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ORIGINAL ARTICLE

Designing for user confidence in intelligent environments

Fulvio Corno[1] · Elena Guercio[2] · Luigi De Russis[1] · Eleonora Gargiulo[1]

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Abstract Intelligent environments aim at supporting and assisting users in their daily activities. Their reliability, i.e., the capability of correctly accomplishing the intended tasks and of limiting or avoiding damage in case of malfunctions, is essential as for any user-facing technology. One aspect of reliability, often neglected, is guaranteeing the consistency between system operation and user expectations, so that users may build confidence over the correct behavior of the system and its reaction to their actions. The paper will review the literature concerning methodologies and tools that directly involve users and have been specifically applied or adopted for intelligent environments, throughout the entire design flow—from requirements gathering to interface design. The paper will then propose, building on top of the previous analysis, a set of guidelines that system designers should follow to ensure user confidence in their intelligent environments.

Keywords User-centered design · Human factors · User confidence · Design methodology

✉ Fulvio Corno
fulvio.corno@polito.it

Elena Guercio
elena.guercio@telecomitalia.it

Luigi De Russis
luigi.derussis@polito.it

Eleonora Gargiulo
eleonora.gargiulo@polito.it

[1] Politecnico di Torino, Turin, Italy

[2] Telecom Italia, Turin, Italy

1 Introduction

An intelligent environment (IE) is a complex system, where complexity is spread over several technology layers, from sensors to networks, from intelligence to user interfaces, from devices to context. The layering of so many differing technologies, all equally needed and equally important to realize the vision of IEs, has the effect of splitting and fragmenting the research community, where each set of problems may be explored and tackled by specialized groups: this is beneficial for the discovery of new methods and solutions at various levels. When considering reliability of IEs, however, this fragmentation becomes an issue, since the reliability properties depend on the characteristics of the system as a whole, and on the interaction of its components.

Reliability is an attribute of any computer-related component (software, or hardware, or a network, for example) that consistently performs according to its specifications; more formally it describes the ability of a system or component to function under stated conditions for a specified period of time [27].

The application of this definition to the field of intelligent environments has deep implications, since all the architectural layers of an IE should be designed and tested with reliability in mind, and by adopting suitable design processes and verification methodologies.

In particular, this paper focuses on the highest layer in an IE system: the interaction with the users. Humans (inhabitants, householders, workers, customers, or just passing by) are the ultimate targets of any IE system, and also for human users the system must "perform according to its specifications" or "function under stated conditions"; in other words, system operation must be *understandable* and *predictable* by its users. Providing an effective and satisfactory user experience is a crucial requirement for an IE: if system operation is not transparent to its users, they will perceive it as an unpredictable, or even unreliable, environment, and will wish themselves out.

The focus on end users is not new: since the inception of the research field on ambient intelligence (AmI), all researchers acknowledge that “the emphasis of AmI is on greater user-friendliness, more efficient services support, user-empowerment, and support for human interactions” [23]. However, after nearly 15 years, we must acknowledge that the majority of the research, and of the literature, has been technology driven, rather than user driven, as we will discuss in Sect. 3.

The goal of this paper is to stimulate IE researchers to fully consider the user experience in their proposed designs. We propose to use the concept of “user confidence,” defined as the property of a system to offer user–system interactions that create the perception of a reliable and understandable intelligent system, whose behavior is transparent and on whose actions users can build trust.[1] We remember that the user experience is directly mentioned in 6 out of 9 priorities[2] proposed in the Intelligent Environments Manifesto [8], and indirectly involved by the other 3, too.

The main contribution of the paper is to propose a set of guidelines, reported in Sect. 5, to define a Research Agenda in the field of User Experience for Reliable Intelligent Environments. Such guidelines are derived by a comprehensive analysis of the relevant literature, that is presented in Sect. 3 and whose main findings are discussed in Sect. 4. Section 2 recalls the general usability principles in design methodology, while Sect. 6 draws some conclusions and opens some future perspectives.

2 General principles

Before presenting the state of the art about user-related approaches in intelligent environment, we would like to introduce here, in a summarized form, some basic and general principles related to user experience and human–computer interaction. Such principles are well defined and widely accepted in the related multidisciplinary research areas and should serve both as forerunners and reading keys for the guidelines reported in Sect. 5. Moreover, they are important to improve the quality and the engagement of the user experience and to make “things” work better, by avoiding user frustration and annoyance during the interaction and by leveraging human capabilities, needs and behaviors.

These general principles should guide researchers and system designers towards focusing on user activities and on interaction goals, not on single, specific tasks; towards an interaction with the environment and the devices that are seamlessly integrated and present in it, so that people can have an unique and continuous experience, without explicit starting and ending points. Therefore, we summarize two set of principles: the ones promoted by Norman in the revised edition of “The Design of Everyday Things” [40] and those presented by Dix in his “Human–Computer Interaction” book [22]. All these principles imply ease of use, pleasantness of interaction, coherence in the experience and can help in preventing many errors.

Norman’s principles revolve around seven concepts: discoverability, feedback, conceptual model, affordances, signifiers, mappings, and constraints. According to *discoverability*, it is always possible to determine what actions are allowed and the current state of a system or device. With *feedback*, there is full and continuous information about the results of actions and about the current state of a system or process. A good *conceptual model* of the system is created by projecting all the information needed to predict the effect of the actions, leading to understanding and a feeling of control for the user. *Affordances* help to understand, without explicit explanation, if the desired actions are possible. *Signifiers* communicate where and how a possible action can be executed; their effective use ensures discoverability and that the feedback is well communicated and intelligible. With *mappings*, the relationship between controls and their actions are enhanced as much as possible through spatial layout and temporal contiguity. Finally, physical, logical, semantic, and cultural *constraints* guide actions and ease interpretation.

