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Accessible Interaction Solution based on Confidence for the Deployment of Pervasive Sensitive Services in Intelligent Environments

TESIS DOCTORAL

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‘Lo que nosotros tenemos que practicar hoy, es la solidaridad. No debemos acercarnos al pueblo a decir:

Aquí estamos. Venimos a darte la caridad de nuestra presencia, a enseñarte con nuestra presencia, a enseñarte con nuestra ciencia, a demostrarte tus errores, tu incultura, tu falta de conocimientos elementales.

Debemos ir con afán investigativo, y con espíritu humilde, a aprender en la gran fuente de sabiduría que es el pueblo’.

— Ernesto Guevara de la Serna (August 1960)

Dedicated to my dear mother and father
&
Lidia
(woof woof Thor!)

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PREFACE

This PhD research has been conducted under a double PhD agreement degree between the School of Telecommunications Systems and Engineering (ETSIST) at the Technical University of Madrid (UPM) in Spain and the School of Technology and Health (STH) at the Royal Institute of Technology (KTH) in Sweden.

This research was performed at the UPM in Spain, under the supervision of Dr. Iván Pau de la Cruz from UPM (Spain) and Dr. Fernando Seoane from KTH (Sweden).

ABSTRACT

Services based on the Information and Communications Technologies (ICT) are present more and more in the lives of people. The advancement of ICT in technical and social acceptance terms has led the creation of new models of service provision. These provision models involve further integration with people's activities so that are not only present in their professions or civic space but also in a more intimate areas related to their own identity. So it is now common to find services aware of user's health, their domestic habits, ideology, etc. Therefore, the analysis of existing services must be open out to include other aspects related to the way of being and feeling of their members. This way is possible to ensure both the technical correctness of its features as promoting safe and respectful solutions both of civic rights as the way of being and feeling of its members.

From the engineering point of view, the user perspective has historically encompassed under the concept of technological acceptance. Within this field can be interpreted as friendly solutions adapted to users will encourage the acceptance by them. Solution acceptance is desirable although it is difficult to ensure. This difficulty is due to the lack of the number of variables that affect the acceptance of technological solutions and the difficulty of optimizing the known variables.

In this thesis it is studied and characterized one of the variables that affect the acceptance of existing services: confidence. Confidence is defined in psychological terms, providing its characterization with the aim of be used in typical methods of engineering. Also different tools are proposed to facilitate the optimization of this confidence in services whose complexity establishes this variable in a basic issue to improve acceptance.

Health services deployed in a home have been chosen as working context for this thesis. This scenario presents a number of acceptance restrictions on the technology used to create services and how they manage the acquired user information. It comes to highly sensitive and delocalized services that can affect to the user's perception of the environment, the home, and generate fear or rejection to prevent final adoption as a valid solution.

Once defined the generic framework, the main objective of this dissertation is focused on promote the acceptance of new pervasive and personalized health services and their deployment in domestic intelligent environments through a layout that promotes a psychological state of confidence in users. To achieve this goal, a set of results, both conceptual, technological and experimental, have been provided. In particular, it has offered a complete characterization of the feeling of confidence from a viewpoint of engineering and a definition of sensitive or delocalized pervasive service. Furthermore, a method for the inclusion of the Interaction Design discipline in engineering processes of such services through a set of patterns of interaction is offered. Finally this thesis provides the development of a software architecture to ensure proper deployment of these pervasive sensitive services in intelligent environments in a confident way.

Discussion of the results suggests the extension of the deployment model to different services of the Information Society that handle sensitive data both in the context of the digital home and other settings where the user perform

everyday activities such as work spaces or schools. The future work lines include the imminent need to apply the results to ongoing developments, within research projects in those the author takes part, and the development of new research lines aimed at creating new spaces and interaction technologies as advanced accessible interfaces, toys of the future, confident visualization systems or security systems based on the condition of the user.

Keywords: Pervasive Technology, Ubiquitous Computing, Pervasive Sensitive Services, Interaction Design, Technology Acceptance, Confidence.

RESUMEN

Los servicios basados en las Tecnologías de la Información y las Comunicaciones (TIC) están cada vez más presentes en la vida de las personas. El avance de las TIC en términos técnicos y de aceptación social ha dado lugar la creación de nuevos modelos de provisión de servicios. Estos modelos de servicio implican una mayor integración con las actividades de las personas de forma que ya no solo están presentes en su ámbito profesional o de espacio ciudadano sino también en un ámbito más íntimo relacionado con su propia identidad. Así en la actualidad es común encontrar servicios conocedores del estado de salud de las personas, sus hábitos domésticos, su ideología, etc. Por tanto el análisis de los servicios actuales no puede limitarse a una componente técnica sino que es más necesario que nunca la inclusión de aspectos más relacionados con la forma de ser y sentir de sus usuarios. De esta forma no solo se garantizará la corrección técnica de sus funcionalidades sino que también se fomentará la generación de soluciones cívicamente seguras y respetuosas tanto con los derechos como con la forma de ser y sentir de sus usuarios.

Desde el punto de vista de ingeniería, la perspectiva del usuario se ha englobado históricamente bajo el concepto de aceptación tecnológica. Dentro de este ámbito se puede interpretar que soluciones respetuosas y adaptadas a los usuarios fomentarán la aceptación por parte de éstos. La aceptación de una solución es algo deseable si bien es difícil de asegurar. Esta dificultad es debida al desconocimiento del número de variables que afectan a la aceptación de soluciones tecnológicas y a la dificultad de optimización de las variables conocidas.

En esta tesis doctoral se estudia y caracteriza una de las variables que afecta a la aceptación de los servicios actuales: la confianza. Se define la confianza en términos psicológicos caracterizándola para permitir su uso en los métodos propios de la ingeniería. Además se proponen distintas herramientas que facilitan la optimización de la confianza en servicios cuya complejidad convierte a esta variable en una cuestión básica para mejorar la aceptación.

Como contexto de trabajo para la tesis se ha escogido un servicio de salud desplegado en un hogar. Este escenario presenta una serie de restricciones de aceptación relativas a la tecnología utilizada para la creación de los servicios y la forma en que éstos gestionan la información adquirida del usuario. Se trata de servicios altamente sensibles y deslocalizados que pueden afectar a la percepción del usuario sobre el entorno, el hogar, y generar temores o rechazos que impidan su adopción final como solución válida.

Una vez definido el marco genérico de trabajo, el objetivo principal de esta tesis doctoral se concreta en contribuir al fomento de la aceptación de nuevos servicios de salud pervasivos y personalizados y su despliegue en entornos inteligentes domésticos mediante un marco de diseño que promueva un estado psicológico de confianza en los usuarios. Para lograr abordar correctamente este objetivo se han proporcionado una serie de resultados tanto a nivel conceptual como tecnológico y experimental. En concreto se ha ofrecido una caracterización completa del sentimiento de confianza desde un punto de vista de ingeniería y una definición del concepto de servicio sensible deslocalizado o pervasivo. Además se ofrece un método para la inclusión del Diseño de Interacción, herramienta muy relacionada con la mejora de las variables de aceptación de

tecnología, en los procesos de ingeniería de este tipo de servicios mediante un conjunto de patrones de interacción Persona – Entorno Inteligente. Finalmente se ha proporcionado el desarrollo de una arquitectura software para garantizar el correcto despliegue de estos servicios sensibles pervasivos en espacios inteligentes de una forma confiable.

La discusión de los resultados obtenidos sugiere la extensión del modelo a diferentes servicios de la Sociedad de la Información que manejen datos sensibles tanto en el contexto del Hogar Digital como otros contextos donde el usuario realice actividades cotidianas, como los espacios de trabajo o los centros educativos. Las líneas de trabajo futuras contemplan la necesidad inminente de aplicar los resultados a desarrollos en curso, dentro de proyectos de investigación en los que participa el autor así como el desarrollo de nuevas líneas de investigación orientadas a la generación de nuevos espacios y tecnologías de interacción como el Colegio Digital, juguetes del futuro, sistemas de visualización confiables o sistemas de seguridad basados en el estado de las personas.

INTRODUCTION

Introduction detail the motivation that has led to the completion of this thesis, summarizing technical and technological, social and psychological aspects that have caused. Also summarizes the organization of each chapter of the PhD dissertation to facilitate its study and understanding.

