaluated effectiveness and efficiency of different type of telemedicine interventions, but they only considered the medical aspects. Finally Chidzambwa [11] illustrated the results of a pilot study but it adopted a high-level approach without any quantitative evaluation. An interesting work was carried out by Ted Lour et al [25], which classified the smart home features and explored the users' perceptions and attitudes toward the smart home system. However, it represents more a guideline for services development rather than a method to select the most proper commercial technologies.

As a conclusion, we see that none of prior studies provided a quantitative evaluation of the SOs performances according to the user's needs. There is a lack of a quantitative and well-structured methodologies supporting user-oriented devices' selection and, consequently, user-centred design for smart homes. These are the main open issues that the present paper wants to satisfy.

### **3.2 Research approach**

The approach can be summed up in four main steps:

- 1 Analysis of the needs of elderly people: in-depth analysis of the specific context of use and user scenario by means of brainstorming sessions, workshops and focus groups involving both experts and end-users. In particular, users are involved in a set of situations and are asked to express their feelings, impressions, demands and wishes. Experts observe the users and objectify the ideas of users into a set of needs, and finally users are asked to weight such needs according to their personal perspective. The adopted technique for information gathering is ethnography: ethnography is a way to immerse into the user world by observing users into real or simulated situations. This method is very useful for exploring the needs and behaviours of a target population directly in the context or sway opinions about design alternatives. Field observation gives researchers the opportunity to collect a useful plethora of data. Photos, notes, and a pre-defined checklist for guiding the observation are usually used for this purpose [37]
- 2 Selection of a set of SOs able to satisfying the specific needs: identification of those devices able to satisfy the identified needs by two interrelated correlations. Firstly the user needs as highlighted in the previous step (step 1) are correlated with a set of information that has to be managed to satisfy those needs (Matrix 1), and subsequently such information is correlated with a set of SOs (Matrix 2). In order to do that, the classification proposed in section 2.2 is adopted. The four categories of information identified from the analysis of the state of art are considered the reference model; information are then detailed by experts on the basis of the analysis with users (step 1). The first correlation (needs – information) provides a set of weights to be used for SOs' selection in the second correlation (information – SOs). SOs are finally ranked according to how good they provide and/or manage the information required
- 3 Definition of the Smart Home network architecture: a set of functionalities is defined according to the identified needs (step 1) and the requirement analysis carried out by experts. Such a correlation allows weighting the functionalities according to the specific needs and, subsequently, functionalities are mapped with needs and a final relative importance is defined for each of them (Matrix 3). After that, functionalities are mapped with the selected SOs (from step 2): according to the analysis of the SOs capabilities, a structured correlation is defines (Matrix 4). Correlation between SOs and functionalities drives the system architecture and expresses the system features
- 4 Evaluation of the smart home performance: measuring the sustainability performances of the system items in terms of social, economic and environmental impacts. The evaluation is achieved by the correlation between the identify needs (step 1) and selected SO architecture (step 3) to highlight how good the system architecture supports the identified needs. In particular, each SO of the home system is evaluated in terms of generated impacts necessary to execute those activities satisfying each considered need: the impacts are expressed in terms of consumption of energy and other resources (environmental), related costs (economic), user satisfaction and interoperability (social). While environmental and economic aspects are proportionally related to their impacts

(higher is the value registered and higher is the impact), satisfaction and interoperability are inversely proportional to the social impact (higher are the value and lower is the impact)

The proposed approach is used to define a generic concept of Smart Home for elderly (Figure 1).

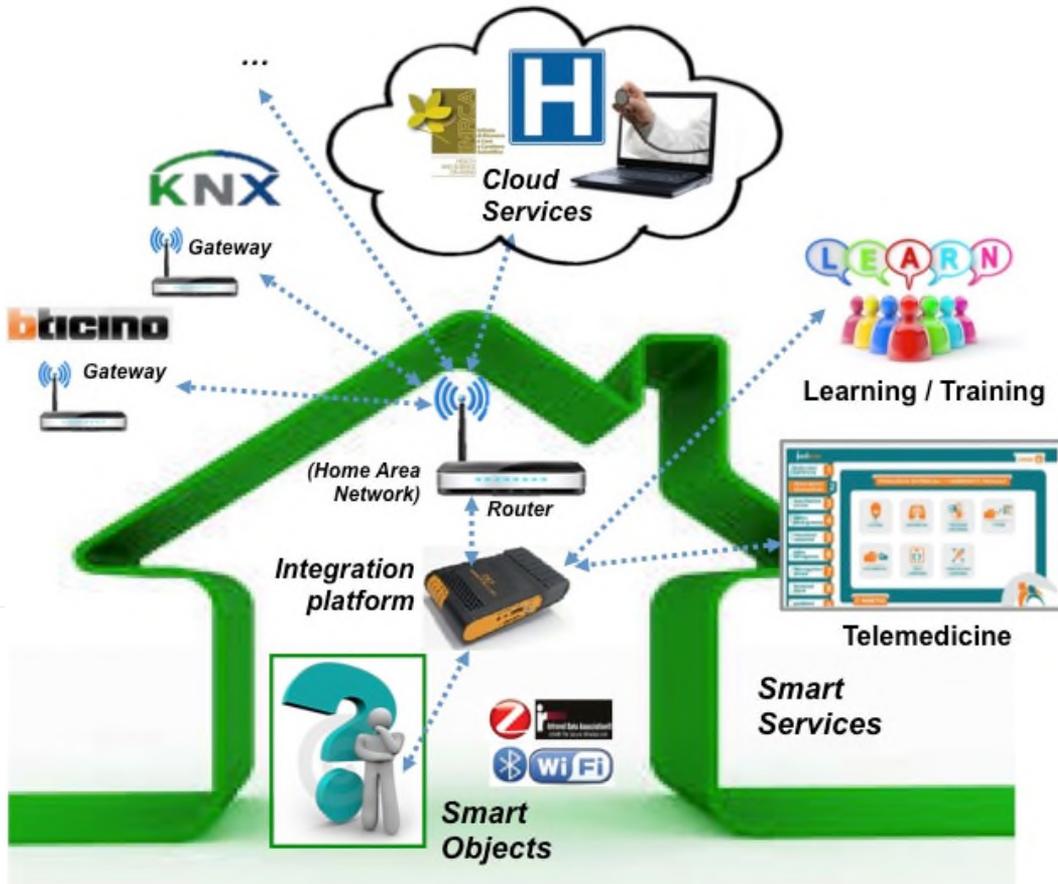


Figure 1 The smart home concept for elderly

The core of the system is an integration platform that concentrates data from/to different Smart Objects and Smart Services supporting older people in their daily living. The platform should guarantee the openness, flexibility, scalability and interoperability of the system, so it must be open to multiple standards and communication protocols and able to exchange information among them. About Smart Objects, different devices could be included: for user action monitoring like sensorized shoes, bracelets or T-shirts, for assistive purposes like fitness tools or kitchen aids, for home automation like environmental sensors or automatic actuators for furniture. Furthermore, services of telemedicine e learning / training can be included. The system can operate within the Home Area network (HAN) but can also exploits the Internet by a common router and http communication. In this way the system can interoperate with commercial home automation buses like Konnex, Bticino or ModBus, and exchange information with any kind of cloud services by web services. In this context, SOs are able to provide support to elderly by realizing their inner functions but also functions from other system or services thanks to an interoperable information

management environment that can assure functions' customization and, finally, the smart home sustainability since it allows to control and optimize the resources spent according to the specific user needs and conditions.

As far as research contributions are concerned, the adopted approach represents a step forward the state of art since it pays attention to user-centred aspects as well as sustainability and interoperability, that is not common in smart home system network. Indeed, it allows designing a smart home for elderly taking into account their needs specifically, but also promoting sustainability from the environmental, economic and social perspective. In this way, it merges technology with assistive and medical goals, energy-efficiency and economic sustainability. As a result, the approach is definitely multi-disciplinary in respect with the current approach from smart home, that are more technology-driven.

### 3.3 The design methodology

In this section the research approach is translated into a structured methodology, which is used to design the sustainable smart home system for elderly. The methodology is described step by step in the following paragraphs. Figure 2 describes more precisely the four method steps and the procedure to move from user analysis to the smart home system architecture and evaluation.