In a similar way, Dix presents three principles to support the usability of a system: learnability, flexibility and robustness. *Learnability* represents the ease with which a new user can begin effective interaction and achieve maximal performance with a system; it is reached thanks to the predictability and visibility of actions, their familiarity (i.e., how prior knowledge applies to new system), their generalizability (i.e., extending specific interaction knowledge to new situations) and their consistency. *Flexibility* shows the multiplicity of ways the user and system exchange information, thanks to the ability of a system to support user interaction for more than one task at a time, the possibility to migrate a task execution between the user and the system, and the customizability of the system. *Robustness* is the level of support provided to the user in determining successful achievement and assessment of goal-directed behavior; it is connected to ability of users to take corrective action once an error has been recognized and to the system overall stability.

The mentioned user interaction principles, presented by the main researchers in the field, are also formalized in the international standard ISO-9241:2010, section 210 [29], dealing with ergonomics of human–system interaction. The standard applies to any interactive systems, including intel-

[1] “user confidence” is thus a subset of the typically adopted “confidence” concept, that relates to the correct and reliable behavior of a mission-critical system.

[2] P3, P4, P5, P6, P8, P9.

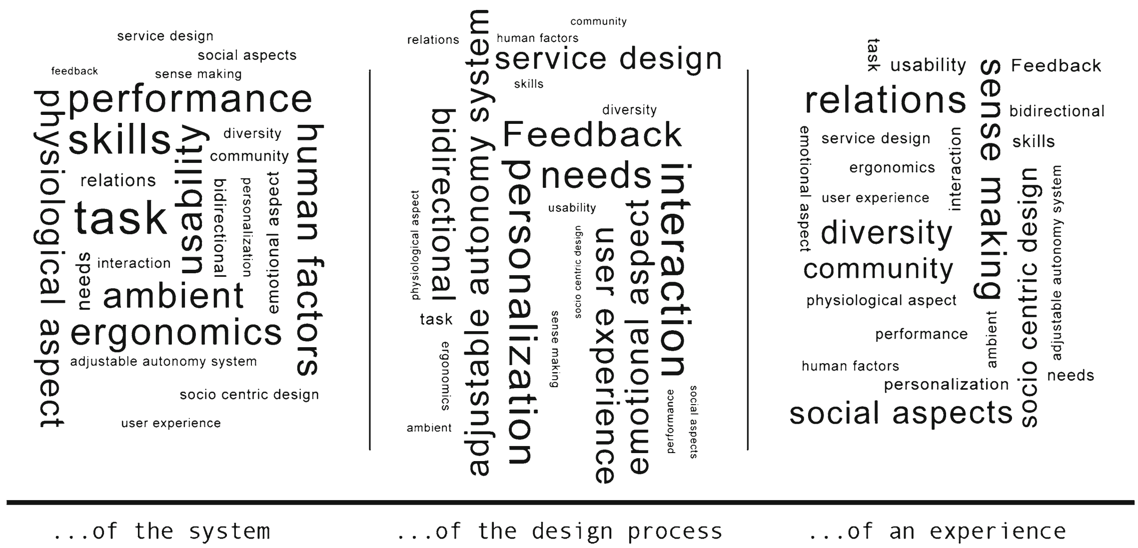

Fig. 1 Main keywords defining the three wide categories. Keywords are extracted from the keywords section or from the abstract of each analyzed paper

ligent environments, but has no specific provision for the latter.

These general principles inspire our work on defining *guidelines* applied to intelligent environment projects. Researchers and system designers should always have in mind these principles, and follow the proposed guidelines, to fully ensure trustworthiness in an intelligent environment.

3 State of the art

To assess the current state of the art of the adoption of user-centered approaches in the design of intelligent environments, we performed a literature analysis on papers published in the last decade, from 2004 to 2014, by querying major scholarly search engines. After a first analysis of the found papers, we defined three wide categories in which they can be classified, according to the kind of user involvement in the research and development process of systems and services in the IE.

For each wide category, we extracted the specific highlights presented by each paper related to the characteristics and to the behavior of both the user and the intelligent environment. A bird's-eye view of the overall topics and their grouping in categories can be appreciated in Fig. 1.

The main goal was to understand, in the current research panorama, how the research perspectives on intelligent environments and smart solutions consider the role of their users, both in their methodologies and approaches, and in the attained results.

We realize that each presented study aims at specific needs and at different objectives, therefore in our analysis we avoided to consider the specific characteristics of different types of intelligent environments (e.g., ambient-assisted living, smart homes, work spaces, etc.) and, consequently, the specific needs of their users. Our analysis, consistently with our main goal to derive some design and evaluation guidelines for user experience in IEs, aims at defining, for each wide category, some practical hints and significant theoretical perspectives.

The wide categories that we selected are the following ones:

- "*Users are part of the system*:" in this category, we collect all papers that select, as the main focus of their study, the characteristics of users and intelligent environments considered as interacting elements of the same system. These papers (detailed in Sect. 3.1) stress the various user factors that are involved in the usage of the intelligent system, or one of its parts, and that affect the evaluation of the consistency of the system according to the characteristics of the end user.
- "*Users are part of the design process*," where the design process is that of an intelligent environment. In this category, papers (listed in Sect. 3.2) analyze the characteristics, the dynamics and the processes that lie at the basis of the interaction among users and intelligent environment. Such papers stress the processes that are involved in the mutual modeling of user and intelligent ambient: building an intelligent system is seen as the result of a satisfactory matching for both actors.
- "*Users are part of an experience*," includes those studies considering both an enrichment of the system components that are needed to realize an intelligent environment, and an enrichment of the research perspective over the user experience. Such papers (reported in Sect. 3.3) stress the

uniqueness and the unity of the experience lived by the user, that includes new and wider perspectives, reaching a socio-centric design vision, and that therefore takes into account the users in their overall life system.