1.1 Motivation

A society in continuous growth and a high level of life expectancy means that access to key resources as health services, promoting employment or education are presented as a key issue for its maintenance and future development. In the case of the EU-28 the current situation of demographics shows continued growth and a marked aging of its society (EU Employment and Social Policies, 2013). In particular, access to health and wellness systems by an overpopulated society, whose life expectancy is increasing every year (EU Employment and Social Policies, 2013), represents an increase of resources that each state should earmark to these critical areas. The latest projections by the OECD on the impact of aging on public expenditure indicate that health and long-term care will account for almost half the increase in social expenditure related to the next 35 years (Gray, 2005; Kea, Saksenaa, & Hollyb, 2011). In this sense, the current context of cyclical economic crisis in that developed countries are involved implies a continuous review of this expense.

Meanwhile, new technologies, techniques and methods of improvement have become a determining factor for the development of new models of health care provision and welfare role (Ailisto, Kotila, & Strommer, 2003; Mulvenna et al., 2006). The objectives of these new provision models are designed to meet the socioeconomic needs of this overcrowded society. This paradigm shift identifies a number of challenges (Sultan, 2014) that developers, suppliers and integrators must face with the goal of creating a solution with identical characteristics and acceptance of traditional models by end users.

The thesis work done has focused on one of the possible scenarios that identifies this new paradigm that sets the home as a means of deploying healthcare services. This represents a paradigm shift from a hospital-centered approach to a more customized model and user-centered. This scenario also involves a series of restrictions that could affect the final acceptance of the services by the user in two ways: on the one hand, this is sensitive services that manage private information; and secondly, its operation and deployment affects

intimate and personal spaces, transforming them into highly technical spaces that can alter the perception that users possessed them. Because the spectrum of types of health services is very broad, this work focuses on the concept of sensitive service as an abstract model. In addition, this work focuses on the techniques and methods offered by pervasive technology for developing more personalized and accessible services, and ubiquitous computing and ambient intelligence as a basis for transformation the home into a smart environment capable of supporting the deployment of this kind of service.

Finally, the priority of the research work done is to promote user acceptance of pervasive sensitive services from the end user perspective. Therefore, this dissertation focuses on users and the activities which they carry out daily within everyday environments such as the home. Thus, this context has established the aim of this thesis as the detailed study of the relationship of communication or interaction established between the user, sensitive services and the physical space where these services are deployed.

1.2 Contextualization

The research work carries out in this thesis is framed in the context of research groups where the author and supervisors are members, Telematics Systems for Information and Knowledge Society research group (T> SIC) within Universidad Politécnica de Madrid and Medical Sensors, Signals and Systems (MSSS) in KTH-Royal Institute of Technology. The T>SIC research group has offered its expertise in e-Health systems, construction and validation of solutions for the promotion of personal autonomy, ambient intelligence and development of systems for the digital home. For its part, the group MSSS has supported the work done in defining physiological monitoring services based on smart textiles signals and processing this information to develop pervasive sensitive solutions in the context of telemedicine.

The starting point of this thesis is the proposal of the director of the research, Professor Dr. D. Ivan Pau de la Cruz, that pointed out a security model, oriented to developers and ICT service providers, contributing to its acceptance at the Digital home. This security model provides an original reference architecture which development process defines two complementary views. First, an innovative approach to security in the digital home, consistent with the open information systems, transforming the informal knowledge into a set of formal requirements embodied in the final architectural design. Secondly, it proposes a specific methodology, based on scenario analysis, whose specification has been used to implement a real telemedicine system, obtaining improvements in functionality and interoperability. The research presented in this thesis has as reference the knowledge gained from the work presented in the following sections.

1.2.1 Intelligent System for Monitoring and Promotion of Personal Autonomy (TALISMAN+)

The coordinated research proposal presented in TALISMAN+ set as its main objective the creation of a framework for the interoperability of products and services to promote personal autonomy in three areas: conjunction of the fields of knowledge engineering, accessible tele-monitoring and confident user-centric safety procedures; evaluation and installation of solutions developed in

the context of the accessible digital home; and transfer of acquired knowledge and developed technology to the scientific community and the society in general.

In particular, the work of the author of the thesis is part of the sub-project TALISec+, oriented to the development of a framework for knowledge based management of accessible security guarantees for personal autonomy, and carried out entirely by the T>SIC research group. The objective of the subproject is to develop and validate a comprehensive framework that includes interoperable modules and procedures for the provision of e-inclusion and e-health services and applications. It would involve in an accessible and noticeable way knowledge-based guarantees of security and reliability for the electronic management of the information exchanged between actors. Thus, members of the public, professionals and the technologies would interact in a secure and effective manner in the application context chosen to promote personal autonomy.

1.2.2 Suggestive Autonomy for Elderly People

The main objective of this research project, which the author has been principal investigator, is to reinforce the motivation of the elderly for physical, mental and social activities through suggestive and non-intrusive methods. To this aim, and by means of technology, the everyday objects in a smart home will play the active role of increasing such stimulus. The activity information is adapted and customized to users on the Smart Space offering channels of information from the environment tailored to their interests, and on the other hand, information about the smart home that can help users to feel safer when performing their daily lives. Thus, the project developed a method to encourage personal motivation, promoting a positive psychological state for conducting physical and cognitive activities related with the personal development, both within the home and outdoors. For those activities whose complexity exceeds the user's capabilities, the research project provided a computer system for reciprocal exchange of skills and services from people whom make a neighborhood community, as a community time bank.

1.3 Thesis Outline

This thesis report is structured in a total of seven chapters and six appended publications that have resulted from this research. This section provides a global view of the document's organization to make easy its reading and understanding of work done. A summary of the contents of the seven chapters of this thesis is as follows:

- **Chapter 1 – Introduction**

This chapter explains and details the approach that has led to the completion of this thesis, summarizing technical, technological, social and psychological aspects that have motivated. Also summarizes the organization of each chapter of the PhD dissertation to facilitate its study and understanding.

- **Chapter 2 – Background**

The background points out the most relevant research aspects used as theoretical, methodological and conceptual basis of the thesis. This chapter presents the technological context in which the thesis is framed and the subset of services of the Information Society encompassed. Also concepts and experiences

related to previously mentioned services through traditional approaches that represent a validated starting point for the formalization of objectives and hypotheses of the research are described.

- **Chapter 3 – Hypothesis and Objectives**

This chapter presents the hypothesis and objectives that guide and materialize the research.

- **Chapter 4 – Research Method**

This chapter describes the procedures used to achieve the objectives set out in the previous chapter as well as their theoretical basis. Moreover, it details the design approach conducted for the realization of the experiments discussed in Chapter five.

- **Chapter 5 – Research Results**

The results of the research proposed in this thesis are discussed in this chapter, organizing them into three different groups: conceptual, technological and experimental.

- **Chapter 6 – Discussion and Conclusions**

The Chapter six summarizes the main findings obtained during the execution of the thesis, its meaning and the consequences that resulting therefrom. In addition, the conclusions and future research lines are presented.

- **Chapter 7 – Bibliography**

Finally, this chapter list alphabetically the references used in the completion and formalization of the doctoral dissertation.

BACKGROUND

This chapter details the ideas, concepts and experiences essential to the research conducted in this Doctoral Thesis. In the first instance are entered the enabling technologies of new services in the Information Society and the evolution that they have suffered from a socio-economic and industrial point of view. What follows is the description of the vision of the acceptance of technology in the context of the Information Society and how, management of user confidence toward the services has been carried out so far. Finally, there the field of study of interaction design and its relationship with the topic of study proposed in this thesis is presented.

2.1 Enabling Technologies

Technology is defined as the set of theories and techniques that enable the practical exploitation of scientific knowledge (Real Academia Española, 2014) with the aim of aiding human adaptation to the environment and thus satisfying both the essential needs and the wishes of the humanity. Technology allows us, therefore, to design and create goods and services to meet these endeavours.

The choice, development and use of technologies has very varied impacts on the progress of human beings and nature. In some cases, this impact leads to a radical change in the context of users of a specific technology, both in social and cultural terms. This technological innovation or invention is labelled enabling technology and is mainly characterized by the rapid development of subsequent technologies, often present in several scientific and social fields.