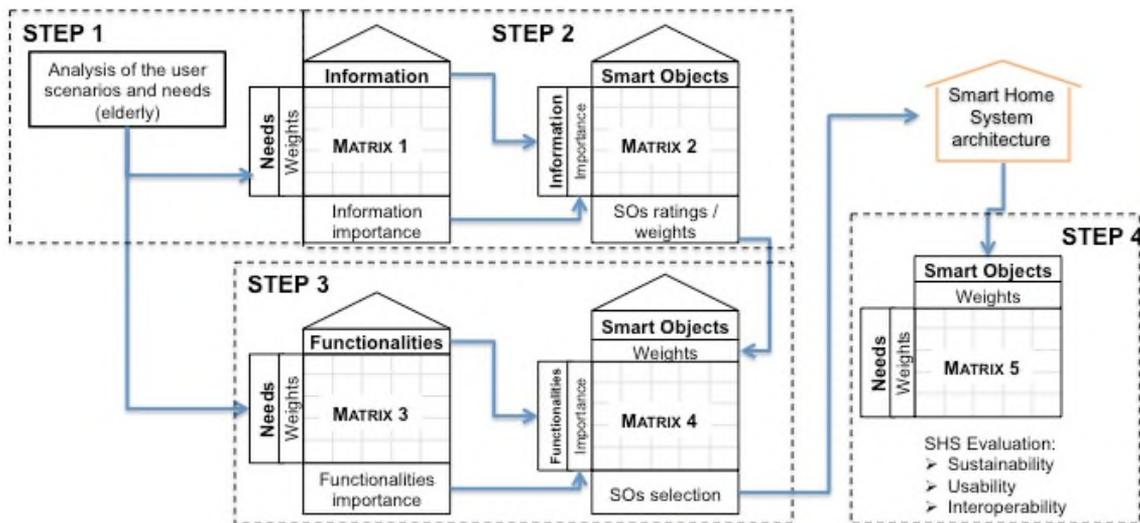


Figure 2 The QFD-based methodology to design the sustainable smart home

The entire process begins with the analysis of the user scenarios and the investigation of the user needs (Step 1). The analysis of the users' needs is based on ethnography and is carried out by the combination of different techniques such as brainstorming, interviews, questionnaires, and focus groups. Ethnography consists of the involvement of experts observing users carrying out real activities or simulating them, and objectifying the users' feelings. After that, experts list a set of needs that are evaluated and weighted by users themselves. This process allows eliciting the most significant needs for the specific target users and weighting them according to their priority and importance by providing a set of weights ( $w_i$ ). Weights express the perceived importance assigned by users to each need according to a 5-points scale (1 - Low and 5 - High).

Step 2 aims at identifying the more appropriate set of SOs to satisfy the users' needs. It is based on a two-fold correlation: needs – information and information – SOs. Matrix 1 contains the selected needs and their weights, as defined in the previous step, and contains a score ( $A_{ij}$ ) expressing the relevance of each information  $j$  to satisfy each specific need  $i$ . It is populated by a team of experts in Cognitive Sciences and Smart Technologies, who assign a 3-classes value ( $A_{ij}$ ) according to the strength of the relationship (9 - Strong, 3 - Medium, 1 - Weak, 0 - No correlation). When Matrix 1 is completed, the absolute importance ( $AI_j$ ) of each type of information can be defined as the sum of all contributions obtained from all considered needs as suggested by (1):

$$AI_j = \sum_i A_{ij} \quad (1)$$

$AI$  represents the importance of each information typology for the specific context of application investigated. If the needs' weighting is considered, a relative importance ( $RI_j$ ) can be calculated by multiplying each score  $A_{ij}$  for its corresponding weight  $w_i$  and by summing all contributions for each information typology  $j$  as suggested by (2):

$$RI_j = \sum_i w_i * A_{ij} \quad (2)$$

Information typologies are ranked according to their relative importance in order to highlight which ones better support the needs satisfaction. Now, it is possible to define the weights of the information  $j$  as in (3):

$$\sigma_j = \frac{RI_j}{\max\{RI_1; RI_2 \dots RI_j \dots\}} \quad (3)$$

It is worth to notice that also the processing requirements (e.g., data capture frequency, formats, etc.) of such information have to be considered in the definition of the Smart Home network architecture. However, they are not considered in the SOs selection stage because they are not directly linked to the specific parameter but depend on various factors such as the offered service, the product characteristics, the context and the user needs. In order to fulfil Matrix 2, for each SO  $k$  a 3-classes values ( $B_{jk}$ ) is assigned depending on how each SO is able to provide a certain information  $j$ . Also in this case, the strength of the relationships depends on the level of satisfaction: for instance, when the SO can properly monitor the information the relation is strong and judge as 9; when the SO needs optional devices the relation is judged as 3; if the SO partially captures the information and provide a limited management (e.g. SO provide data only by smartphone) the relation is judged as 1. When no relationship is evident, a zero value is always assigned. When Matrix 2 is fulfilled, absolute and relative performance ( $AP_k$  and  $RP_k$ ) can be defined for each selected SO.  $RP_k$  considers the weighted sum of all contributions for information as suggested by (4):

$$RP_k = \sum_j \sigma_j * B_{jk} \quad (4)$$

Furthermore, the SOs performances and ratings can be normalized in order to define a set of weights  $\eta_k$  expressing the appropriateness of each SO as suggested by (5):

$$\eta_k = \frac{RP_k}{\max\{RP_1; RP_2 \dots RP_k \dots\}} \quad (5)$$

Step 3 follows the same procedure to correlate the smart home functionalities with the users' needs (Matrix 3) and the SOs (Matrix 4). Matrix 3 expresses the strength of the relation between the need  $i$  and the functionality  $z$  ( $F_{iz}$ ) according to a 3-classes value (9 - Strong, 3 - Medium, 1 - Weak, 0 - No correlation). Absolute and relative importance values are calculated and a set of weights expressing the importance of the considered functionalities for the specific context of application is defined. Matrix 4 maps the ability of each SO to satisfy a specific functionality ( $S_{zk}$ ) according to a 3-classes value (9 - High, 3 - Medium, 1 - Low, 0 - None). It allows selecting the best set of SOs for the specific purpose and defining the network architecture. When no ability is evident a zero value is always assigned. Matrix 4 uses the weights defined

in Matrix 3 to weight the SO capabilities according to the strategic importance of the functionalities for the specific context of use. Finally, Matrix 4 allows identifying a set of SOs that better satisfy the users' needs by realizing the most appropriate functionalities. They will be integrated in the smart home network architecture.

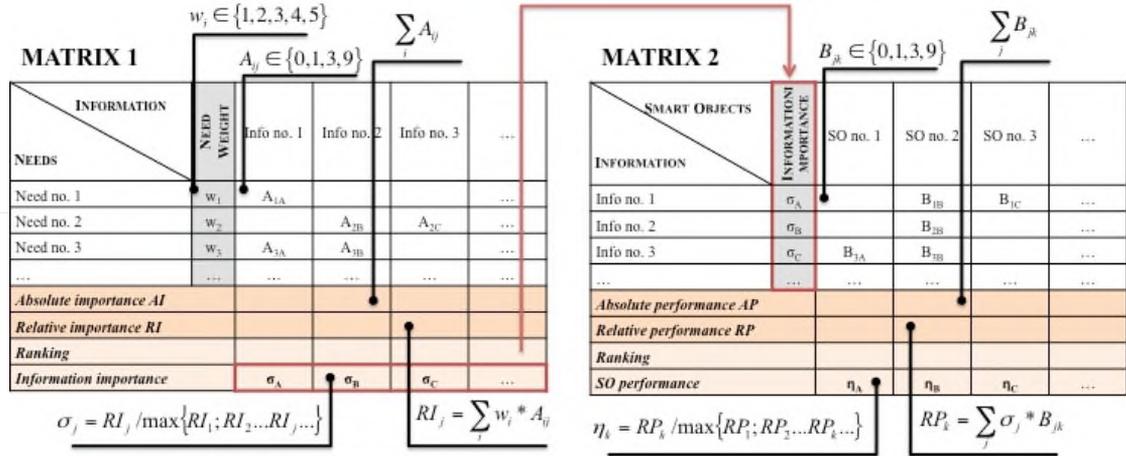


Figure 3 The benchmarking method for Smart Objects selection

Step 3 follows the same procedure to correlate the smart home functionalities with the users' needs (Matrix 3) and the SOs (Matrix 4). Matrix 3 expresses the strength of the relation between the need  $i$  and the functionality  $z$  ( $F_{iz}$ ) according to a 3-classes value (9 - Strong, 3 - Medium, 1 - Weak, 0 - No correlation). Absolute and relative importance values are calculated and a set of weights expressing the importance of the considered functionalities for the specific context of application is defined. Matrix 4 maps the ability of each SO to satisfy a specific functionality ( $S_{zk}$ ) according to a 3-classes value (9 - High, 3 - Medium, 1 - Low, 0 - None). It allows selecting the best set of SOs for the specific purpose and defining the network architecture. When no ability is evident a zero value is always assigned. Matrix 4 uses the weights defined in Matrix 3 to weight the SO capabilities according to the strategic importance of the functionalities for the specific context of use. Finally, Matrix 4 allows identifying a set of SOs that better satisfy the users' needs by realizing the most appropriate functionalities. They will be integrated in the smart home network architecture.

Step 4 concerns the evaluation of the designed smart home system on the basis of the needs' satisfaction. In particular, it considers how the SOs network supports the users' needs; it exploits data from Matrix 3 and Matrix 4 as well as the needs' priority weights from Matrix 1. Indeed, all the functionalities provided by the selected SOs are summarized and a total score is assigned to express the global performance on the basis of needs satisfaction in Matrix 5 (Figure 4). Needs' priority weights are used to calculate relative satisfaction values. The level of satisfaction  $SS_i$  for each need  $i$  is provided by considering both the information managed and the functionalities provided; after that, it is calculated by summing all the contribution for each row, as in (6):

$$SS_i = \sum_k w_i * N_{ik} \quad (6)$$

Finally, summing  $SS_i$  for all needs provides the network performance indicator ( $NP$ ) as in (7).

$$NP = \sum_i SS_i \quad (7)$$

In case of joint winners, the balance among the SOs categories and information provided is considered and experts will prefer that SO which assure a more balanced system. The evaluation allows to easily compare the performances achieved by different SHS architecture and/or configuration.