As mentioned before, the following sections present in more detail the papers belonging to each of the three wide categories, whose main features and identifying keywords are collected in Fig. 1. We should not regard the different categories as being more or less "right or wrong;" rather, they follow different approaches and focus on different aspects, that should all be integrated and cross-related, as suggested by Fig. 1.

Finally, Sect. 3.4 reports some additional and specific experiences developed by the authors or their institutions, and encases them in the proposed classification framework.

3.1 Users are part of the system

In the studies considered in this section, we generally notice the lack of a direct involvement of the end users in the research and development phases, while the main focus is on the developed technology and how it affects the system in which the user is involved.

The analysis of the interaction between system and users is exclusively aimed at studying the technology characteristics, such as the adaptive user interface in Tazari [50], or in new Kinect-based gestures in Budde et al. [15]. In both cases, the experience of simulating user responses happens in a laboratory setting, only.

In some cases, the papers present an explicit hypothesis about the user and the measure of his interaction with the system such as in Gouin-Vallerand et al. [26], Mavrommati and Darzentas [34], and Moran and Nakata [36]. These works describe the user factors involved in designing the intelligent environment (e.g., awareness, control, trust, etc.), user profiles (basic vs. advanced users) and application scenarios. The environment is described in terms of context awareness, thus is assumed to be dynamic and adaptable to user needs. There is a focus on user interfaces and on the possibilities of building an adaptive infrastructure that is able to combine different technologies (such as augmented reality, gestures, speech interfaces, etc.). The common and dominant factor, however, is always the technical implementation.

The research proposals presented in the works by Sadri [47], Augusto et al. [8] and Rashidi and Cook [42] demonstrated that the intelligent system is the core of the research project, and it must learn from the user through suitable rules and algorithms; in such cases it is fundamental "to preserve privacy of the users and to prioritize safety of users at all times."

The intelligibility principle is put forward by the works of Dey [21] and Mennicken et al. [35], who state that technology must be able to explain its own behavior, also by anticipating user needs and user actions, and being able to predict erroneous conditions and deviations from the routine.

In the papers by Xiang-ting et al. [52] and Mozer [37], conversely, the user is assumed as an "evaluator" of cost–benefit trade-offs in very complex systems involving large numbers of sensors. The focus is here shifted to the user that must learn, and must increase his decision-making strategies to optimize energy consumption and efficiency.

3.2 Users are part of the design process

In the literature described in this section, users are involved in the design process of the intelligent environment, and in some cases even in the initial research and specification phases. The ambient is in most cases invisible [24], sometimes wearable, such that it guarantees a transparent interaction.

The main focus in Gilman et al. [25] is the notion of bi-directionality of the design and evaluation phases, that considers the system and the user as a part of the same building process for the intelligent ambient.

In Koskela and Väänänen-Vainio-Mattila [31], users are involved since the requirement elicitation and analysis phases, until the final field experience, using many of the methods proposed by the user-centered design approach (test in laboratory, interviews, questionnaires, ethnographic analysis, etc.). The goal, here, is comparing three different user interfaces, and the final results claim that users can gain confidence in a new technology using it, testing its functionality, and evaluating the results.

If we consider the works by Stephanidis [48], Röcker [44], and Sun et al. [49] besides the fact that they focus on designing different types of smart environments, we see that the user is always at the center of the design process and of the technological world. The user is dominant, with respect to the surrounding environments, and he must be "understood" and "supported" by the system through the understanding of his needs and the provision of a continuous feedback stream to his actions. The requisites of the smart environment must thus be non-intrusiveness, personalization and adaptability.

The user is the main actor also in the studies by Rizopoulos [43] and Nijholt [38], and he may also play the role of a designer: as an actor of the system, the user assigns human characteristics to all elements of the surrounding environment, including computers and new technologies. The environment is a medium, a social actor that must be characterized by embodied agents that gain behaviors and communication styles similar to the human ones.

In Corgnati et al. [19] (see also Sect. 3.4), users are at the center of the analysis, as they are involved in several experimental phases, and the focus is on their opinions and on the energy-saving behaviors that they gradually learn thanks to the act of monitoring and controlling their smart environment.

Similarly, in Aztiria et al. [9] the Action Map theory stresses the evaluation of user behaviors in different usage scenarios, evaluating not only the information agendas but more importantly of the emotional and health state of the users.

A "System for Emotion-Aware" is also the focus of the study by Acampora et al. [3], where the user is at the center of the system and the paper analyzes the hypothesis that user emotions may drive the behaviors of the environment.

In Ball and Callaghan [10] and more extensively in Matthew and Vic [32], we find a literature analysis about user needs in terms of autonomy, control and personalization. Their study also performed a user evaluation with increasing autonomy levels, according to an "adjustable autonomy system," where the user learns to interact with technology. In these studies, the environment is assumed to be highly dynamic, exactly because it learns from the user and from his control feedback, that ultimately become a communication channel between user and system.

3.3 Users are part of an experience

The final set of studies, reported in this wide category, tends to outline all practical experiences and theoretical perspectives where, according to different degrees of involvement of the final users in the research and development process, we observe a twofold enrichment: of the user perspectives, and of the specific features of a complex intelligent system (that is not considered merely as the set of its technical possibilities).

The intelligent environment must favor user engagement, as claimed by Alves et al. [7]. Their study, in fact, states the need of working in multidisciplinary teams to follow a user-centered design pattern that is able to consider both points of view: the user and the technology.

In Kaasinen et al. [30], there is a clear stress on the complexity of the analysis levels for the user experience: the user is situated in an analysis scale that ranges from the evaluation of his acceptance (usefulness, value, usage, control perception, etc.) to the evaluation of his experience (control, manipulation as a concrete, funny and immersive experience), until the top level of the "do it your experience". The focus is on the role as an active guest of the intelligent ambient.

In Aarts and Grotenhuis [1], user experience is analyzed through the lens of the analysis of sense-making processes, i.e., the user is seen as an actor of 'sensing' and 'knowing' processes, as he lives in an equilibrium between body (health), mind (well-being), community (participation) and earth (social responsibility).