The wheel, glass, the printing press, or in more modern times, the electric motor, the internal combustion engine, the aircraft, personal computers or computer networks, represent some examples of this type of technology developed since the origin of humanity. Within the context of this thesis some of these technologies of high social significance will be explored in detail. Specifically, the technical aspects and social implications of ubiquitous computing, pervasive technology and smart spaces will be discussed in detail.

2.1.1 Ubiquitous Computing

Ubiquitous Computing represents a new paradigm in computing where the person relates physically with a large number of computers without temporal or spatial restrictions. The first paradigm, and origin of modern computing, known with the word *Mainframe*, placed a single computational element at the service of multiple users. The irruption of the personal computer or *PC* brought the next

paradigm shift, allowing each user to have a single computational unit or computer. Finally, the inclusion of technology with computing capacity in the background of the daily life of people, ubiquitous computing, represents, according to Alan C. Kay, "*the third computational paradigm*".

The irruption of the Internet facilitated the transition from the era of the PC to this new computational paradigm. The Internet has deeply affected business models, technological practice and even social and cultural relationships. It has allowed the interconnection of millions of users, encouraging information sharing and management. The developments carried out within the Internet follow a client-server paradigm on a massive scale, where web clients, PCs, and web servers, the *Mainframes*, offer services to a huge number of users. The new business models arising from this context and the opportunities for innovation and research underlying have favoured the development of this third paradigm in computing or ubiquitous computing.

Following on the foundations of the Internet, ubiquitous computing allows each user to act as a server, sharing a large number of computers with the rest of users and computer systems. These elements, through the use of the Internet, allow the inclusion of almost anything, walls, furniture, clothes, cars, etc. in the world of computing, at any scale, including on a microscopic level. M. Weiser and J. S. Brown pointed out that (M Weiser & Brown, 1996) before 2020 ubiquitous computing will unseat the era of personal computing as a computational paradigm and definitively introduce the third era. In short, ubiquitous computing, through the use of the Internet as a communication medium, allows us to interconnect the numerous small-scale computers that are already in our daily lives and can be found in appliances, vehicles, entertainment systems or toys. In this way, it is possible to increase the experience that the user can have when using these objects, extending their computational capacity to address goals closer to the user.

Ubiquitous Computing also represents a major leap forward for the development of new services in the Information Society. It provides the operational capacity to offer services that are closer to the users in such a way that they may be present at all times and be able to offer their capabilities to users in a manner that is transparent and aligned with the daily tasks that they perform. As pointed out by M. Weiser (M Weiser & Brown, 1996), ubiquitous computing offers a new approach based on the calm, tranquillity and confidence, making the user feel at home, thus allowing them to carry out their daily activities in a normal, intuitive fashion, while at the same time benefitting from the functionality of these shared components, in a serene and controlled manner.

2.1.2 Pervasive Technology

Ubiquitous Computing, as a computing paradigm, requires technology for its application. In this sense, pervasive technology represents a potentially ideal environment, due to its characteristics, to support this paradigm. Although not all technology has a pervasive computational capacity, its uprising is subject to the development of the paradigm of pervasive computing, translated into products and services what can be offered.

The properties that the technology must comply with to be considered pervasive, which are at the same time its fundamental characteristics, are resilience and persistence. Resilience, a term taken from the field of psychology, refers to the human characteristic related to flexibility in borderline situations and the ability to overcome them. Applied to the field of engineering it

determines the ability of a product or service to be used in any way other than what it was developed for without causing injury to the user. Persistence refers to the ability of an element to endure in time and space, i.e., it must be accessible regardless of the context in which we want to use it.

When pervasive technology is applied to ubiquitous computing, it should ensure that not only it satisfies the formal requirements established initially but, in addition, it must allow the user to use it for other pursuits, should they wish to do so. If we consider everyday objects endowed with certain computational ability, such as for example a scale, its use in the context of pervasive computing must allow it to not only measure the weight of its users, but it must also ensure the functionality of the underlying pervasive system or service.

2.1.3 *Intelligent Environments and the Digital Home*

Intelligent environments are the most common implementation and deployment elements for solutions based on ambient intelligence. The concept of "environment" refers to any physical space where people carry out their daily activities, such as homes, buildings, streets, fields of crops, etc., on the other hand, the term "smart" applied to these environments refers, in general, to artificial intelligence. In this sense, Augusto and Callaghan define them as spaces where the actions undertaken by many interconnected controllers are organized by proactive services in such a way that is possible to offer comprehensive interactive functionality to improve the experience of their occupants (Augusto, Callaghan, Cook, Kameas, & Satoh, 2013).

From a point of view based on information and communication technologies (ICT), the intelligent environments represent homogeneous platforms and custom for the interaction between its inhabitants and the services that they are deployed. In the context of this thesis, the smart space under study is the Digital Home. This smart space provides a custom interface through the use of the home's own devices, such as household appliances, furniture, clothing, etc., that are widely accepted by users because they are part of their own home.

The services of the Digital Home should make use of the existing resources in the home and integrate into the daily habits of the people so that they benefit the users instead of being a new problem to be solved. In this sense, Edwards and Grinter (2001) proposed a set of seven challenges that the Digital Home must face before its final adoption as a smart space that covers the needs and expectations that society has placed in this technology (Edwards & Grinter, 2001). These challenges are defined from a social, pragmatic and technological point of view and are still in use today as technology has not completely resolved many of the issues proposed.

- I. *The accidentally Smart Home.* Due to the technological complexity of homes is increasing, the possibility of unwanted fortuitous actions, even with other homes, increases. Thus, the user of the home must have knowledge and complete control over the house so that accidents do not occur and the technology used is not rejected.
- II. *The impromptu interoperability.* The diverse devices in the home must interact to deliver value-added services. If this interaction does not exist, or exists only between devices of the same type, the house becomes a functional set of islands which weaken the holistic concept of the home.

- III. *No system administrator.* Systems Administrators are usually responsible for the maintenance and installation of new devices and services. Digital home environments must avoid the need for a system administrator, just like the majority of household devices. This is not an easy task, since the Digital Home environment, due to its nature, involves the handling of complex technology.
- IV. *Designing for Domestic Use.* The design of home devices should also be aimed at domestic users and not be an update to existing solutions for environments where users require certain skills. It is not only a question of usability, the devices should improve certain domestic routines and not condition them in any way.
- V. *Social implications of Aware Home Technologies.* A correct understanding of how technology can be adjusted to daily routines is a key aspect in the Digital Home. All the implications of a social nature that the inclusion of this type of technology entail must be taken into account, so a thorough study of the implications of this type of technology is necessary.
- VI. *Reliability.* Home devices tend to have greater reliability requirements than the services and devices in other environments. Typically the devices installed in the home have a physical (and logical) access that is more complicated than in other environments. This makes the devices have reliability as a objective from the initial stages of their design. To meet this objective, according to the authors of the study, technology must be changed in four main areas:
 - The development culture of new devices and services, including reliability from the design stages.
 - Technical aspects. The fact that part of the intelligence is left in the network and part is left on the device must be taken into account.
 - Market expectations. Users have developed a certain degree of tolerance to errors in computing applications. This tolerance must disappear with the inclusion of computers in the home environment.
 - Legislation. We should promote the existence of regulations about the level of service that certain dwellings must have.
- VII. *Inference in presence of ambiguity.* There is the tendency to make homes increasingly "smart" but it is necessary to define the level of "intelligence" of the home. There are certain actions that can be inferred from information collected from sensors, with a very low probability of error. This type of actions are suitable to be incorporated in the short term in a Digital Home. However, these actions do not require great intelligence of the system. The actions that require the simultaneous use of several sensors and even from prior inferences generally involve more complicated decisions and, therefore, a higher probability of error. These errors must be understood by the user and solved to avoid them being repeated later as their spread to other types of functionality. It is therefore necessary that users understand how certain conclusions are reached so that they can understand the nature of the error and help rectify it. This means that the system's behaviour models must be able to explain, in a way that can be understood by users, the decisions taken and what sources

of information they have been based upon. In this way users can predict the behaviour of the system and verify corrections, if the elements for detecting conditions are correct or not and, finally, modify the behaviour of the system.

Solving these challenges, as well as the advancement in technologies related to the implementation and development of smart spaces, will allow real implementation of the Digital Home as a valid and complete smart space.