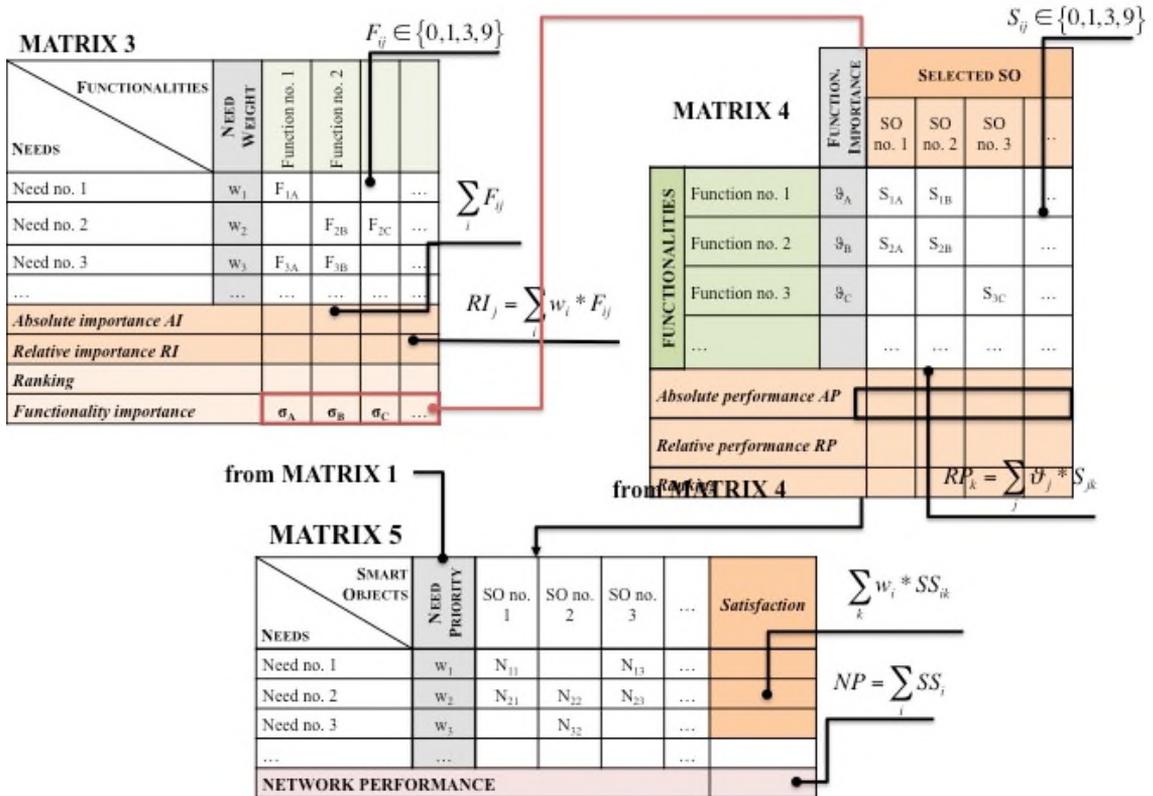


Figure 4 Evaluation of the Smart Home performance

## 4 The case study

### 4.1 Elderly living at home

The case study is represented by the design of a smart home to support elderly in independent living in the Marche Region, in Italy. This region is located in the centre of Italy, on the Adriatic coast, and is characterized by one of the oldest population in Italy and in Europe (over-65 population is about 23%); it is mainly organized in small and medium towns distributed on a varied territory, which shortly changes from seaside to countries and mountains. Furthermore, elderly generally live in private houses, 30% of them live with another elder and 15% of them live alone. In the Marche Region we found that almost 80% of over-65s assumes one medicine at least and about 50% is affected by one or more chronic diseases influencing their lifestyle.

In this context, target users are those people aged from 60 to 70 years old, which are in discrete health condition but living alone and following a medical therapy about medicine assumption, diet and lifestyle, so they should live in a controlled way. As a consequence, the smart home to be realized must be targeted

on such user profile with a preventive purpose by controlling users' behaviours and lifestyle to make people age safely, increase their active lifetime and prevent incidents.

The analysis of the users' needs have been carried out by exploiting the Delphi technique, which is a widely used and accepted method for encouraging the knowledge sharing among experts and reaching a progressive convergence of their opinions. In particular, sample users were submitted by structured questionnaires to investigate their needs and the quality of the support provided by existent technologies as well as the relative driving forces, benefits and barriers. Considering the research topic, about 50 experts pertaining to medical and health care sector (e.g., general practitioner, specialized medical doctor, health care provider, etc.) have been involved. The variety of the user sample allowed obtaining an overall vision of the context and validating the analysis. The answers to questionnaires have been elaborated during a brainstorming session to define the users' needs and establish the relative priority (according to a 5-point scale) according to the frequency of similar answers. According to functional objectives the identified needs have been grouped into four classes:

- Monitoring of physiological and environmental parameters
- Monitoring of people actions within the environment
- Communication
- Supporting a correct lifestyle

The classes have been also divided into sub-classes as reported in the following tables. Finally, experts have been involved also in a workshop to validate the need identified and the relative weights, which have been normalized. From the analysis, the most relevant needs for the specific context of use (with 5-value) belong to following classes: *physiological parameters*, *fall detection*, *assistance*, and *alert*.

## 4.2 Smart home definition

In order to identify which SOs are more appropriate for the case study, correlation between needs and information available from smart devices is found by brainstorming sessions with experts, during which the relative House of Quality matrix was fulfilled. Information types considered are numerous (more than 100). Figure 5 shows the first part of the resulting matrix, according to the ranking: it considers the most significant parameters (top-20 information types) (i.e. blood glucose level, blood pressure, video information, fall detection data, breathing rate, heart rate, oxygen saturation, skin temperature, etc.) After that, an in-depth analysis of the SOs available on the market has been carried out; over than 200 devices have been considered (including clothes, accessories, medical devices, household appliances) and correlated to the treated information typology as shown in Matrix 2. At this stage the regulatory compliance of products (i.e., certification marks such as CE, UL, FCC, etc.) has been also investigated. Considering the relative importance allowed the best performing devices to be selected as shown in Figure 6. Also in this case, the table shows the most significant SOs (top-20 devices). For the following steps, the top-20 SOs have been selected and deeply investigated. Matrix 2 allows also defining a technological performance indicator for each device (on the last row). According to Matrix 2, a set of SOs is selected. In particular it includes:

- personal care products such as scales (e.g., Libra by Runtastic)
- medical devices such as electrocardiographs, pulse oximeters, sphygmomanometers and glucometers (e.g., Cardio Lab wireless by iHEALTH, Blood Glucose & Pressure Meter TD-3280B by TaiDoc etc.)
- clothes such as T-shirt and elastic bands (e.g., Wearable Wellness System by Smartex, BioHarness™ 3 by Zephyr, Equival™ TnR etc.)
- accessories such as watches, pedometers and bracelets (e.g., Basis Peak, wActiSleep+ Monitor by ActiGraph, Amiigo etc.)
- household appliances such as thermostat and video-cameras (e.g., Nest, CubeSensors, Baby Monitor by Withings etc.)