The user, in fact, is no longer a passive utilizer and unique actor in the system, but a wider set of variables are involved, such as communities and social networks to which he belongs. In Mavrommati and Darzentas [17] and Cook and Das [33] the authors describe not just isolated individuals, but their encompassing communities (e.g., users do not live alone at home, do not work alone in the office, etc.). The environment must therefore be structured such that it may cause and influence changes in the user communities that inhabit it.

The study in Aarts and de Ruyter [2] analyzes social interaction, and the user is represented in a systemic way, according to all processes that concern him and that potentially involve interaction with the intelligent environment.

Wilson et al. [51] and Ishida and Hattori [28] discuss the possible future challenges lying in the design of a comprehensive framework, that could start from a functional analysis (user needs), go through an instrumental one (interactions with technology) and reach a socio-technical one, where a smart home is seen as a complex system.

The same topic is widened in the work of Roden et al. [41], de Ruyter [45], and Queirós et al. [46], who discuss the need to adopt a holistic and socio-technical perspective, where the policies and the strategic choices relevant to each social context cannot be ignored in designing an intelligent environment. Their research projects evaluate the opinions of the user according to: his perception of autonomy and control, which smart agents would be appreciated, how would such infrastructures be perceived as useful, and how he evaluates the monitoring of his energy consumption related to his privacy expectations.

3.4 Experiences

This section provides more details about some specific experiences, developed by the authors or their institutions, in which the role of users in smart environments has been considered in the design process.

Energy@Home [19] is a new system[3] for domestic monitoring or electric energy consumption and production, based on the ZigBee technology [53]. The system uses smart plugs, smart appliances (e.g., a washing machine by Indesit), a "Smart Info" module by Enel to interact with the official energy meter, and a smart gateway (by Telecom Italia) to manage the devices in the house and integrate with cloud services. This project represents a good case study for the application of a design process *with* the user and *for* the user, as it also involved a field trial with more than 50 households involved for more than 1 year. A strength of the system consists in its graphical user interface (GUI), that represents the access point and interaction medium for users interacting with the complex system, and that has been designed

[3] More information is available on the Energy@Home association's website: http://www.energy-home.org/.

according to Norman's principles [40]. In brief, the GUI is a web-based system that adopts the metaphor of a dashboard through which users may monitor their consumption at any time, with any device, web or mobile. The system operates in a "transparent" modality, where no algorithmic computations are shown, and no repeated requests are needed: the system automatically reports consumption and cost values, shown and updated in real time, accompanied by some deeper information about each appliance and about stand-by power. The system also delivers suggestions for saving energy (e.g., starting appliances when energy costs are lower) or ringing alerts when operating in the more expensive hours. The user is also alerted if the consumption approaches the maximum allowed power, to avoid cut-offs, and shows where the excess consumption is located. Finally the consumption data may be queried and visualized in different ways, including an "anonymous" comparison with other users, and with the user's own history.

Another experience related to energy monitoring, and in particular on user involvement in educational institutions (i.e., students and professors in technical schools and universities) is reported in Bonino et al. [13], where a semantically aware system has been installed in two educational institutions in Italy, with the goal of providing building users with a real-time and informative view of current and historical measurements concerning electrical energy consumption and photovoltaic production, environment comfort variables, exchanged calories, etc. The project has been designed and conducted as a "Living Lab", and students were directly involved (at different degrees, according to their technical knowledge) in the validation of user interfaces, in the understanding of the physical quantities, and on the architecture of the technical system.

An interesting application domain for intelligent environments is that of health institutions, e.g., hospitals or care facilities; we can easily understand that in these settings, where the safety of persons is involved, the reliability requirement should be particularly stressed. A first study, applied to assisted living facilities for adult persons with motor and cognitive disabilities is reported in Aced Lopez et al. [4]:[4] in that work, the system requirements have been extracted, discussed and validated through user-centered methodologies, such as focus groups and system mockups. Other experiences of involving users in the design of intelligent ambient interactions may be found in De Russis [20].

The readers interested in an updated overview about the most significant experiences, in this topic, are encouraged to follow the latest developments of the most prominent research groups and laboratories, whose main authors may easily be identified in the proposed literature. In particular, some notable research groups are: Ambient Intelligence Research Lab (AIR Lab),[5] Stanford, USA; Center for Advanced Studies in Adaptive Systems (CASAS),[6] Washington State University, USA; e-Lite: Intelligent and Interactive Systems,[7] Politecnico di Torino, IT; Intelligent Environments Group,[8] University of Essex, UK; Research GrOup On the Development of Intelligent EnvironmentS (GOODIES),[9] Middlesex University, UK; and MIT Media Lab,[10] MIT, USA.

4 Discussion

Since the end of 1990s, the idea of a design process that is oriented toward the user and her point of views has been fundamental and widely diffused in various fields. Today the user, in one of the most accredited meanings, is at the center of the design activity and is continuously involved in the design process, contributing with her feedback and other types of intervention like user studies, field trials and evaluations.

In the same way, the user should be a primary element in the design of an intelligent environment, contributing in the design as well as in the optimization phase of the system with her perspectives, her needs and wishes, together with the design team and other users.

Starting from the reported literature analysis, in many cases the user is **not** at the center of the intelligent system design process, sometimes not even involved in the final evaluation of the system. In the set of papers present in the category *"Users are part of the system"*, the user is typically absent or considered as a "component" of the system, not dissimilarly from a device or an appliance: the main focus is on the technology and about the algorithms and procedures. This technology-driven approach is quite common and diffused in most of the literature about intelligent environments. However, a strong technology-driven approach can reduce user confidence and the related perceived usefulness of an intelligent environment, interfering with its adoption. Even if technology is important and widely investigated in the intelligent environment field, the need to consider the user, the environment inhabitant, as the driver start to emerge: the technology, in fact, should become the enabler and the human the driver, not viceversa.