2.2 Services in the Information Society

The Information Society refers to the social model in which the means of wealth generation are based on the production, management and transmission of information (Sarell & Machlup, 1963). In the information society, information and knowledge are established as the main economic engine, giving greater importance to services over production and products. Information and knowledge technologies (ICT) are an essential tool for the development of information society services. Their main objectives are the generation of knowledge and the exchange of information, through its encapsulation in the form of services to ensure its efficiency and accessibility to the citizen.

The services deployed in this society have undergone a continuous evolution to adapt to the needs of society and the specific characteristics of the technology used for its development. The incidence of these services in the information society goes beyond the technical field, and its evolution has been influenced, not only by the technology used in its development, but also by the socio-economic factors related to new forms of communication and global coexistence.

In (Achrol & Kotler, 2014) services are defined as the application of specialized competence by an entity through actions, processes and activities for the benefit of another entity or the own. This concept, in the context of the information society, refers to any set of features provided at a distance, electronically and by individual request from the recipient of the service (Directive 98/48/EC of the European Parliament and of the Council). To achieve this, ICTs are used as a means of developing the transmission, processing, and storage of the data associated with it.

In contrast to a specific product, the services deployed in the information society are specified at the time they are required by the user. The specifications or design requirements of the services can and must be defined a priori, but their implementation, deployment and behaviour are subject to their use. This means that the services are tailored to the needs of the moment when they are required. This situation requires that the users can control and understand the elements involved in the use of the service at the time in which they are accessed, regardless of the technical complexity and underlying technology. In this way, the information society offer their users increasingly complex and useful services whose efficiency and effectiveness is subject to the relationship of communication between them. Given the complexity of nuances in many existing services deployed, a detailed study and design of all of the elements of the service is necessary. Within these elements, the communication relationship between users and services is of particular importance for two basic reasons related to their implementation in society and the management of the inherent complexity of these services. On the one hand, the ever increasing inclusion of these services in the daily lives of people means that these affect more intimate and personal aspects of users, which could generate rejection or fears that did

not exist initially. On the other hand, a more complex functionality that addresses needs closer to the user implies an increased degree of service sophistication and interconnection.

To better understand the importance of the relationships between users and the services of the information society it is necessary to analyse its evolution, from a more focused approach in the management of the information until a conception aligned with the enabling technologies presented in the previous section.

2.2.1 The Evolution of Services in the Information Society

As has already been mentioned, the evolution of services in the Information Society has been marked not only by the ICT used in its definition, but also by the needs and wants of the citizens that make up the society of the availability of the basic resources needed for its proper development.

Throughout this section, the evolution of services in the Information Society will be presented from two perspectives. The first analyses said evolution from a socio-economic focus in order to understand how key aspects of today's society and its needs have influenced the development of these new services in the Information Society. The second presents a view of the evolution of development efforts and investments made by the big ICT companies over different sectors of society in order to create new services in the Information Society.

Although development efforts for these services and their evolution are currently oriented towards various areas of people's lives, this Doctoral these is centred on two fundamental aspects, health and the intelligent home. Health and social well-being represent a group of services with an extremely high tendency to impact society and industry. Intelligent homes offer an important tool for enabling the spread of healthcare and personal wellness services.

Socio-economic Focus

An ever-higher quality of life and an ageing population paint a picture where the number of users of health and wellness services is constantly increasing. Health assistance and wellness services play an increasingly critical role in consumer and, especially, State expenditures. This picture, along with the cyclical economic crisis situations that our society suffers from, forces States to redirect the distribution method for this type of services towards more sustainable methods in regards to time and resource use.

Enabling technologies, such as ubiquitous computing and pervasive technology, have allowed health assistance to be transferred into the daily context of users. This new paradigm of service distribution, along with the expected capacity of the Digital Home, are considered promising and more sustainable alternatives to traditional hospital-centred developments. Thus, the telehealth industry has turned into a competent complement to traditional health services and, as seen earlier, also into an opportunity for the development and distribution of new services by the ICT industry. In 2013, this industry generated US \$240 million in revenue through three primary means of care: store-and-forward, programmed real time, and emergency real time (GrowthCap, 2104). According to analysis company HIS¹, the telehealth market is about to grow to an annual cumulative rate of 56%, to \$1.9 billion in 2018. This implies that the

¹ www.ihs.com

number of patients using telehealth will grow from 250 thousand in 2013 to 3.2 million in 2018.

This evolution has created a change in vision for service development from a more complete and complex concept to a simple and more accessible solution. In this way, the acceptance of services by users is fostered, while improving its distribution in society and, thus, its socio-economic impact. The application of mobile technologies, such as smart phones or tablets, as well as enabling technology, such as pervasive technology and ubiquitous computing, has favoured the inclusion of companies that are foreign to the sector and the participation of governments as support entities.

If the expectations for Telemedicine are, in fact, promising, the reality is that, up until now, the telemedical solutions distributed had achieved varying levels of success. In addition, this variability in the success of Telemedicine occurs in disparate development indexes. Even now, Telemedicine is used in a residual manner as a method for rendering routine services and only a few pilot projects have been able to sustain themselves once the development phase of the prototypes has finished.

The majority of studies related to the analysis of the true distribution of Telemedicine solutions show that patients and service providers are resistant to adopting service models that differ from the traditional focus or local practices, while others lack an ideal level of necessary knowledge and technological culture to use the new focus effectively. The most notable complex problems are related to linguistic and cultural differences between patients (particularly the underserved) and service providers (Al-Shorbaji, 2008; Craig & Patterson, 2005; Currell, Urquhart, Wainwright, & Lewis, 2010).

Another cause related to real Telemedicine service distribution is that it has not been a priority for most governments. In a 2010 global e-health study carried out by the World Health Organization (World Health Organization, 2010), only 52% of health and wellness services offered via Telemedicine had been adopted and established in countries by their governments. However, it seems that currently, governments have become more conscious of the need for this type of services. States are primarily concentrating their economic efforts on the investigation and creation of services aimed at healthcare and wellness, including Telemedicine. In the European Union, Eurobarometer 419 (European Commission, 2014), researching European citizens' perceptions on the topics of science, research and innovation, established that the evolution of the services in the Information Society dedicated to the promotion and protection of health and wellness represent, along with job creation, the main priority for science and technological innovation for the next 15 years. Figure 1 shows an analysis about the priority of research and development-based on 13 basic aspects of current society and the expected positive impact of research and technology with regard to the expected impact of each citizen's individual action.

Figure 1. Comparative graph of the expected impact of science and technology and the individual actions of each citizen for the 13 most representative areas of current society's activity (European Commission, 2014).

It becomes clear that current society is aware that the inclusion of ICTs to create effective and useful services represents a necessary aspect of its development. Nonetheless, the manipulation of private and personal data performed by this type of services, together with its inclusion in the daily life of users in a pervasive manner (clothing, home, work spaces, schools), generates a certain level of rejection and fear that inhibits its complete adoption. Governmental agencies are aware of this and continue working on legislation for these sensitive services as a means of user protection since the mid-90s. As will be analysed in the following sections, adopting this type of services is determined by the factors intervening in the development of sensitive services and how the enabling technologies presented in this chapter affect the storage and management of the information they control.

Industrial Focus

Market movement and business investing from the largest companies in the ICT arena offers an addition perspective on understanding how services in the Information Society have evolved over the years. Figure 2 shows investment trends by business sector in the group of all American start-ups in their creation phase from 2010 to 2014. It can be seen that the traditional sectors related to Hardware and Software development, instant messaging, education, and mobile technology maintain a high investment index. However, movement towards an increased investment in other sectors can be discerned, marking an evolutionary trend in the services in the Information Society. The fashion sector, covering manufacture of intelligent fabrics, among other things (Fashion), E-Commerce, Hospitality and Digital Home development (Hospitality), and sectors related to health and wellness (Healthcare and Health and Wellness) have received a larger rate of investment since 2010, putting them on par with the traditional sectors.

Figure 2. Trends in seed capital investment from 2010 to 2014 in the USA (Image source: <http://tomtunguz.com/hot-sectors-2014/>; Data source: Crunchbase).

If we focus our analysis on large companies such as Google, Microsoft, Apple, etc., we can see how this trend continues. In the case of Google, the services developed originally were oriented towards the need and desire of its users to share and acquire knowledge, and it was managed and organized with a powerful search engine, the symbol and brand of the company. However, during the 2010-2015 period, Google has reoriented its development and acquisition of external companies towards the study of life sciences and development of Digital Homes. As shown in Figure 3, in 2014, investments made by Google Ventures, a sub-company dedicated to the acquisition of other companies as subsidiaries of Google, exceeded 35% in the Health and Life Sciences sector, putting it above even the mobile phone sector. This trend materialises in the creation of a highly protected division, Google[X], aimed at producing major technological advances, emphasising its line of research and innovation in the study of life sciences.