SMART OBJECTS INFORMATION	Information importance																					
	ActiGraph - w/ActiSleep+ Monitor	ActiGraph - w/GTX+ Monitor	AiDC Advise <sup>sm</sup> - 900IBPSTO	Amigo	BAM Labs TLC Smart Bal Platform	Basis Peak	Equivital <sup>sm</sup> TNR	Fitbit - One	FORA <sup>®</sup> - DUOultima D40	HEALTH - Cardion Lab wireless	Larklife	Maximo - Stat-K <sup>sm</sup>	Maximo - Radical-7 <sup>®</sup>	Sevensbags - hugOne	Smartee - Wearable Wellness System	TalDoc - Blood Glucose & Pressure Meter TD-3200B	Withings - Baby Monitor	Withings - Smart Activity Tracker	Withings - Smart Body Analyzer WS-50	Zephyr - BioHarness <sup>sm</sup> 3		
Acceleration peak	0.11																					
Activity level	0.38	0	0																		0	
Activity pace	0.35																					
Activity speed	0.17																					
Activity time	0.64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Altitude	0.11																					
Ankle Brachial Index (ABI)	0.46																					
Arterial oxygen content (CaO2)	0.43																					
Audio	0.90																					
Awake numbering	0.45	0	0																			
Basal Metabolic Rate (BMR)	0.26																					
Bed exit activity	0.55																					
Blood glucose	1.00																					
Blood lactate	0.43																					
Body fat	0.56																					
Body Mass Index (BMI)	0.36																					
Body water	0.30																					
Body weight distribution	0.58																					
Bone mass	0.36																					
Breathing rate	0.96																					
Brushing duration	0.38																					
Brushing frequency	0.38																					
Calories burned	0.64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Carboxyhaemoglobin (COHb)	0.46																					
Cardiac Output (CO)	0.43																					
Core body temperature	0.43																					
Covered distance	0.35																					
Daily Caloric Intake (DCI)	0.26																					
Diastolic Blood Pressure	1.00																					
Electrocardiogram (ECG)	0.46																					
Electroencephalogram (EEG)	0.46																					
Electromyogram (EMG)	0.40																					
Energy use	0.80																					
Exercise type	0.33																					
Fall detection	0.98																					
Fertilizer	0.13																					
Fork servings frequency	0.38																					
Fork servings interval	0.38																					
Galvanic Skin Response (GSR)	0.43																					
Heart Rate (HR)	0.96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Heart Rate Variability (HRV)	0.44																					
Hemacrit	0.46																					
Hemoglobin (Hb)	0.46																					
In bed time	0.55																					
Indoor air quality (CO - level)	0.46																					
Indoor barometric pressure	0.21																					
Indoor humidity	0.40																					
Indoor light level	0.31	0	0																			
Indoor noise level	0.50																					
Indoor temperature	0.72																					
Laps numbering	0.03																					
Last sip time	0.38																					
Lean mass	0.36																					
Meal duration	0.30																					
Meal time	0.30																					
Metabolic age	0.26	0	0																			
Metabolic Equivalent Task (MET)	0.26	0	0																			
Methaemoglobin (MetHb)	0.43																					
Motion detection	0.76																					
Muscle mass	0.36																					
Out of bed time	0.52																					
Outdoor temperature	0.06																					
Oxygen saturation (SpO2)	0.96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Pertusion Index	0.46																					
Perspiration	0.39																					
Phonocardiogram (PCG)	0.43																					
Plethysmogram	0.46																					
Position (GPS)	0.72																					
Position change in the bed	0.52																					
Posture	0.60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
R-R Interval	0.43																					
Skin temperature	0.96																					
Sleep cycle	0.46																					
Sleep quality	0.45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Sleep time	0.49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Soil moisture	0.13																					
Spirometry	0.46																					
Stairs climbed numbering	0.35																					
Steps numbering	0.35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Stress level	0.57																					
Stroke Volume (SV)	0.43																					
Systolic Blood Pressure	1.00																					
Video	0.99																					
Visceral fat rating	0.36																					
VO2	0.43																					
VO2 max	0.43																					
Water consumption	0.38																					
Weight	0.24																					
<b>Absolute performance</b>	90	90	36	72	72	99	78	72	36	54	72	72	83	66	83	36	45	81	54	108		
<b>Relative performance</b>	42.89	42.89	35.23	42.06	45.06	55.47	57.04	35.30	35.62	38.43	35.04	45.96	42.13	35.30	38.49	35.62	33.89	41.78	32.36	59.36		
<b>Ranking</b>	6	6	16	8	5	0	2	17	13	12	17	4	8	20	11	13	9	20	18	1		
<b>SO performance</b>	0.72	0.72	0.59	0.71	0.76	0.93	0.86	0.59	0.60	0.65	0.59	0.77	0.71	0.54	0.65	0.60	0.57	0.70	0.55	1.00		

Figure 6 Correlation between information categories and SOs (Matrix 2) – top-20 Smart Objects for brevity

NEEDS \ INFORMATION		Needs importance	INFORMATION																					
			Activity time	Audio	Bed exit activity	Blood glucose	Breathing rate	Calories burned	Covered distance	Diastolic Blood Pressure	Energy use	Fall detection	Heart Rate (HR)	In bed time	Indoor temperature	Motion detection	Oxygen saturation (SpO2)	Position (GPS)	Posture	Skin temperature	Stress level	Systolic Blood Pressure	Video	Weight
Monitoring of physiological and environmental parameters	Physiological parameters	5				9	9			9			9			9		3	9		9		9	
	Environmental parameters	3		9							9			9	3								9	
	Other parameters	1										9					3							
Monitoring of people actions within the environment	Mobility	4	9	1	9			9	9			3		9		3		9	3				3	
	Falls detection	5									9				1		1	3					1	
	Comfort	3									9	9			9	9					9			
Communication	Sociality	4		9						9	1		9				9	1		9		9	9	
	Assistance	5		9		9	9												9		9	9	9	
	Alert	5		3		9	9			9		9	9						9		9	3	1	
Supporting the correct lifestyle	Analysis	4	9		9			9	9			9	9		9	9		9	9		9	3	1	
	Training	2	9		3	3		9	3	3	9		3	3			1	1			9	3	9	
<b>Absolute importance</b>			27	31	21	30	27	27	21	30	37	39	27	21	31	34	27	27	20	27	27	30	34	28
<b>Relative importance</b>			90	127	78	141	135	90	78	141	113	138	135	78	101	107	135	102	85	135	81	141	140	104
<b>Ranking</b>			16	10	20	1	6	16	20	1	11	5	6	20	15	12	6	14	18	6	19	1	4	13
<b>Information importance</b>			0,64	0,90	0,55	1,00	0,96	0,64	0,55	1,00	0,80	0,98	0,96	0,55	0,72	0,76	0,96	0,72	0,60	0,96	0,57	1,00	0,99	0,74

Figure 5 Correlation between users' needs and smart home information (Matrix 1) – top-20 information types for brevity

Finally, in order to define the smart home system, the correlation between needs and smart devices functionalities has been firstly mapped in Matrix 3 (Figure 7). It highlights the most important functionalities to be realized, in particular they are: *Smart Object interoperability*, *Data visualization* (by remote devices and local displays), *Audio/Video communication*, *Contents customization*, *Taking medicines monitoring*.

At this point, it is possible to define the smart home system architecture by Matrix 4, which expresses the ability of the selected SOs to ensure the most important functionalities (Figure 8) shows the top 20 SOs). Among them, ten SOs have been finally selected scrolling the ranking and passing over the similar products. However, it is possible to select more SOs able to provide the same information increasing the data accuracy and the reliability of the real-time decisions. The selected technologies are: Basis Peak, Equival™ TnR, Sevenhugs - hugOne, Withings - Smart Activity Tracker, FORA® - DUO ultima D40, Nest.

NEEDS \ FUNCTIONALITIES		Needs importance	FUNCTIONALITIES																				
			Feedback and remind	Goals, progress and advices	Medical test	Data visualization	Audio/Video communication	SMS	Contents customization	Web services	Cloud	Training about specific smart product-service	Taking medicines monitoring	Medicines conservation	Action and vitality monitoring	Acquisition and elaboration of mobility	Acquisition and elaboration of state	Energy saving	Support in devices use and accessibility	Domestic environment monitoring	Smart Object interoperability		
Monitoring of physiological and environmental parameters	Physiological parameters	5		3	9	9			9	3							9						9
	Environmental parameters	3				9			9	3				1	3				1			9	3
	Other parameters	1				9			9	3			9	9	3						3	3	
Monitoring of people actions within the environment	Mobility	4												9	9	3				3	3		
	Falls detection	5					3	9						3	3					3	3	3	3
	Comfort	3		3		3	1	1	3		1							9	9	9	9	3	
Communication	Sociality	4		1			9	1		3	1												
	Assistance	5	9	3	9	9	9	9	3	9	9	9	9				9	1	9	3	9	9	
	Alert	5	3		3		9	9		3			9	3	3		3	1	3	3	9	9	
Supporting the correct lifestyle	Analysis	4		3		9			9			9	1	9	9				9			9	9
	Training	2	9	9		3	9		9	9	9	3	3	3	3		9	9				9	9
<b>Absolute importance</b>			21	22	21	51	40	29	51	33	20	40	26	33	24	24	30	36	33	57			57
<b>Relative importance</b>			78	73	105	177	162	142	159	117	70	146	82	120	93	117	94	132	114	225			225
<b>Ranking</b>			16	17	12	2	3	6	4	9	18	5	15	8	14	9	13	7	11	1			1
<b>Functionality importance</b>			0,35	0,32	0,47	0,79	0,72	0,63	0,71	0,52	0,31	0,65	0,36	0,53	0,41	0,52	0,42	0,59	0,51	1,00			1,00

Figure 7 Mapping between target users' needs and SOs' functionalities (Matrix 3)

SMART OBJECTS FUNCTIONALITIES	Functionalities importance	SMART OBJECTS																			
		Basis Peak	Equivalent TnR	Sevenhugs - hugOne	Withings - Aura	Withings - Smart Activity Tracker	Fitbit - One	Zephyr - BioHarness™ 3	FORA® - DUO ultima D40	Nest	AcitGraph - wActiSleep - Monitor	AcitGraph - wGT3X+ Monitor	MIR - Spiriel	Masimo - Rad-87™	TaiDec - Blood Glucose & Pressure Smartex - Wearable Wellness System	Amiigo	Withings - Baby Monitor	Masimo - Radical-7®	Larklife	Fitbit - Flex	
<b>SO performance</b>		0,93	0,96	0,54	0,47	0,70	0,59	1,00	0,60	0,29	0,72	0,72	0,54	0,77	0,60	0,65	0,71	0,57	0,71	0,59	0,54
Feedback and remind	0,35	3	9	9			1			9											1
Goals, progress and advices	0,32	9		9	9	3	1			9	1	1	1				1			1	1
Medical test	0,47		1				9						1	1					1		
Data visualization	0,79	9		1	3		1		9	9			9	9	9				9		1
Audio/Video communication	0,72																		9		
SMS	0,63												9					9			
Contents customization	0,71		9	1		9	9		9	9			3		9	9				9	9
Web services Cloud	0,52	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Training about specific smart product-service	0,31				1					3											
Taking medicines monitoring	0,65																				
Medicines conservation monitoring	0,36																				
Action and vitality monitoring	0,53	9	9	3	3	3	9	3			9	9	1			1	9			9	9
Acquisition and elaboration of mobility parameters	0,41	9	9			9	9	9			9	9	1			9	9			9	9
Acquisition and elaboration of state parameters	0,52	9	9	9	9	9	3	9	9	9	3	3	9	9	9	9	9		9	3	3
Energy saving	0,42									9											
Support in devices use and accessibility	0,59			3	3					3											
Domestic environment monitoring	0,51			9	9				9	3	3								9		
Smart Object interoperability	1,00			9	9	1		1	1	9	3	3						1	1		
<b>Absolute performance</b>		57	46	62	64	43	51	31	37	87	37	37	43	29	36	37	37	37	29	40	42
<b>Relative performance</b>		27,02	23,74	18,40	16,29	16,18	15,92	15,68	14,28	14,18	14,17	14,17	14,02	13,86	13,68	12,95	12,90	12,79	12,71	12,66	12,21
<b>Ranking</b>		1	2	3	4	5	6	7	8	9	10	10	12	13	14	15	16	17	18	19	20