The papers classified in the other two categories of the literature analysis, i.e., *"Users are part of the design process"*

[4] An extended version of the paper is under the final stages of review in the UAIS journal, and will likely be available at the time of publication.

[5] http://airlab.stanford.edu, last visited on March 23, 2015.

[6] http://casas.wsu.edu, last visited on March 23, 2015.

[7] http://elite.polito.it, last visited on March 23, 2015.

[8] http://ieg.essex.ac.uk, last visited on March 23, 2015.

[9] http://ie.cs.mdx.ac.uk, last visited on March 23, 2015.

[10] http://media.mit.edu, last visited on March 23, 2015.

and *"Users are part of an experience"*, show a user that is—in some way—involved in the design process or considered from a theoretical perspective in an intelligent environment. The gap from the previous category is enormous: here, the user is central and the technology is marginal, when present; in the other case, the technology is dominant and the user is a passive "actor", if considered. Most of the results and discoveries that emerge from these two categories are typically slightly or not applied to "working" intelligent systems, but are extrapolated from surveys, user studies with mockups or graphical user interfaces, or obtained with user-centered methodologies applied to "not-so-intelligent" environments, as in home automation settings. The intelligent environment envisioned in such cases is not a unique entity, but a small part of it. From these two categories, various needs emerge: to design intelligent system for all persons and cultures and for infusing positive behavior changes; to balance the system autonomy according to users' desiderata, and to bring real intelligent systems into the field, outside the labs and environments built "ad hoc".

Some common ideas and themes are, however, shared between most of the papers: the technology in the environment should be unobtrusive, hidden in the environment itself or wearable, thus ubiquitous; communication and interaction should be seamless between users, devices, and the environment. User interfaces, if any, should be intelligent and adaptive, and all interactions should be secure and take into great consideration the privacy aspects.

Moreover, an issue that emerges from various papers, independently from their classification in the literature analysis, is the absence of a clear vision and a set of human–environment guidelines able to address in a specific way the design and the interactions with the intelligent environment, as demonstrated also by a recent special issue about ambient interaction [18]. These guidelines and the related vision could be one of the key ingredients to really make the user *confident* to move in the environment as the main actor, motivated in interacting with the system, aware of her acts and possibilities, and totally oriented to the enhancement of the system's intelligence.

5 A research agenda

Stemming from the works available in the literature and discussed in the previous section, a set of guidelines and criteria for system designers and researchers can be extracted, to ensure user confidence in Intelligent Environments. When applicable, the most relevant references are reported to better explain each guideline, for further consideration or as an

Table 1 Overview of the proposed guidelines

Guideline	Focus		Phase	
	User	Technology	Design	Validation
1. Consider people as the driver, and technology as the enabler	✓		✓	✓
2. Design for all persons and cultures	✓		✓	
3. Design in a simple and emotional way	✓		✓	
4. Balance system autonomy with user will and needs	✓	✓	✓	✓
5. Design for positive behavior changes	✓		✓	
6. Consider the world as the interface; explore new interaction means		✓	✓	
7. Do not forget personalization, security and privacy issues	✓	✓	✓	✓
8. Design for uncertainty and cope with complexity		✓	✓	
9. Learn in and from the field	✓		✓	✓
10. Consider social aspects	✓		✓	✓
11. Consider the environment as a single intelligent entity		✓	✓	✓
12. Explore "strange, new" environments; embrace other species		✓	✓	

example. These guidelines can be also used as a research agenda for guiding researchers and practitioners in the next decade. A general overview is shown in Table 1, while the guidelines are detailed below.

1. *Consider people as the driver, and technology as the enabler.*
   It is widely demonstrated that, by getting the user in the loop from the first phase of a project, the overall user confidence in the system increases, as reported by Sun et al. [49] in analyzing AAL systems. The researcher and the system designer should, therefore, apply participatory design methodologies to their work. Moreover, in designing a system, user-centered design processes oriented to intelligent systems should be considered, involving multiple disciplines and professionals in the design activity. For example, Bellotti et al. [11] propose five questions with some possible responses to take into account when designing a sensing system; in a similar way, Mavrommati and Darzentas [33] start from the same five questions and propose ten issues to be addressed in realizing an intelligent environment.
2. *Design for all persons and cultures.*
   Intelligent environments should be adjusted to different user groups, targeting the specific values and challenges in their lives. Intelligent environments should fit into users' daily practice and cultural context: different cultures expect different functionality and aims from an intelligent system, as reported in Kaasinen et al. [30]. For these reasons, the development of an intelligent environment should start with the understanding of the target user group and their cultural contexts: what is useful to the elderly, what the expected level of use is, how to ensure a sense of control and trust in the environment, etc. Policy and political choices of each context cannot be ignored in designing an intelligent system.
3. *Design in a simple and emotional way.*
   Users like simplicity and want to interact and to be emotionally involved in the interaction with the environment, as reported by Norman [39,40]. By doing this, they are stimulated to interact more, to interact better (i.e., avoiding errors) and to be more involved during the entire interaction process. The emotional aspects, moreover, can help users to be more engaged and to stimulate the repetition of previous experiences, enhancing the user confidence of the overall system.
4. *Balance system autonomy with user will and needs.*
   To fully realize the user acceptance of an intelligent environment system, ease of use and a sense of control need to be in balance, as widely demonstrated in the literature (e.g., [10,32]). In many cases, for example, users want to be in control of their setting and do not desire large amounts of information to be manually managed.
5. *Design for positive behavior changes.*
   There is, often, a profound disconnect between our everyday behaviors and the effects that they have on our health and on the environment around us. An intelligent environment has the opportunity to reduce this gap, promote awareness and enable positive behavior changes, thanks to its intelligent components and its data availability. Successful examples are related to improving energy-related behavior, like in Corgnati et al. [17], Cook and Das [19], and Mozer [37].
6. *Consider the world as the interface. Explore new interaction means.*
   Most of the proposed interactions with the environment are based on graphical user interfaces and are screen-dominated (as reported by Mavrommati and Darzentas [33]). Few works propose speech-based or vision-based, seamless, interaction. In an intelligent environment, however, the inhabitants should use the physical world as the primary interface, moving from explicit input mechanisms to implicit ones (see [1,12,33]). To accomplish this, modern human–computer interaction methods and tools should be explored and considered, such as augmented objects, tangible interaction, natural user interfaces and on-body interaction. Intelligent environments, therefore, should be considered using expressive models that are typical for the human being.
7. *Do not forget personalization, security and privacy issues.*
   User trust and confidence are related to privacy and monitoring, control, security, data protection of intelligent systems and all the components of a transparent system (as reported by Aarts and Grotenhuis [1] and Böhlen [12]). Privacy and security considerations should be designed into the system from the start, and individuals should be able to specify their privacy preferences in a way that is easy to use and to understand.
8. *Design for uncertainty and cope with complexity.*
   People are not "using" an intelligent environment, but they live in them and experience the environment via various services and tools. The overall experience should be pleasing to all the human actors who live, visit and act in the environment. Intelligent environments should be designed as continuously evolving ecosystems that include: (a) people in different roles with different and sometimes opposite needs, emotions and preferences that change over time, and (b) different services that are launched and withdrawn at different times.
9. *Learn in and from the field.*
   Most of the current research prototypes and systems are operated and researched in dedicated laboratories or "fake" environments built on purpose. However, studying technology in a representative context of use is