Other relevant ICT sector companies such as Microsoft, Apple, or IBM have also evolved their developments towards a convergence with healthcare. Specifically, Microsoft created the company Avanade alongside Accenture in 2010 with the objective of covering the needs of society focusing on health and wellness. With this initiative, Microsoft's technologies such as Kinect, Skype, and HealthValue (a tool based on services on the cloud for the exchange of patients' clinical histories) are joined together. In Apple's case, the development trend for this type of sensitive services materialises in their bet on information processing in regards to health through HealthKit, available on all its new devices. Lastly, IBM has aimed its technical and technological capacities towards clinical data analysis and development of technical tools for improving the healthcare process, an idea that has been captured in the interoperability framework IBM Watson Health.

Figure 3. Investments in 2014 by Google Ventures (The New York Times).

Another sector where the biggest representatives of the ICT sector have overwhelmingly decided to invest since 2010 is the development of Digital Homes. In 2014, Google acquired the companies DropCam and NestLabs, cutting-edge enterprises in the development of solutions for the Digital Home. In this way, Google attempted to turn itself into a reference source in this field through development of systems and services for the Digital Home alongside adapting and using its mobile operating system, Android. In addition, Microsoft or Apple, who in the beginning were aimed towards the development of tools for knowledge processing or communications, have seen the opportunity that the Digital Home offers. In this way, new systems and technological developments aimed at this sector have appeared, such as HomeOs (Microsoft Research), an ad-hoc operating system aimed at device management, communication frameworks for Digital Home elements such as HomeKit (Apple Inc.), AllJoyn (Linux Foundation), and Thinking Things (Telefónica), or research and development divisions such as Lab-of-Things (Microsoft). Amazon has also jump onto the Digital Home bandwagon with Echo, a coordinating device for home device networking and direct communication between the user and the Digital Home. As such, this means an important bet from the big ICT companies on the development of this technology that transforms the user's most private and personal spaces. Conscious of the business advantages and development possibilities that the Digital Home offers, they have decided to broaden their fields of business to all levels of the Digital Home, from a purely physical level with sensor and actuator development to a functional and logical level, represented by operating systems and interoperability, communication, and implementation platforms.

As observed in the development of investments by the big ICT sector and Information Society companies, the development of services for user health management and wellness and the transformation of the home into an intelligent platform for distribution of services represents a field of development with a

wide margin of benefits, both economic and social (Balta-Ozkan, Boteler, & Amerighi, 2014; Martin, Kelly, Kernohan, McCreight, & Nugent, 2008).

2.2.2 Sensitive Services

The evolution analysed in the previous section shows a design and development trend towards services with a greater social impact in terms of quality of life. In addition, technologies giving shape to those services with a greater degree of autonomy, ubiquity, delocalisation, and control over their users' personal aspects are evolving in parallel.

These new services manage data that is not only based on the physical disposition of the user in regards to the environment (such as geographical position, interior positioning, or patterns of movement) but also related to more personal aspects of their physical state, psyche, or behaviour patterns (Ackerman, 2013).

More and more studies show the difficulties related to services that manage data or situations that are considered personal or of special importance to the user. In this thesis, since an adequate definition has not been found in the literature, the concept of sensitive service will be used to refer to this type of services. A sensitive service will be formally understood in this thesis as a service that fulfils the following conditions:

- The combination of its functionalities significantly affect its users' quality of life;
- It manages information that is considered private by its users. This information may be provided by users or service providers, learned via automations, or inferred via data mining processes;
- It involves the psychological responses of its users, being able to condition its own behaviour or activities;
- They are present in the users' personal spaces, such as the home, school, or workplace, and as such affect the development of day-to-day activities.

Another defining trait of this type of service is where it is to be implemented. They not only affect their users' personal data, but also must be implemented in living spaces where daily life unfolds, such as the home, school, hospitals, or workplaces. Bettini & Rinobi propose, in (Bettini & Riboni, 2015), a classification of personal and sensitive data according to the category of the sensitive services provided. As may be seen in Table 1, e-Health and wellness services are joined under the context of the Digital Home. A health service deployed in the Digital Home, for its proper functioning, must record and analyse user activities in such an intimate and personal space as is the home. Mismanagement of the information managed by this service could alter the behaviour of the inhabitants of that space, affecting its final acceptance. As such, this represents a clear example of a sensitive service that fulfils the requirements for a sensitive service that were previously expressed.

Chapter 2. Background

Table 1. Main application categories, sensitive data, and adversaries (Bettini & Riboni, 2015).

Category Of Service	Information Management Entity	Sensitive Data
Location based services	Service provider	-
Mobile advertisement	Service provider, merchant	Location, absence, co-location
Geo-social network applications	Service provider, other users	-
Participatory sensing	Data collector, service users	Location, sensed data
Healthcare and well-being	Service provider	Location, body-worn sensor data, activity
Vehicular applications and smart city services	Other drivers, city and road authorities	Movement traces, driving behaviour, user habits
Smart home and smart grid applications	Power companies, home automation service providers	Occupancy, habits and activities

From a legal point of view, it is common for governments to write up laws with the aim of guaranteeing the protection of the data managed by this type of service and the privacy of its citizens. In the European arena, the goal of the European Data Protection Supervisor (EDPS) is to assure, via directives, that institutions and EU organizations respect people's right to privacy personal data is being handled. These directives establish several levels of data sensitivity, placing information related to users' ideology, union affiliation, religion, beliefs, race or ethnic origin, health, and sex life in a *highly sensitive* grouping.

Another example of actions taken to guarantee citizen privacy is the case of the United States. In the Health and Human Services (HHS) Department, in 1996, the Health Insurance Portability and Accountability Act (HIPAA) was defined as a means of protecting personal medical information and rights conceded to individuals. Under the scope of these recommendations and the associated laws that were put forward by the Office of Civil Rights (OCR), as an entity dedicated to the protection of individual information, it was established that each service provider entity must define an associated privacy and security policy. A specific example would be the HIPAA policy of Carnegie Mellon University, which established a group of identifiers that define Protected Health Information (PHI).

Table 2. Group of data considered protected in a health context by Carnegie Mellon².

Protected Health Information (PHI)
Name
Address (all geographic subdivisions smaller than state including street address, city, county, precinct or zip code)
All elements of dates (except year) related to an individual including birth date, admissions date, discharge date, date of death and exact age if over 89)
Telephone numbers, Fax numbers, Electronic mail addresses
Social security numbers, Medical record numbers, Health plan beneficiary numbers

² <http://www.cmu.edu/iso/governance/guidelines/data-classification.html>

Account numbers
Certificate/license numbers
Vehicle identifiers and serial numbers, including license plate number
Device identifiers and serial numbers
Universal Resource Locators (URLs)
Internet protocol (IP) addresses
Biometric identifiers, including finger and voice prints
Full face photographic images and any comparable images
Any other unique identifying number, characteristic or code that could identify an individual

However, and despite the fact that the number of laws and regulations directed at creating privacy and protection for users of this type of services has grown over the last 20 years, the perception of control from the citizen's perspective has deteriorated. According to Eurobarometer 431 (European Commission, 2015), from 2015, researching Information Protection, it can be seen that only 15% of the European population believes that they have total control over data shared when using services in the Information Society. On the other hand, 31% of the population believes that they do not exercise any control over this information and finally, 50% believes that they exercise some control over shared data while using services in the Information Society.

A comparative analysis of the results offered by the 2015 Eurobarometer with the one created in 2010 show that the feeling of control over this data has varied. In 2010, the users of these services had a greater perception of control over data than in 2015. While in 2010, only 20% of users believed they did not exercise any control over information, in 2015 it increased by 12%, decreasing the percentage of users that were confident in their control over shared sensitive information. However, these users show a greater awareness, in comparison with the 2010 results, of daily activity monitoring with the use of Information Society services. Figure 4 shows a tendency towards the feeling of having to share more information on-line between the years 2010 and 2015.

Figure 4. Feelings about having to provide personal information on-line. 'Total 'Agree' (European Commission, 2015).