Figure 8 Correlation between target functionalities and smart home SOs (Matrix 4)

NEEDS	SMART OBJECTS	SMART OBJECTS					
		Basis Peak	Equivalent TnR	Sevenhugs - hugOne	Withings - Smart Activity Tracker	FORA® - DUO ultima D40	Nest
Monitoring of physiological and environmental parameters	Physiological parameters	405	738	234	288	603	378
	Environmental parameters	135	135	432	120	192	549
	Other parameters	135	225	108	120	192	243
Monitoring of people actions within the environment	Mobility	468	270	90	486	27	63
	Falls detection	54	165	72	39	3	63
	Comfort	378	108	762	282	57	543
Communication	Sociality	36	27	36	30	27	39
	Assistance	459	552	417	288	603	558
	Alert	252	465	225	153	387	216
Supporting the correct lifestyle	Analysis	945	351	576	729	171	513
	Training	504	228	462	459	279	684
<b>TOTAL SCORE</b>		<b>3771</b>	<b>3264</b>	<b>3414</b>	<b>2994</b>	<b>2541</b>	<b>3849</b>

Figure 9 Social Sustainability assessment for the smart home (Matrix 5)

### 4.3 Cognitive and social sustainability

About sustainability, in this paper we focused on cognitive and social sustainability that is measured in terms of user needs satisfaction. Indeed, environmental and economic performances can be easily measured respectively by estimating the SOs consumptions and costs, according to traditional methods. Several prior works dealt with such aspects [9, 24]. Contrarily, assessing cognitive and social sustainability for elderly is less obvious and more difficult.

As stated in section 2, the present research assumes that the social dimension of sustainability consist of supporting users in executing their tasks and satisfying their needs. In this context, for a rigorous assessment of cognitive and social aspects, the quantitative evaluation from Matrix 5 is merged with a usability testing

with sample users. Firstly, Matrix 5 offers a quantitative analysis of the SOs composing the smart home by considering their relevance in respect with target users' needs for the specific case study, and their performance from technological investigation. It quantitatively expresses how the smart home can satisfy the users' needs. Higher indicators mean a more sustainable network. Results for the case study are shown in Figure 9. The sum of the total scores in the last row express the global sustainability.

#### **4.4 System usability**

Finally, system evaluation is completed by considering the usability perceived by system users. In particular is considered according to its three dimensions (i.e. effectiveness, efficiency, and satisfaction), and a usability protocol has been defined on the basis of international standards [21, 41]. Effectiveness and efficiency can be measured in relation to the fulfilment of the predefined objectives; they can be measured collecting performance data by objective metrics. Satisfaction is derived from the users' subjective impression and is measured collecting preference data by subjective metrics through questionnaires and interviews.

The protocol focuses on the assessment of satisfaction that is directly connected to social and cognitive sustainability. In particular, the protocol is structured according to the Rubin's model (Rubin, 1994) and consists of six main phases:

- Definition of the objectives of the tests: first defining the tests to be carried out, the entities to be measure and so-called metrics (i.e. the product or system characteristics that are most important for usability)
- Definition of the user sample: the user sample must have certain characteristics, for instance it must be large enough to have a proper statistical weight but, at the same time, not too big not to be dispersed, and it must be representative of the target market segment, in our case elderly people requiring assistance at home
- Direct observation of users performing tasks: experts define a list of tasks to execute in order to test the main product / system functionalities and properties, and observe the users in their interaction with the product / system
- Enquiries direct users: after task execution, experts directly interview the users on the basis of an ad-hoc questionnaire to collect subjective impressions (i.e. preference data) that are subjective data measuring the users' opinions expressed about system usability with reference to satisfaction
- Collection of qualitative measurements: data collected in the previous step are analysed using appropriate correlations in order to obtain the degree of usability with a particular focus on satisfaction

For the implementation of the proposed protocol, a set of specific tasks is defined in respect with the SOs involved. At the end of the testing session, users are interviews about the level of satisfaction achieved during task execution and the preference data are expressed in form of judges according to a 5-point scale. Tests were carried out on 20 users. Figure 10 shows the post-pilot testing protocol adopted for the user satisfaction assessment. It is based on the QUEST 2.0 [15] and User Experience questionnaires [20]. Figure 11 shows the results obtained by the proposed smart home on all users (average values).

#### **4.5 Results discussion**

The case study results show how the defined smart home is able to carry out complementary functions and satisfying the different target needs. It is worth noticing that, during the analysis, we found that more than one SOs was able to carry out the same function and achieve similar performance value: in this case other factors were considered to drive the choice (cost, acceptability, easy to use, etc.). The proposed method allows identifying the most relevant SOs for the specific context of application and designing the network itself according to these priorities. The smart home architecture has been defined considering both the integration of the selected SOs and the creation of an interoperable system able to mutually control the devices and properly manage all the data.

**QUEST 2.0**

1 = not satisfied at all; 2 = not very satisfied; 3 = more or less satisfied;  
4 = quite satisfied; 5 = very satisfied

How much are you satisfied about:					
... the dimensions (size, height, length, width) of the product / device?	<input type="checkbox"/>				
	1	2	3	4	5
... the weight of the product / device?	<input type="checkbox"/>				
	1	2	3	4	5
... the ease of adjusting (fixing, fastening) of the product / device?	<input type="checkbox"/>				
	1	2	3	4	5
... the safety and security of the product / device?	<input type="checkbox"/>				
	1	2	3	4	5
... the reliability (durability, resistance) of the product / device?	<input type="checkbox"/>				
	1	2	3	4	5
... the ease to use of the product / device?	<input type="checkbox"/>				
	1	2	3	4	5
... the comfort provided by the product / device?	<input type="checkbox"/>				
	1	2	3	4	5
... the global support provided by the product / device?	<input type="checkbox"/>				
	1	2	3	4	5

Which aspects are more important for you (select 3 of them):

- |                                      |   |
|--------------------------------------|---|
| <input type="checkbox"/> Dimensions  | <input type="checkbox"/> Reliability      |
| <input type="checkbox"/> Weight      | <input type="checkbox"/> Ease to use      |
| <input type="checkbox"/> Regulations | <input type="checkbox"/> Comfort          |
| <input type="checkbox"/> Safety      | <input type="checkbox"/> Support provided |

**USER EXPERIENCE QUESTIONNAIRE**

Which is your general impression about the smart home product / device?

	1	2	3	4	5	6	7		
not understandable	<input type="radio"/>	understandable	1						
dull	<input type="radio"/>	creative	2						
difficult to learn	<input type="radio"/>	easy to learn	3						
inferior	<input type="radio"/>	valuable	4						
boring	<input type="radio"/>	exciting	5						
not interesting	<input type="radio"/>	interesting	6						
slow	<input type="radio"/>	fast	7						
inventive	<input type="radio"/>	conventional	8						
bad	<input type="radio"/>	good	9						
complicated	<input type="radio"/>	easy	10						
leading edge	<input type="radio"/>	usual	11						
unpleasant	<input type="radio"/>	pleasant	12						
demotivating	<input type="radio"/>	motivating	13						
inefficient	<input type="radio"/>	efficient	14						
confusing	<input type="radio"/>	clear	15						
impractical	<input type="radio"/>	practical	16						
cluttered	<input type="radio"/>	organized	17						
unattractive	<input type="radio"/>	attractive	18						
unfriendly	<input type="radio"/>	friendly	19						
conservative	<input type="radio"/>	innovative	20						

Figure 10 Usability evaluation protocol

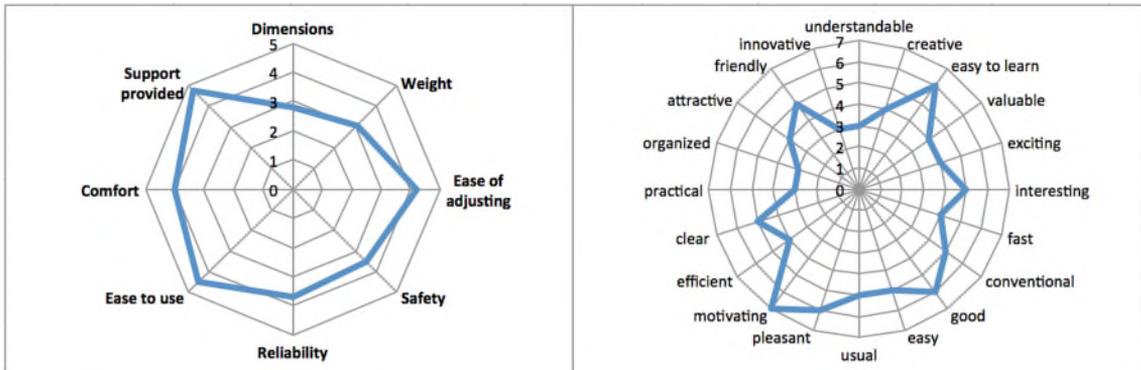


Figure 11 Usability test results (on average)

Indeed, a central information management system need to be created and each SO requires a different connection to the communication infrastructure to deliver all the collected data and make them available to other systems (e.g. for data analysis, for user monitoring, for remote control). In addition, an appropriate logic control of the system is required but it is not treated in this paper because strictly linked to the service that has to be provided.