crucial to assess its suitability for everyday usage and whether or not it addresses inhabitants needs and goals, enabling a better comprehension of the complexity and uncertainty of the real world. Researchers and practitioners should, therefore, "go in the wild" and experiment their systems in real settings, thanks also to the great availability of commercial Internet of Things devices. Some inspiring works and examples about this topic are Lab of Things by Brush Bernheim et al. [14], the CASAS Project by Cook et al. [16] and the Energy@Home project Corgnati et al. [19].

10. *Consider social aspects.*
Social affiliation is an essential aspect of people psychological and sociological development and it is reported in the literature as a primary need in an intelligent environment (see de Ruyter [46] for further details). An intelligent environment with a social intelligence, moreover, can have a positive effect on the technology acceptance and overall satisfaction of its inhabitants. An example is present in the trial test reported by Corgnati et al. [19], where the introduction of different persuasive stimuli, highlighting social aspects and delivered through personal newsletters, generates an (electric) energy saving of 9 % in smart homes.
11. *Consider the environment as a single intelligent entity.*
Research in the Intelligent Environment field typically focuses on some specific areas of applications or underlying technologies (context-aware system, indoor localization, support for the elderly or disabled, smart objects, ...). As a result of this deep but narrowed focus, technologies or devices are often studied in a rather isolated manner without considering effects on the larger context of the environment and whether inhabitants' larger goals and values are effectively supported. Interaction with the environment is, often, interaction with a single part of it. The intelligent behavior of the environment, again, is strictly confined in a single component. We need, as a community, to start thinking and considering the environment as a whole, greater than the sum of its single parts. This will enable a true collaboration between humans and their environments, instead of mere control or complete autonomy.
12. *Explore "strange, new" environments. Embrace other species.*
The majority of the research about intelligent environments focuses on the home environment, with some exceptions that consider classrooms, office or industrial settings and transportation-related systems. The only living being that, sometimes, is considered as a proactive entity in such environments is the human. From one side, research activities in Intelligent Environment can still do much to improve people's live in such environments. People live and act in various environments and sometimes they share their spaces and activities with other entities. Thus, from another side, it is time to start thinking to other environments (like parks, schools, hotels, mountain trails, etc.) and to intelligent systems for supporting other living beings together with humans (such as dogs, cats, horses, etc.).

6 Conclusions

This paper explored a journey over the last decade of literature on the involvement of users in the research, design, development and validation of intelligent environments. All researchers acknowledge that IEs should be built with the users in mind, with a main goal enriching their living experience, and additionally improving efficiency or the related life or work processes. However, the technology-centered view is dominant in the IE and AmI fields, demanding for a stronger effort in the understanding an application of user-centered methodologies. An interesting volume published in the middle of the considered decade [5], has an interesting epilog [6] that provides a set of challenges that are still valid today, 5 years later, and whose closing words mention that:

> If smart environment applications are going to be adopted by the world to the extent so eloquently portrayed by Weiser's metaphor of the "disappearing computer," their interfaces must be human-centric. The technology deployed in homes and public spaces will not become "transparent" if the user has to go to a great deal of effort to interact with a system in order to obtain a benefit from it. [...] Analogously, only through a concrete and comprehensive study of the fundamental principles of user satisfaction will the field of ambient intelligence flourish. Human-centric interfaces will be instrumental in its success.

The contribution of this paper, besides the critical analysis of the main literature, consisted in proposing a set of 12 guidelines (Sect. 5) that can build a reference basis for orienting a research agenda for future developments of intelligent environments, where the reliability of the user–system interaction is taken into account.

Finally, we observe that the domain of intelligent environments is undergoing a significant explosion and transformation, thanks to the various (although a bit disconnected and chaotic) initiatives collectively labeled as the Internet of Things (IoT). The advent of IoT systems (that imply many devices, many form factors, many interaction modalities) will make user-centrism even more demanding, and we really urge all researchers to be prepared for this transition, and aim at useful and validated user-appreciated systems, instead of 'just' interesting and fun technological toys.