This shows that the sensitivity of the data managed by these services has increased, in large part because these services are more present in users' daily life, affecting individuals' spheres of day-to-day life more and more. Citizens are more and more aware of the existence of risks related to the use of this specific type of services. These risks include fears that impede the acceptance of a technological solution and encourage its rejection in the presence of a viable alternative (Khadke & Chavan, 2014; Mark Weiser, 1995). The study of the acceptance of technology by society presents a way of understanding the motives and factors that intervene in the success of the adoption of a specific technology by its users.

2.2.3 Pervasive Services

The consolidation of the Internet as a means of communication in the IS has encouraged the evolution of computing systems from a centralized concept towards a viewpoint based on a shared information network where all users store and execute services. This situation is commonly known as Cloud Computing. Additionally, advances in the miniaturization of technological components linked to computing has enabled them to be embedded in everyday objects, creating computing networks based on common objects. This phenomenon is known as the Internet of Things (IoT).

These advances have also affected the development of IS services. At one point, these services were offered as a complex element that involved a higher level of control from their users. Currently, these services are offered by operators as simple functionality packets in objects that are already utilized and known by users such mobile phones, electrical appliances, furniture, etc. The orchestration of the capacities offered by these objects with computational capacity and the possibility of remotely processing information has contributed to the appearance of new ICT services called pervasive services. Although a concrete definition has not been found for this type of services, in this Doctoral Thesis a pervasive service will be defined as a delocalised and persistent ICT service that allows its users to access the functionalities it offers at any time or place. The delocalisation of these services and their accessibility via the Internet independent of the user's location has facilitated their inclusion in individuals' daily life, thus offering more personalised ICT services. This simpler, delocalised, and persistent IS service concept promotes access by all users, independent of their location, technological culture and knowledge, social condition, or purchasing power.

However, the adoption of these ICT services must confront a series of problems for their total adoption by society. The use of pervasive technology for their implementation and their delocalised nature foster a state of rejection towards the information managed by pervasive services, generating, as we have previously analysed, insecurities about who manages such information and how. A study carried out by the CloudT³ project among European (Spain, France, and Italy) and Japanese entities, whose goal was to boost citizen influence in a future concept of an intelligent city, shows a global viewpoint on citizens' familiarity with the concepts of Cloud Computing and Internet of Things. Figures 6 and 7 show a representation of those concepts concerning citizens who do not work in any of these areas.

³ <http://clout-project.eu/>

Figure 5. Familiarity with Cloud computing³. Figure 6. Familiarity with Internet of Things concept³.

While the Cloud Computing concept seems to be better-understood by society with 24% positive responses, the IoT turns out to be familiar for only 15% of the surveyed population. That means that 60% of the population is unaware of the nature and objectives of this type of technology, affecting acceptance of the services constructed with it.

2.3 Technological Acceptance

Currently, information technology is very present in individual life, in a personal realm as much as the workplace and its success as a tool drastically depends on how it is used and accepted by its users. (Hu, Chau, Liu Sheng, & Tam, 1999) explains that the study and analysis of user acceptance of a new technology is one of the most mature lines of research in the field of contemporary Information Systems (IS). In this section, the origins of this line of research, the associated and commonly used prediction models, as well, as their application in the context of this Doctoral Thesis, are gathered.

2.3.1 Origins and Definitions of Technological Acceptance

The concept of technological acceptance or the acceptance of technology references to the degree of adoption, use, and acquisition of a specific technology by a user and, by extension, society (Van Ittersum et al., 2006). Two groups of concrete variables determine this definition: those that reference the characteristics of the technology being studied, such as complexity, intuitiveness, innovation, or utility, and the characteristics associated with the user, such as motivation, his or her prior experience, or socio-economic condition, among others. Through a separate analysis of both variable groups, the group that is inherent to the technology and the one related to acceptance, an integral definition of the concept is established (Merriam-Webster, 2013; Real Academia Española, 2014; Van Ittersum et al., 2006):

"Degree of adoption and use by the user of goods or services as the practical application of knowledge, whose objective is to satisfy a need or want of society"

The origin of the concept of technological acceptance is intrinsically linked to the origin of the study and analysis of technology and the relationship that is established between it and its user or users. However, it was during the 1980's that the first models and theories related to this study appeared. In 1989, Fred D. Davis established the first information technology acceptance model, known by its acronym, TAM (Technological Acceptance Model). Davis establishes this predictive model as a theory for determining how users come to accept and utilize a new technology. Specifically, he establishes two fundamental factors: the perception of utility, which is defined by the degree to which a person believes that, with that technology, he or she can perform an activity or improve a process, and the perception of ease of use, which is represented by the degree to which a person believes that the effort relative to learning to manage the technology is less than the benefits it offers (Davis, 1989). The model created by Davis represented a direct application of the Theory of Reasoned Action (TRA) (Ajzen et al., 1980) applied to the Information Society context. This theory establishes a general psychological model where the attitudes of a subject towards an object are connected. These attitudes are replaced in TAM by the measurements of technological acceptance introduced by Davis, ease of use, and utility. Figure 7 shows a diagram of the TAM model and the cognitive and behavioural determiners that define it.

Figure 7. The Technology Acceptance Model, version 1 (Davis, 1989).

Investigation of the model presented by Davis, TAM, continued through the 1990's and 2000's, resulting in new versions, such as TAM2 (Viswanath Venkatesh, Davis, & College, 2000), UTAUT (Viswanath Venkatesh, Morris, Davis, & Davis, 2003) and TAM3 (V. Venkatesh & Bala, 2008).

The TAM2 model introduces new determiners to the original model that are related to social aspects and are aligned with the perception of utility generated in the user. Specifically, TAM2 introduces variables referring to Subjective Norm, Voluntariness, Compliance with Social Influence, and Internalization of Social Influence. These three new concepts are consistent with the concepts set forth in the TRA and their purpose is to introduce social aspects related to the adoption of a new technology by society. Figure 8 shows a diagram of the added concepts in the model proposed by TAM2.

Figure 8. The Technology Acceptance Model, version 2.

Later, Venkatesh proposed the Unified Theory of Acceptance and Use of Technology (UTAUT). It is a theory grouping the technological acceptance models, created from the study and review of the constructs coming from 8 previous models. An important aspect that this model brings to the study of the relationship between users and technology is the inclusion of four moderators of dynamic user distribution: gender, age, voluntariness and experience. Figure 9 shows how these determiners are related to the constructs extracted from the rest of the models and theories studied in UTAUT. Currently, this model is strongly oriented towards the study of ICTs applied to education and banking (Khechine, Lakhal, Pascot, & Bytha, 2014; Marchewka & Kostiwa, 2014; Slade, Dwivedi, Piercy, & Williams, 2015).

Figure 9. Unified theory of acceptance and use of technology (UTAUT).

Lastly, Venkatesh establish TAM3 (currently under development) as a revision of the TAM2 and more focused on the constructs that define and manage the perception of ease of use or interventions. Figure 10 shows the organization of this model.

The models presented, although valuable from the point of view of knowledge related to research on technological acceptance, have been criticized by a variety of authors. These criticisms have been primarily directed towards what the models lack in a practical sense and the large number of constructs involved in their definition (Bagozzi, 2007; Benbasat & Barki, 2007). As a consequence, it is estimated that the most mature models, TAM and TAM2, can only cover 40% of Information Systems use, a scenario that puts their applicability into question (Chuttur, 2009). For example, these models present application problems in the field of Telemedicine or e-commerce due to the fact that the ease of use perceived by users of this type of system does not represent a determining factor for its final adoption as a valid solution (Chau & Hu, 2001; Pikkarainen & Pikkarainen, 2004).

Figure 10. The Technology Acceptance Model, version 3.

The study of the application of these models in the field of ubiquitous computing and pervasive technology development began in 2007 with the work presented by K. Connelly (Connelly, 2007). The Pervasive Technological Acceptance Model (PTAM) establishes the necessity of adapting the existing models to the context of ubiquitous computing, where pervasive technology is introduced in the user's space as a common element in daily life, offering modes of interaction different from those established by traditional technology. One of the fundamental principles of this acceptance model is that it lets go of the factors that are most linked to the technological adoption part, such as marketing

or business models, focusing on personal matters that directly affect the user, such as availability or service prevalence and product affordability.