As far as the proposed SHS, devices were selected according to sustainability principles since Matrix 5 was finally used to choose the more sustainable smart home configuration. Furthermore, different operative

solutions have been tested also from a usability point of view and, also in this case, the final configuration maximized usability dimensions.

The case study demonstrated how such methodology assures contemporarily both the respect of the users' needs and the technological constraints (e.g. cost, function availability); it finally allows achieving high levels of sustainability and satisfaction of the users' needs.

## 5 Conclusions

This paper presents a methodology to support the design of an interoperable smart home enabling elderly people active aging by means of domotic and assistive functions. In particular, it allows selecting that information to be managed in order to effectively support the user needs for a specific context of application, identifying the most proper set of smart devices to be included and the necessary functions to be realized, defining the most appropriate system architecture to realize the desired functions and, finally, assessing system performances with particular attention on social and cognitive sustainability. The method validity is demonstrated by a case study focused on the definition of a smart home for elderly in the Marche Region, in Italy. The new smart home concept is sustainable as it respects the users' requirements as well as the technological constraints and device interoperability.

The main research contributions are:

- adoption of a user-centred perspective for the definition of smart homes, which is usually a technology-driven process: the proposed method exploits Quality Functional Deployment (QFD) to correlate users' needs and system functionalities and a User-Centred Design (UCD) approach to define the system architecture by progressively correlating the most significant aspects at each stage
- identification of a set of guidelines to drive the design of both smart objects and systems in general
- exploration of the users' acceptability of adopted technology and users' satisfaction
- ideation of an interoperable and multi-protocol system overcoming the standard communication protocols and technologies;
- classification of the smart objects available on the market according to a structured approach and a rigorous technological analysis
- definition of a general-purposes model, that can be easily adapted to different scopes as well as target users (it is applied to elderly but it can be easily adapted for designing smart home in different application scenarios)
- evaluation of performances achieved by the smart home as well as its cognitive and social sustainability by indicators, and easy comparison among different SHS architecture and/or configuration

Main limitations of the actual method is the effort necessary for device classification and definition of the correlation matrices with information and functionalities; in order to overcome such limits a structured database and a configuration software system for smart object and intelligent devices are under development. It could be used to validly apply the proposed method easier and faster.

Future works will be oriented to realize a wider evaluation of the performances also by quantitatively measuring. Furthermore, the designed architecture will be implemented in practice and usability tests involving final users will be carried out to assess system usability and global sustainability on practice.

## Acknowledgement

The present paper is the extension of a previous research work presented at the 10<sup>th</sup> International Conference on Tools and Methods of Competitive Engineering TMCE 2014, Budapest, Hungary.

## Bibliography

- [1] **Adams WM** (2006) The Future of Sustainability: Re-thinking Environment and Development in the Twenty-first Century, Report of the IUCN Renowned Thinkers Meeting.
- [2] **Aiello M** and **Dustdar S** (2008) Are our homes ready for services? A domotic infrastructure based on the Web service stack, Pervasive and Mobile Computing, 4:4 506-525 [dx.doi.org/10.1016/j.pmcj.2008.01.002]
- [3] **Bakshi B** and **Fiksel J** (2003) The Quest for Sustainability: Challenges for Process Systems Engineering, AIChE Journal, 49:6 1350-1358 [dx.doi.org/10.1002/aic.690490602]

- [4] **Bansal P Vineyard E** and **Abdelaziz O** (2011) Advances in household appliances - A review, Applied Thermal Engineering, 31:17-18 3748-3760 [dx.doi.org/10.1016/j.applthermaleng.2011.07.023]
- [5] **Beaudin M** and **Zareipour H** (2015) Home energy management systems: A review of modelling and complexity, Renewable and Sustainable Energy Reviews, 45 318-335 [dx.doi.org/10.1016/j.rser.2015.01.046]
- [6] **Bertoldi P Hirl B** and **Labanca N** (2012) Energy Efficiency Status Report, Institute for Energy and Transport, Joint Research Center, European Commission
- [7] **Bohn J Coroama V Langheinrich M Mattern F** and **Rohs M** (2004) Living in a World of Smart Everyday Objects - Social, Economic, and Ethical Implications, Journal of Human and Ecological Risk Assessment, Taylor & Francis 10 763-786
- [8] **Chan M Campo E Estève D** and **Fourniols JY** (2009) Smart homes - Current features and future perspectives, Maturitas, 64 90-97 [dx.doi.org/10.1016/j.maturitas.2009.07.014]
- [9] **Chan M Estève D Fourniols JY, Escriba C** and **Campo E** (2012) Smart wearable systems: Current status and future challenges, Artificial Intelligence in Medicine, 56, 137-156 [dx.doi.org/10.1016/j.artmed.2012.09.003]
- [10] **Chen CY Tsou YP Liao SC** and **Lin CT** (2009) Implementing the Design of Smart Home and Achieving Energy Conservation, Proceedings 7<sup>th</sup> IEEE International Conference on Industrial Informatics (INDIN 2009), Cardiff, Wales, 273-276 [dx.doi.org/10.1109/INDIN.2009.5195816]
- [11] **Chidzambwa L** (2013) The social considerations for moving health services into the home: A telecare perspective, Health Policy and Technology 2 10-25 [dx.doi.org/10.1016/j.hlpt.2012.12.003]
- [12] **Cohen L** (2005) Quality Function Deployment, How to make QFD Work for You? Addison-Wesley New York
- [13] **CORDIS** (2004), Applications Related to Health. Fifth Research and Development Framework Programme 1998-2002, Final report [ftp.cordis.europa.eu/pub/ist/docs/directorate\_c/ehealth/projectbooklet/040416eHealthProjectsFP5.pdf]
- [14] **Cowan D** and **Turner-Smith A** (1999) The role of Assistive Technology in Alternative Models of Care for Older People, in Tinker A et al Alternative Models of Care for Older People research, London, 2 325-346
- [15] **Demers L Weiss-Lambrou R** and **Ska B** (2002) The Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST 2.0): An overview and recent progress, Technology and Disability 14 101-105
- [16] **Ferguson GT** (2003) Have your objects call my objects, Harvard business review 80:6 138-143
- [17] **Gellersen HW, Schmidt A** and **Beigl M** (2000) Adding Some Smartness to Devices and Everyday Things, Proc. WMCSA 2000 – 3<sup>rd</sup> IEEE Workshop on Mobile Computing Systems and Applications, IEEE Computer Society 2000, Monterrey, USA, 3-10
- [18] **Germani M Mengoni M** and **Peruzzini M** (2012) A QFD-based method to support SMEs in benchmarking co-design tools, Computers in Industry 63:1 12-29 [dx.doi.org/10.1016/j.compind.2011.10.007]
- [19] **Ghaffarian Hoseini A Dahlan ND, Berardi U** and **Makaremi N** (2013) The essence of future smart houses: From embedding ICT to adapting to sustainability principles, Renewable and Sustainable Energy Reviews 24 593–607 [dx.doi.org/10.1016/j.rser.2013.02.032]
- [20] **Hassenzahl M** (2001) The effect of perceived hedonic quality on product appealingness. International Journal of Human-Computer Interaction 13 481-499 [dx.doi.org/10.1207/S15327590IJHC130407]
- [21] **ISO 9241-11:1998** (1998) Ergonomic requirements for office work with visual display terminals (VDTs) - Part 11: Guidance on usability
- [22] **Kailas A Cecchi V** and **Mukherjee A** (2012) A Survey of Communications and Networking Technologies for Energy Management in Buildings and Home Automation, Journal of Computer Networks and Communications, Article ID 932181 [dx.doi.org/10.1155/2012/932181]
- [23] **Kofler MJ, Reinisch C** and **Kastner W** (2012) A semantic representation of energy-related information in future smart homes, Energy and Buildings 47 169-179 [dx.doi.org/10.1016/j.enbuild.2011.11.044]
- [24] **Lowe SA** and **ÓLaighina G** (2014) Monitoring human health behaviour in one's living environment: A technological review, Medical Engineering & Physics 36 147-168 [dx.doi.org/10.1016/j.medengphy.2013.11.010]
- [25] **Ted Luor T Lu HP Yu H** and **Lu Y** (2015) Exploring the critical quality attributes and models of smart homes, Maturitas [dx.doi.org/10.1016/j.maturitas.2015.07.025]
- [26] **Mattke S Klautzer L Mengistu T Garnett J Hu J** and **Wu H** (2010) Health and Well-Being in the Home - A global Analysis of Needs, Expectations, and Priorities for home health care Technology. RAND Corporation, Occasional Paper [www.rand.org]
- [27] **Mubashir M Shao L** and **Seed L** (2013) A survey on fall detection: Principles and approaches, Neurocomputing, 100 144-152 [dx.doi.org/10.1016/j.neucom.2011.09.037]
- [28] **Papetti A Peruzzini M Capitanelli A** and **Germani M** (2013) A methodology for interoperability and information management in smart home environments, Proceedings ICED13 International Conference on Engineering Design, Seoul, Korea, 6 149-158
- [29] **Perumal T Ramli A R, Leong C Y, Mansor S** and **Samsudin K** (2008) Interoperability for Smart Home Environment Using Web Services, International Journal of Smart Home 2:4 1-16
- [30] **Peruzzini M** and **Germani M** (2014) Designing a user-centred ICT platform for active aging, in Proceedings 10<sup>th</sup> IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications, Senigallia, Italy [dx.doi.org/10.1109/MESA.2014.6935624]