References

1. Aarts E, Grotenhuis F (2009) Ambient intelligence 2.0: towards synergetic prosperity. In: Tscheligi M, de Ruyter B, Markopoulus P, Wichert R, Mirlacher T, Meschterjakov A, Reitberger W (eds) Ambient intelligence. Lecture notes in computer science, vol 5859. Springer, Berlin, pp 1–13. doi:10.1007/978-3-642-05408-2_1
2. Aarts E, de Ruyter B (2009) New research perspectives on ambient intelligence. J Ambient Intell Smart Environ 1(1):5–14. doi:10.3233/AIS-2009-0001
3. Acampora G, Loia V, Vitiello A (2011) A cognitive multi-agent system for emotion-aware ambient intelligence. In: 2011 IEEE symposium on intelligent agent (IA), pp 1–8. doi:10.1109/IA.2011.5953606
4. Aced Lopez S, Corno F, De Russis L (2015) Iot meets caregivers: a healthcare support system in assisted living facilities. In: Proceedings of the 1st international conference on IoT technologies for healthcare
5. Aghajan H, Augusto JC, López-Cózar Delgado R (eds) (2010a) Human-centric interfaces for ambient intelligence. Elsevier Science Publishers B. V., Amsterdam
6. Aghajan H, Delgado RLC, Augusto JC (2010b) Epilogue: challenges and outlook. In: Human-centric interfaces for ambient intelligence. Elsevier, Amsterdam, pp 505–509. doi:10.1016/b978-0-12-374708-2.00021-8
7. Alves LJ, Salem B, Rauterberg M (2010) Responsive environments: user experiences for ambient intelligence. J Ambient Intell Smart Environ 2(4):347–367. doi:10.3233/AIS-2010-0080
8. Augusto JC, Callaghan V, Cook D, Kameas A, Satoh I (2013) Intelligent environments: a manifesto. Hum Centric Comput Inf Sci 3(12):12. doi:10.1186/2192-1962-3-12
9. Aztiria A, Augusto J, Basagoiti R, Izaguirre A, Cook D (2013) Learning frequent behaviors of the users in intelligent environments. IEEE Trans Syst Man Cybern Syst 43(6):1265–1278. doi:10.1109/TSMC.2013.2252892
10. Ball M, Callaghan V (2011) Perceptions of autonomy: a survey of user opinions towards autonomy in intelligent environments. In: 2011 7th international conference on intelligent environments (IE), pp 277–284. doi:10.1109/IE.2011.68
11. Bellotti V, Back M, Edwards WK, Grinter RE, Henderson A, Lopes C (2002) Making sense of sensing systems: five questions for designers and researchers. In: Proceedings of the SIGCHI conference on human factors in computing systems, CHI '02. ACM, New York, pp 415–422. doi:10.1145/503376.503450
12. Böhlen M (2009) Second order ambient intelligence. J Ambient Intell Smart Environ 1(1):63–67. doi:10.3233/AIS-2009-0009
13. Bonino D, Corno F, De Russis L (2014) a semantics-rich information technology architecture for smart buildings. Buildings 4(4):880–910. doi:10.3390/buildings4040880
14. Brush Bernheim AJ, Filippov E, Huang D, Jung J, Mahajan R, Martinez F, Mazhar K, Phanishayee A, Samuel A, Scott J, Singh RP (2013) Lab of things: a platform for conducting studies with connected devices in multiple homes. In: Proceedings of the 2013 ACM conference on pervasive and ubiquitous computing adjunct publication, UbiComp'13 adjunct. ACM, New York, pp 35–38. doi:10.1145/2494091.2502068
15. Budde M, Berning M, Baumgärtner C, Kinn F, Kopf T, Ochs S, Reiche F, Riedel T, Beigl M (2013) Point & control—interaction in smart environments: you only click twice. In: Proceedings of the 2013 ACM conference on pervasive and ubiquitous computing adjunct publication, UbiComp '13 adjunct. ACM, New York, pp 303–306. doi:10.1145/2494091.2494184
16. Cook D, Crandall A, Thomas B, Krishnan N (2013) Casas: a smart home in a box. Computer 46(7):62–69. doi:10.1109/MC.2012.328
17. Cook DJ, Das SK (2007) How smart are our environments? An updated look at the state of the art. Pervasive Mobile Comput 3(2):53–73. doi:10.1016/j.pmcj.2006.12.001
18. Cook DJ, José R, Bravo J (2014) Special issue on ambient interaction. Int J Hum Comput Interact 30(10):753–754. doi:10.1080/10447318.2014.927260
19. Corgnati S, Guercio E, D'Oca S (2014) Energyhome: energy monitoring in everyday life. In: Stephanidis C, Antona M (eds) Universal access in human–computer interaction. Aging and assistive environments. Lecture notes in computer science, vol 8515. Springer International Publishing, Berlin, pp 483–492. doi:10.1007/978-3-319-07446-7_47
20. De Russis L (2014) Interacting with smart environments: users, interfaces, and devices. PhD thesis, Politecnico di Torino. doi:10.6092/polito/porto/2536887
21. Dey AK (2009) Modeling and intelligibility in ambient environments. J Ambient Intell Smart Environ 1(1):57–62. doi:10.3233/AIS-2009-0008
22. Dix A, Finlay J, Abowd G, Beale R (1997) Human–computer interaction. Prentice-Hall Inc, Upper Saddle River
23. Ducatel K, Bogdanowicz M, Scapolo F, Leijten J, Burgelman JC (2001) Scenarios for ambient intelligence in 2010. Office for official publications of the European Communities
24. García-Herranz M, Alamán X, Haya PA (2010) Easing the smart home: a rule-based language and multi-agent structure for end user development in intelligent environments. J Ambient Intell Smart Environ 2(4):437–438. doi:10.3233/AIS-2010-0085
25. Gilman E, Davidyuk O, Su X, Riekki J (2013) Towards interactive smart spaces. J Ambient Intell Smart Environ 5(1):5–22. doi:10.3233/AIS-120189
26. Gouin-Vallerand C, Abdulrazak B, Giroux S, Dey AK (2013) A context-aware service provision system for smart environments based on the user interaction modalities. J Ambient Intell Smart Environ 5(1):47–64. doi:10.3233/AIS-120190
27. IEEE (1991) IEEE standard computer dictionary: a compilation of IEEE standard computer glossaries, vol 610. IEEE Press, New York, pp 1–217. doi:10.1109/IEEESTD.1991.106963
28. Ishida T, Hattori H (2009) Participatory technologies for designing ambient intelligence systems. J Ambient Intell Smart Environ 1(1):43–49. doi:10.3233/AIS-2009-0006
29. ISO (2010) Standard 9241-210:2010: ergonomics of human–system interaction—part 210: human-centred design for interactive systems
30. Kaasinen E, Kymäläinen T, Niemelä M, Olsson T, Kanerva M, Ikonen V (2012) A user-centric view of intelligent environments: user expectations, user experience and user role in building intelligent environments. Computers 2(1):1–33. doi:10.3390/computers2010001
31. Koskela T, Väänänen-Vainio-Mattila K (2004) Evolution towards smart home environments: empirical evaluation of three user interfaces. Pers Ubiquitous Comput 8(3–4):234–240. doi:10.1007/s00779-004-0283-x
32. Matthew B, Vic C (2012) Managing control, convenience and autonomy. Ambient Intell Smart Environ 12(Agents and Ambient Intelligence):159–196. doi:10.3233/978-1-61499-050-5-159
33. Mavrommati I, Darzentas J (2006) An overview of ami from a user centered design perspective. In: 2nd IET international conference on intelligent environments, 2006, IE '06, vol 2, pp 81–88
34. Mavrommati I, Darzentas J (2007) End user tools for ambient intelligence environments: an overview. In: Jacko J (ed) Human–computer interaction. Interaction platforms and techniques. Lec-