The means of interaction that pervasive technology offers and the way in which this technology process information represent a paradigm change, where the user no longer directly interacts with the specific interfaces of computational systems (keyboards, screens, mice, cameras, microphones, etc.), but is surrounded by technology, turning into another element in the system (Tennenhouse, 2000). Addressing these new characteristics, Connelly (Connelly, 2007) establishes the following factors that must be included in the acceptance model:

Work Environments. Applications developed with pervasive technology and ubiquitous computing use technology embedded in daily use environments in order to be able to be used anywhere, at any time. In this computing context, applications do not represent a central element where user activity is focus, but rather they support the user in daily tasks, whatever they may be. Because of this, the acceptance models for pervasive technology must keep in mind personal aspects of the users such as motivation, beyond reasons related to work activities.

Trust. The nature of pervasive technology implies processing very intimate and personal data from users, in order to be able to adapt the behaviour of the developed systems to the needs of their users. As such, the user's trust towards the system represents a key factor to keep in mind in final acceptance studies.

Integration. Pervasive technology is immersed in the user's life context, so the ability to be integrated naturally into the user's daily life without adding distractions represents another key factor.

Demographics. The inclusion of pervasive technology in the user's daily life determines a heterogeneous spectrum of target users, with diverse ages, education levels, experience, and socio-economic status. Various acceptance models already include demographical aspects such as age, experience, or gender of their users. However, PTAM introduces factors related to the degree to which a person considers that the use of a certain technology may contribute to the betterment of their social image or aspects related to extrinsic or intrinsic motivation.

Figure 11 shows how the factors studied by Connelly have been introduced in PTAM.

Figure 11. Graphic representation of PTAM(Connelly, 2007).

The research performed for this Doctoral Thesis has focused on one of the new determiners included in PTAM, trust, which will be analysed in the next section of this chapter.

In conclusion, Figure 12 shows the relationship between the most extensive and presented acceptance models in this section and the theories they are based on. It is shown how the analysis of the acceptance of technology by users is a field of study that transverses psychology, sociology, economics, and engineering. As such, the adoption of a concrete technology is shown to be affected by the factors closest to the user, cognitive and socio-economic, which go beyond the objective of the concrete technology's development.

Figure 12. Evolution of technological acceptance models and their fields of application.

2.4 The Management of Trust in the Information Society

Historically, the study of trust generated by an Information Society product towards its users has been carried out by researchers in the field of Human Computer Interaction (HCI). In 1982, B. Shneiderman defined the concept of “direct manipulation”, which has been used as the basis of the study of user trust towards the product being analysed (Shneiderman, 1981). During the last 25 years, direct manipulation has directed the design and implementation of communication interfaces between users and systems, products, and services of the Information Society. This concept is based on a visual representation of objects and actions of interest, physical or positioning, disengaging the users from complex operations, generating a rapid and comprehensible response for the user. In this way, users have a comprehensible, predictable, and controllable interface available with which they can communicate with ICT systems.

Another interesting matter within the concept of direct manipulation is that, as shown in Figure 13, trust represents a direct interactional relationship between a user and an entity (technology, service, etc.). This relationship is determined as much by the cognitive aspects of the user, such as comprehension of the relational process, control over said relationship, and the fulfilment of the expectations developed before use.

Figure 13. Representation of the concept of confidence traditionally used in Engineering and Computer Science.

However, evolution of Information Society services towards a delocalised and persistent context places the user in a different scenario. Now, the user find themselves surrounded by technology that operates proactively and autonomously, which impedes upon their direct participation in the system, primarily due to the quantity of objects with which they could interact. Thus, it diverges from the rule of direct manipulation. The user is placed in a role of supervision (Tennenhouse, 2000), removing them from the centre of interaction and transforming the process of Person — System interaction into a more complex cognitive task (Blackwell, 2002).

Figure 14. Representation of relationships of trust, according to the traditional conception of the concept in the context of ubiquitous computing and pervasive technology.

As can be seen in Figure 14, direct manipulation and trust management, according to the tradition conception of the concept, is transformed into a more and more complex cognitive process as interactive elements are introduced into the user's environment (Hoffman & Novak, 2015; Rowland, Goodman, Charlier, Light, & Lui, 2015). This situation, taken to an extreme where the user is unaware of a large part of the interactive elements, something common in an environment where pervasive services are deployed, undermines comprehension, control, and predictability of actions that users, as entities, may engage in. Thus the study of more complex psychological processes is introduced, which allow the creation of a more abstract context of trust that fits into the scenario presented by the new services in the Information Society (Blackwell, 2002; Hoffman & Novak, 2015). In that sense, a new term that allows the differentiation of an original concept of trust with another definition that is more favourable to the new interaction scenario put forth seems necessary.

In English, there are two words with a similar meaning that can be used in this context: trust and confidence. In general, researchers specializing in HCI or technological acceptance have utilized both terms indistinctly. However, the intrinsic connotations of each term allow their differentiated use. Although these terms are related, several authors establish key differences, which show us the necessity of approaching them separately. Luhmann explains in (Luhmann, 2000) that trust is only developed when one knows the risks related to a certain type of action, while confidence is only possible if the subject in question does not consider any alternatives. In this way, Schoorman et al. in (Schoorman, Mayer, & Davis, 2007) argue that confidence is only present in cases of risk, uncertainty, and need for interdependence with another person.

The Collins English Dictionary defines the concept of confidence as *"a feeling of trust in a person or thing; belief in one's own abilities; or trust or a trustful relationship."* The Cambridge dictionary lists confidence as *"the quality of being certain of your abilities or of having trust in people, plans, or the future"* in British English or *"a feeling of having little doubt about yourself and your abilities, or a feeling of trust in someone or something"* in American English.

Additionally, depending on the context where the concept of confidence is applied, we find different functional definitions. For example, in the case of economics, confidence refers to those states where relationships between entities can be satisfactorily carried out (Polsky, Glick, Willke, & Schulman, 1997), meaning that the entities involved may control and manage everything that happens in that state. In the field specific to medicine, confidence refers to the relationship between doctors and patients (Crocker et al., 2013). In that sense, doctors represent entities of confidence for the patients, since they cover the needs of comprehension for the patients in relation to medical aspects. In both cases, experts, as entities with a high level of knowledge about the established relationship, generate a state of confidence.

Nevertheless, it was in 2008 that we found the first application of the concept of confidence to the field of computer science. E. Chang et al., in their report (Chang, Dillon, & Calder, 2008), established that facing a scenario constructed under the umbrella of ubiquitous computing and developed with pervasive technology, a change in system objectives was necessary. This new focus must be centred more on the activities and tasks that users were able to perform by using technology rather than the capacity of the technology itself. As such, this new scenario opposes the traditional focus where technology defines the user's capacity via its use, and establishes a new interactive context where the services have to adapt to the activities carried out by users. Due to the difficulty in understanding how a ubiquitous computing solution functions, users must trust that the solution functions correctly and in accordance with their expectations. Thus, E. Chang elaborates on the concept of trust/confidence to a cognitive state in the user, where their feelings and perceptions play an important role on their relationship with the technology, the services developed with it, and as such, its ultimate acceptance.

2.5 Study of the Relationship between User — Service/System

The paradigm change at the beginning of the chapter and the evolution of services offered in the Information Society offer new opportunities for interaction that present new challenges and opportunities for the development of

more efficient and accessible services. These challenges and opportunities should be addressed from the initial stages of development with a detailed analysis of user needs and wants, during the design phase of the proposed solution. Thus, the field of interdisciplinary development presented by Interaction Design (IxD) represents an approximation of great interest for addressing this new context.

The area of IxD centres its efforts on the design of interactive solutions for giving support to the communication and relationship process of users with their environment and the solutions deployed to that end (Sharp, Rogers, & Preece, 2011). Which is to say, IxD tries to model and provide resources to manage the user experience in order to improve the way in which people carry out their daily activities (Thackara, 2001; Winograd, 1997). In this way, IxD presents itself as an interdisciplinary vision that is fundamental to all disciplines, fields, or study and development approaches whose objective is to create systems based on computing technology for individuals. Figure 15 shows this perspective graphically.

Figure 15. Relationship between academic disciplines, design practices, and other interdisciplinary field and their contributions to IxD (Sharp, Rogers, & Preece, 2011).