- [31] **Peruzzini M Germani M Papetti A and Capitanelli A** (2013) Smart Home Information Management System for Energy-Efficient Networks, in *IFIP Advances in Information and Communication Technology*, Springer Berlin Heidelberg, 408 393-401 [dx.doi.org/10.1007/978-3-642-40543-3-42]
- [32] **Robert KH** (1997) *The Natural Step: A Framework for Achieving Sustainability in Our Organizations*; Pegasus: Cambridg, MA
- [33] **Rocha A Martins A Freire Junior JC Kamel Boulos MN Vicente ME Feld R Van de Ven P Nelson J Bourke A ÓLaighin G Sdogati C Jobes A Narvaiza L and Rodríguez-Molinero A** (2013) Innovations in health care services: The CAALYX system, *International journal of medical informatics* 82 307-320 [dx.doi.org/10.1016/j.ijmedinf.2011.03.003]
- [34] **Roos NPR Shapiro EMA and Roos LL** (1984) Aging and the Demand for Health Services: Which Aged and Whose Demand?, *The Gerontologist* 24:1 31-36 [dx.doi.org/10.1093/geront/24.1.31]
- [35] **Rubin J** (1994) *Handbook of Usability Testing: How to Plan, Design, and Conduct Effective Tests*, John Wiley and Sons, New York NY
- [36] **Shaikh PH Bin Mohd Nor N Nallagownden P Elamvazuthi I and Ibrahim T** (2014) A review on optimized control systems for building energy and comfort management of smart sustainable buildings, *Renewable and Sustainable Energy Reviews* 34 409-429 [dx.doi.org/10.1016/j.rser.2014.03.027]
- [37] **Sharp H Rogers Y and Preece J** (2007) *Interaction Design 2*, John Wiley New York
- [38] **Singh VK and Lillrank P** (2015) *Innovations in Healthcare Management: Cost-Effective and Sustainable Solutions*, Productivity CRC Press
- [39] **Tiu K and Kaisa VVM** (2004) Evolution towards smart home environments: empirical evaluation of three user interfaces, *Personal and Ubiquitous Computing*, 8:3-4 234-240 [dx.doi.org/10.1007/s00779-004-0283-x]
- [40] **Torunski E Othman R Orozco M and El Saddik A** (2012) A Review of Smart Environments for Energy Savings, *Procedia Computer Science* 10 205-214 [dx.doi.org/10.1016/j.procs.2012.06.029]
- [41] **UNI EN ISO 10075-3:2005** (2005) *Ergonomic Principles Related To Mental Workload - Part 3: Principles And Requirements Concerning Methods For Measuring And Assessing Mental Workload*
- [42] **Van den Berg N Schumann M Kraft K and Hoffmann W** (2012) Telemedicine and telecare for older patients - A systematic review, *Maturitas* 73 94-114 [dx.doi.org/10.1016/j.maturitas.2012.06.010]
- [43] **Wang L Kong L Wu F Bai Y and Burton R** (2005) Preventing Chronic Diseases in China, *The Lancet* 366 9499 1821-1824 [dx.doi.org/10.1016/S0140-6736(05)]
- [44] **Wong JKW and Li H** (2008) Application of the analytic hierarchy process (AHP) in multi-criteria analysis of the selection of intelligent building systems, *Building and Environment* 43:1 108-125 [dx.doi.org/10.1016/j.buildenv.2006.11.019]
- [45] **Wong JKW Li H and Wang SW** (2005) Intelligent building research: a review, *Automation in Construction* 14:1 143-159 [dx.doi.org/10.1016/j.autcon.2004.06.001]
- [46] **World Population Ageing** (2013) United Nations report, New York [www.un.org/en/development/desa/population/publications/pdf/ageing/WorldPopulationAgeing2013.pdf]
- [47] **Ziefle M and Rocker C** (2010) Acceptance of pervasive healthcare systems: A comparison of different implementation concepts, *Proceedings 2010 International Conference on Pervasive Computing Technologies for Healthcare (PervasiveHealth)* 1-6 [dx.doi.org/10.4108/ICST.PERVASIVEHEALTH2010.8915]



## **International Journal of Design Sciences and Technology**

**Design Sciences, Advanced Technologies and Design Innovations**

*Towards a better, stronger and sustainable built environment*

### **Aims and scope**

Today's design strongly seeks ways to change itself into a more competitive and innovative discipline taking advantage of the emerging advanced technologies as well as evolution of design research disciplines with their profound effects on emerging design theories, methods and techniques. A number of reform programmes have been initiated by national governments, research institutes, universities and design practices. Although the objectives of different reform programmes show many more differences than commonalities, they all agree that the adoption of advanced information, communication and knowledge technologies is a key enabler for achieving the long-term objectives of these programmes and thus providing the basis for a better, stronger and sustainable future for all design disciplines. The term sustainability - in its environmental usage - refers to the conservation of the natural environment and resources for future generations. The application of sustainability refers to approaches such as Green Design, Sustainable Architecture etc. The concept of sustainability in design has evolved over many years. In the early years, the focus was mainly on how to deal with the issue of increasingly scarce resources and on how to reduce the design impact on the natural environment. It is now recognized that "sustainable" or "green" approaches should take into account the so-called triple bottom line of economic viability, social responsibility and environmental impact. In other words: the sustainable solutions need to be socially equitable, economically viable and environmentally sound.

IJDST promotes the advancement of information and communication technology and effective application of advanced technologies for all design disciplines related to the built environment including but not limited to architecture, building design, civil engineering, urban planning and industrial design. Based on these objectives the journal challenges design researchers and design professionals from all over the world to submit papers on how the application of advanced technologies (theories, methods, experiments and techniques) can address the long-term ambitions of the design disciplines in order to enhance its competitive qualities and to provide solutions for the increasing demand from society for more sustainable design products. In addition, IJDST challenges authors to submit research papers on the subject of green design. In this context "green design" is regarded as the application of sustainability in design by means of the advanced technologies (theories, methods, experiments and techniques), which focuses on the research, education and practice of design which is capable of using resources efficiently and effectively. The main objective of this approach is to develop new products and services for corporations and their clients in order to reduce their energy consumption.

The main goal of the *International Journal of Design Sciences and Technology* (IJDST) is to disseminate design knowledge. The design of new products drives to solve problems that their solutions are still partial and their tools and methods are rudimentary. Design is applied in extremely various fields and implies numerous agents during the entire process of elaboration and realisation. The International Journal of Design Sciences and Technology is a multidisciplinary forum dealing with all facets and fields of design. It endeavours to provide a framework with which to support debates on different social, economic, political, historical, pedagogical, philosophical, scientific and technological issues surrounding design and their implications for both professional and educational design environments. The focus is on both general as well as specific design issues, at the level of design ideas, experiments and applications. Besides examining the concepts and the questions raised by academic and professional communities, IJDST also addresses the concerns and approaches of different academic, industrial and professional design disciplines. IJDST seeks to follow the growth of the universe of design theories, methods and techniques in order to observe, to interpret and to contribute to design's dynamic and expanding sciences and technology. IJDST will examine

design in its broadest context. Papers are expected to clearly address design research, applications and methods. Conclusions need to be sufficiently supported by both evidence from existing research (reference to existing design research knowledge) as well as strong case-studies from any design discipline. A paper must contain at least one chapter on research questions, methodology of research and methods of analysis (the minimum length is 1500 words). The concluding chapter (the minimum length is 1000 words) will summarise the paper and its results. The concluding chapter also examines and discuss applications, advantage, shortcomings and implications of the investigation for both professional and educational design communities as well as for the people and the society. Also authors are also encouraged to include in this chapter a discussion of the possible future research that is required or is possible in order to enhance the research findings.

The papers considered for IJDST cover a wide range of research areas including but not limited to the following topics: Design research, design science, design thinking, design knowledge, design history, design taxonomy, design technology, design praxeology, design modelling, design metrology, design axiology, design philosophy, design epistemology, design pedagogy, design management, design policy, design politics, design sociology, design economics, design aesthetics, design semantics, design decision-making, design decisions, design evaluation, design sustainability, design logic, design ontology, design logistics, design syntaxis, design ethics, design objective, design responsibility, design environment, design awareness, design informatics, design organization, design communication, design intelligence, design evaluation, design education, design theories, design techniques, design methods, design operations, design processes, design products, design users, design participation, design innovation, design inspired by nature, design case studies, design experiments, etc.

The *International Journal of Design Sciences and Technology* is devoted to further exploration of all themes and issues that are directly or indirectly relevant to the exploration, introduction, discussion of design sciences and technology, cross referencing domains and any other themes emerging in the future.