ture notes in computer science, vol 4551. Springer, Berlin, pp 864–872. doi:10.1007/978-3-540-73107-8_95
35. Mennicken S, Vermeulen J, Huang EM (2014) From today's augmented houses to tomorrow's smart homes: new directions for home automation research. In: Proceedings of the 2014 ACM international joint conference on pervasive and ubiquitous computing, UbiComp '14. ACM, New York, pp 105–115. doi:10.1145/2632048.2636076
36. Moran S, Nakata K (2010) Ubiquitous monitoring and user behaviour: a preliminary model. J Ambient Intell Smart Environ 2(1):67–80. doi:10.3233/AIS-2010-0049
37. Mozer MC (2005) Lessons from an adaptive home. Wiley, New York, pp 271–294. doi:10.1002/047168659X.ch12
38. Nijholt A (2003) Disappearing computers, social actors and embodied agents. In: Proceedings of the 2003 international conference on cyberworlds, pp 128–134. doi:10.1109/CYBER.2003.1253445
39. Norman D (2005) Emotional design: why we love (or hate) everyday things. Basic Books
40. Norman D (2013) The design of everyday things: revised and expanded edition. Basic Books
41. Queirós A, Silva A, Alvarelhão J, Rocha NP, Teixeira A (2013) Usability, accessibility and ambient-assisted living: a systematic literature review. Univers Access Inf Soc (online):1–10. doi:10.1007/s10209-013-0328-x
42. Rashidi P, Cook D (2009) Keeping the resident in the loop: adapting the smart home to the user. IEEE Trans Syst Man Cybern Part A Syst Hum 39(5):949–959. doi:10.1109/TSMCA.2009.2025137
43. Rizopoulos C (2007) An activity-based perspective of interacting with ambient intelligence systems. In: 3rd IET international conference on intelligent environments, pp 81–88
44. Röcker C (2013) User-centered design of intelligent environments: requirements for designing successful ambient assisted living systems. In: Central European conference on information and intelligence systems, pp 4–11
45. Rodden TA, Fischer JE, Pantidi N, Bachour K, Moran S (2013) At home with agents: exploring attitudes towards future smart energy infrastructures. In: Proceedings of the SIGCHI conference on human factors in computing systems, CHI '13. ACM, New York, pp 1173–1182. doi:10.1145/2470654.2466152
46. de Ruyter B (2011) Social interactions in ambient intelligent environments. J Ambient Intell Smart Environ 3(2):175–177. doi:10.3233/AIS-2011-0104
47. Sadri F (2011) Ambient intelligence: a survey. ACM Comput Surv 43(4):36:1–36:66. doi:10.1145/1978802.1978815
48. Stephanidis C (2012) Human factors in ambient intelligence environments. In: Handbook of human factors and ergonomics. Wiley, New York, pp 1354–1373. doi:10.1002/9781118131350.ch49
49. Sun H, De Florio V, Gui N, Blondia C (2010) The missing ones: key ingredients towards effective ambient assisted living systems. J Ambient Intell Smart Environ 2(2):109–120. doi:10.3233/AIS-2010-0062
50. Tazari MR (2010) An open distributed framework for adaptive user interaction in ambient intelligence. In: de Ruyter B, Wichert R, Keyson D, Markopoulos P, Streitz N, Divitini M, Georgantas N, Mana Gomez A (eds) Ambient intelligence. Lecture notes in computer science, vol 6439. Springer, Berlin, pp 227–238. doi:10.1007/978-3-642-16917-5_23
51. Wilson C, Hargreaves T, Hauxwell-Baldwin R (2014) Smart homes and their users: a systematic analysis and key challenges. Pers Ubiquitous Comput (online):1–14. doi:10.1007/s00779-014-0813-0
52. Xiang-ting C, Yu-hui Z, Wei D, Jie-bin T, Yu-xiao G (2010) Design of intelligent demand side management system respond to varieties of factors. In: 2010 China international conference on electricity distribution (CICED), pp 1–5
53. ZigBee Alliance (2009) Ieee 802.15.4, zigbee standard. Tech. rep., ZigBee Alliance. http://www.zigbee.org