### **Instructions for Authors and Review Process**

*Pre-review Stage* (Editor Global Review): Papers can only be considered for review when they deal with a subject relevant to the content of the journal. In addition all papers submitted must follow the journal's paper structure and author instructions before they can be considered for review. These instructions also affect the content of the paper. The preferred size of a paper is about 10000 words (The minimum length of a paper is about 7000 words). The title must not be longer than seven words. Subtitles are not permitted. The maximum length of the abstract is 150 words. The paper must contain an introductory chapter with extensive literature review of similar research (the minimum length of the introduction chapter is about 1000 words). The paper devotes at least one chapter to detailed discussion of research questions, research analysis and research contributions (the minimum length of this chapter is about 1000 words). The conclusion will summarise the research and its results. In addition this chapter includes a detailed discussion of applications, advantage, shortcomings and implications of the investigation as well as future research for both design professionals and the design education (the minimum length of conclusions is about 1000 words). Submit a paper at this stage as PDF.

*Review Stage* (Peer Review): Only papers meeting all IJDST requirements can be considered for review. All papers are reviewed by at least two expert reviewers. The main author of a reviewed and accepted paper will be notified with instructions to resubmit the paper. All reviewed and accepted papers have to be resubmitted, implementing reviewers and editors comments and/or suggestions. Only accepted papers conforming to instructions will be considered for publication in the *International Journal of Design Sciences and Technology*. A paper should follow the IJDST paper structure. The review process will be repeated until all requirements are met.

The first page of the paper must contain the full title of the paper as well as the Name+Surname (no initials), affiliation, address, telephone, fax and email of the corresponding author to whom all correspondence to be directed. Also mention the Name+Surname (no initials), affiliation, postal address, telephone, fax and email of the co-authors (if any).

The second page contains the full title of the paper (maximum 7 words), the sub-title is not permitted, an abstract of about 50 to 150 words summarising the content of the paper and 3-5 keywords for the purpose of indexing (the use of references in the abstract is discouraged). The length of a paper is about 7000 words (10000 words is preferred). Short papers will not be accepted for publication and have to be resubmitted. The use of Footnotes is permitted (maximum length is about 50 words). Footnotes should be numbered consecutively. For instance: [[17 A 'footnote' reflects additional information, a reference or the URL of a website]].

The paper will be written in the UK English. It will be single-spaced with 30 mm margins on all sides (paper size A4). Use Times New Roman for the main body of text (size 10), figures (size 8) or tables (size 8). The use of Bold, Italics, ALL CAPS, SMALL CAPS, etc. is discouraged. All chapters should be numbered consecutively (more than two level sub-headings is discouraged). All Figures and Tables with their respective captions should be numbered consecutively. They should each, be placed on a separate page, at the end of the paper. Give an approximate insertion point for figures and tables, between double square brackets. For instance: [[insert Figure 5]]. You will be asked to resubmit tables, figures and images if necessary. The paper must be submitted in plain text. Do not layout your paper. Do not use any styles or any automatic layout system. Please do not use 'Track Changes'.

All tables should be clearly referred to in the main body of text as Table 1, Table 2, etc. All Figures should be clearly referred to in the main body of text as Figure 1, Figure 2, etc. Line drawings should be of good quality. Use light background if possible (white is preferred). Photographs and screen-shots should also be submitted separately as JPEG files (use high resolution for better results). Authors should prepare high quality figures and drawings. The use of colours in your illustrations is permitted although the hardcopy of the journal is not published in colour. Maximum width and height of a figure are respectively 150 mm and 190 mm. Maximum width and height of a table are respectively 115 mm and 170 mm. All Equations will be numbered consecutively and should be clearly mentioned in the main body of text.

All references will appear at appropriate places in the main body of text. References are collected at the end of the paper, arranged in alphabetical order (numbered consecutively) by the first author's surname, followed by initials. All authors should be mentioned. Dates will appear between brackets after the authors' name(s). This is followed by the title of the book, name of the publisher, place of publication and page numbers (if applicable). To refer to a journal paper, add the full title of the journal followed by Volume:Number and page(s). The number of references to the author's own previous publications will not exceed 5% of the total number of references. References that are not mentioned in the main body of text are not allowed. Examples of references to a book, a journal or a website are shown below:

- [1] **Beckett KL** and **Shaffer DW** (2004) Augmented by Reality: The Pedagogical Praxis of Urban Planning as a Pathway to Ecological Thinking, University of Wisconsin, Madison
- [2] **Blackman, DA** (2001) Does a Learning Organisation Facilitate Knowledge Acquisition and Transfer? Electronic Journal of Radical Organization Theory, 7:2 [[www.mngt.waikato.ac.nz/Research/ejrot/Vol7\\_1/Vol7\\_1articles/blackman.asp](http://www.mngt.waikato.ac.nz/Research/ejrot/Vol7_1/Vol7_1articles/blackman.asp)]
- [3] **Buxton, W** (1997) Living in Augmented Reality: Ubiquitous Media and Reflective Environments. In: Finne K, Sellen A and Wilber S eds, Video Mediated Communication, Erlbaum, Hillsdale NJ, 363-384
- [4] **Dixon, NM** (2000) Common Knowledge: How companies thrive by sharing what they know, Harvard Business School Press, Boston, MA

- [5] **Djenidi H, Ramdane-Cherif A, Tadj C and Levy N** (2004). Generic Pipelined Multi-Agents Architecture for Multimedia Multimodal Software Environment, *Journal of Object Technology*, 3:8, 147-169
- [6] **Gorard, S and Selwynn, N** (1999) Switching on to the learning society? Questioning the role of technology in widening participation in lifelong learning, *Journal of Education Policy*, 14:5, 523-534
- [7] **World Bank** (2002) Social assessment as a method for social analysis, World Bank Group [[www.worldbank.org/gender/resources/assessment/samethod.htm](http://www.worldbank.org/gender/resources/assessment/samethod.htm)]

The definitive paper is submitted as plain text MS Word file for the PC (MS Word RTF format for the Apple). In addition, a formatted version of the paper (including images and tables at their approximate places) will be submitted in PDF format. All figures must be submitted separately in high resolution jpg format. Submit your paper as an email attachment to: [submit2ijdst@gmail.com](mailto:submit2ijdst@gmail.com).

Author(s) of an accepted paper have to complete, sign and return a *Copyrights Transfer Form* to the publisher. This copyrights transfer assignment will ensure the widest possible dissemination of information. Papers published in the *International Journal of Design Sciences and Technology* cannot be published elsewhere, in any form (digital, paper-based or otherwise) without a prior written permission from the publisher.

The author(s) are responsible for obtaining permission to utilize any copyrighted material. For more details about this subject, please contact the publisher at an early stage.

A paper can be rejected at any stage if the requirements are not met. The decision of the Editor-in-Chief on all matters related to the *International Journal of Design Sciences and Technology* including the review process, publication of papers, etc. is final and cannot be disputed.

There is no deadline for the publication of an accepted paper that will be published online within one to four months after the final re-submission is accepted. The hardcopy book of the volume will be published when 8 papers are published online. The corresponding author of a paper published in the *International Journal of Design Sciences and Technology* will receive a digital copy of the author's paper free of charge. Hard copies of any individual paper (minimum 100 copies) and the hardcopy of the IJDST Volume (containing 8 papers published online) can be purchased from the publisher (ask for an invoice from the publisher [ijdst@europia.org](mailto:ijdst@europia.org)).



## How to Order

### IJDST-online

You can view and download a digital version of individual papers free of charge from the journal's website.

### IJDST Hardcopies

Hardcopies of individual papers (minimum order 100 copies) and volumes (minimum order is one single copy of the book containing 2 issues) can be ordered directly from Europaia Productions. You need to send your **Request for an Invoice** (preferably by email, Fax or letter) indicating details of your order and the quantities. Please provide your full name and initials, postal address, email and telephone number. An invoice will be sent to you indicating the total amount of your order, the cost of packing/postage and method of payment.

### Individual Subscription IJDST Hardcopies

Individuals can subscribe to receive a hardcopy of the book containing 2 issues for € 200.00 (incl. 5.5 % VAT, packing and postage). You need to send your **Request for a Subscription Invoice** (preferably by email, Fax or letter) indicating the IJDST Volume. Please provide your full name and initials, postal address, email and telephone number. An invoice will be sent to you indicating the method of payment.

### Institutional Subscription IJDST Hardcopies

Libraries and organisations can subscribe to receive a hardcopy of the book containing 2 issues for € 200.00 (incl. 5.5 % VAT, packing and postage). You need to send your **Request for a Subscription Invoice** (preferably by email, Fax or letter) indicating the IJDST Volume. Please provide details of the library or organisation, name contact person, postal address, email, telephone number and Fax number. An invoice will be sent to you indicating the method of payment.

### Other Publications

Other Europaia Productions publications can be ordered from the address below. You always need to send your **Request for an Invoice** (preferably by email, Fax or letter) indicating details of your order and the quantities. Please provide your full name and initials, postal address, email and telephone number. An invoice will be sent to you indicating the total amount of your order, the cost of packing/postage and method of payment.

### Europaia Productions

15, avenue de Ségur, 75007 Paris, France

Telephone +33 1 4551 2607 / Fax +33 1 4551 2632

E-mail: [ijdst@europia.fr](mailto:ijdst@europia.fr)

URL: <http://europia.org/ijdst/>

europia