Commonly, IxD is confused with the Human — Computer Interaction (HCI) field of study. The fundamental difference between both concepts is that HCI represents a more focused and centred perspective, according to ACM SIGCHI, in the design, evaluation, and implementation of computing systems for human use and the study of the primary phenomena that surround them (Marsh, 1990). However, IxD represents a wider discipline than HCI, making use of theories, research and design practices for user experience for any type of technology, system, or product.

The study of user experience (UX), from its origins to the present, has undergone an evolution closely related to the same one undergone by the systems and products developed. It is necessary to comprehend the significance of the user experience concept and the contribution it makes to this Doctoral Thesis. UX is established as a fundamental element of interactive design and its correct management affects the final acceptance of a technological solution by its users. Thus, Activity-Centred Design (ACD) methods, as the evolution of User-

Centred Design, widely-used for traditional development in the Information society, turn out to be of special interest.

In the context of this Doctoral Thesis, IxD is used as a transversal instrument for analysis of the elements involved in the design of sensitive services, as shown in Figure 16.

Figure 16. Graphical representation of the Interaction Design discipline and its relationship to the concepts of Person, Service, and Smart Space.

2.5.1 User Experience

User Experience (UX) represents the central concept of IxD. It determines how a development behaves and is used by people in the real-world. More specifically, UX determines how users feel upon using a concrete development and the satisfaction obtained during the process, from a cognitive and social perspective. As such, the fundamental aspects that determine user experience are established, as shown in Table 3.

Table 3. Aspects Related to User Experience (Carroll, 2004; Sharp et al., 2011)

Cognitive/Psychological Aspects	Socioeconomic Aspects	Other Aspects
Usability	Social Capital	Health
Accessibility	Cultural Identity	
Aesthetics	Expectations	
Functionality/Utility	Status	
Contents		
Feelings towards Development		
Sensual and Emotional Attraction		
Fun		

User experience design has traditionally been used in the realm of web design. However, the boom of pervasive technology, the *de facto* installation of ubiquitous computing as a computing paradigm for the development of new services in the Information Society, and its inclusion in the users' living spaces via environmental intelligence, has generated a new shift in the study of this concept. The similarity between applications and web-based systems, with the Internet as a medium for communication, and pervasive services has favoured this fact.

As M. Kuniavsky indicates in (Kuniavsky, 2010), despite the fact that ubiquitous computing and the use of pervasive technology as a means for its physical development have been present since the beginning of the 90's, the complexity of its development and application have almost completely eclipsed all previous considerations on user experience. The fact of having kept interaction designers on the side-lines in the development of this paradigm has generated results that, by necessity, have not been useable or entertaining.

The lack of prior models of devices that combine computers and everyday objects means that user experience design for these new interaction elements had to start from scratch. Thus, the study of user experience, a key factor in the adoption of this new technology and the services that may be carried out with it, presents a series of challenges that experts consider essential in order to general acceptable products and services on behalf of users in the Information Society.

2.5.2 Activity-Centred Design and the Theory of Activity

There are plenty of design philosophies to assist system, service, and product designers in the definition of solutions that resolve the wants and needs of users. Some examples of these philosophies are behaviour-centred design, work task-centred design, objective-driven design, and User-Centred Design.

The most widely-used methodology, at an academic level (research projects and product design training) as much as at an industrial level (product design), is what is called User-Centred Design (UCD), proposed by Donald Norman during the 80's. User-centred or individual-centred design refers to the manner of designing products and services based on requisites extracted from user needs. This process starts by characterising the user or user group that is the target of the product to be developed and continuing as such throughout product development for satisfying these requirements. One important characteristic of this methodology is that the requirements are static, obtained in the analysis phase, and they model the user in the initial phases of development. The objective is to create a way for the users to complete tasks or activities in a manner that is almost completely tailored to their preferences, wants, and needs, defined and solidified *a priori*.

As an alternative to this version centred on user characterisation is Activity-Centred Design (ACD), where the design revolves around the activity that the user is going to carry out. Donald Norman also introduced this methodology at the end of the 90's as an evolution of UCD, with the goal of solving the problems detected in the old methodology. One of the main problems UCD presents is its minimum adaptation level of the implemented system or product to users that were not modelled during analysis stage. Detractors of the UCD, among them, D. Norman himself, determine that the design obtained via this methodology may turn out to be weak and less useable for an extension to other potential users not considered in the initial analysis.

In (Norman, 2005), D. Norman sets forth the main problems of UCD and how ACD can contribute to their resolution. Activity-Centred Design extracts the user from the group of activities, actions, and tasks that it intends on carrying out, centring the design on what the user would like to accomplish. Given that the target of the development is still the user, D. Norman considers ACD another step of UCD that is more adaptable to the evolution that services in the Information Society are undergoing.

Activity-Centred Design is linked to the theory of human activity, defined by the Russian psychologists Vygotsky, Rubinshtein, and Leont'ev (Engeström, Miettinen, & Punamäki, 1999). This theory determines how a person carries out a specific action from its conception as a thought, its transformation into intention, and its attainment as a group of tasks, actions, and operations. Its application to the field of HCI, and by extension, IxD, begins at the beginning of the 90's, whose maximum exponent was B. A. Nardi (Nardi, 1996).

The success of ACD springs from two fundamental reasons: the first being that this methodology is centred on the nature of the activity that is under analysis, and the second being the communication of intention between the designers and the developers. The future of a solution depends upon it adjusting seamlessly to the underlying activity requirements, supporting them in a way that is understandable to users. In this way, comprehending the activity guarantees, to a large extent, comprehending the solution. The activities are, after all, human activities, and as such reflect the possible range of actions, of conditions in which people are capable of functioning, and the limitations of real people. In addition to the need for modelling and becoming familiar with the user or users, ACD provides a profound knowledge of technology, of tools and the reasons why these activities are necessary.

UCD posits a focus centred on people individually or in small groups, improving things for them at a cost of what is worse for the rest. The more adapted a development is to the particular tastes, dislikes, abilities, or necessities of a particular target population; the less likely it will be appropriate for others. In the context of the new Information Society services, with highly changeable contexts, accessible by an enormous quantity of users, a focus of this kind becomes unthinkable.

The individual is a moving target, in such a way that a design planned for today's user could generate a design that is incorrect for the same individual in the near future. Services embedded in individual daily life implies that they should adapt to user evolution, adapt to their experience, and vary in relation to it. In addition, a successful product leads to new, unforeseen uses that tend to not be well supported by the original design. Keeping in mind this dynamic nature of services, where any task requires a sequence of operations and activities that may be composed of multiple tasks. Here is where the difference in focus becomes evident, and where the weakness of user-centred focus shows its greatest flaw.

HYPOTHESES AND OBJECTIVES

This chapter describes the conceptual bases that have defined the concepts for investigation as well as the general guidelines for performing the research.

3.1 Introduction

The proposal of the hypotheses as the basis for the research performed in this Doctoral Thesis has been carried out based on a set of assertions. These assertions have been generated from a synthesis of the concepts presented in the background section from the perspective of the problem taken on in this Doctoral Thesis, meaning, the adoption of sensitive services implemented via pervasive technology and deployed in intimate and private Intelligent Environments such as the Digital Home. They will be considered valid; given that they have adequate support in the existing scientific-technical literature.

The study of these assertions has allowed the detection of a series of needs that must be covered in order to be able to provide a viable solution to the difficulties addressed in this research project. The formalisation of these needs leads to a list of a set of research hypotheses and the objectives that specify and guide the research necessary for verification of said hypotheses.

Lastly, the scope of the research project in this Doctoral Thesis is presented, along with the areas of investigation involved in this Doctoral Thesis and their relationship to the work carried out.

3.2 Assertions for Research Development

Below are the assertions used as the basis of the investigation following the approach used for the exhibition of the background of the research.

Enabling Technologies	
A.1	Intelligent spaces should be interaction platforms between their users and the services deployed in them.

A.2	Pervasive systems and ubiquitous computing environments base their functioning on collecting the user's physical and social information. Similarly, pervasive systems try to adapt their behaviour to the user's context and the physical environment where they are used/deployed. The incorrect management of this information in such a way that the results obtained are different from those expected by the users generates rejection towards this type of technology.
A.3	The Digital Home, a special intelligent space where user expectations are very high and acceptance is quite critical and difficult at the time of deployment, represents an intelligent space that is appropriate for the research performed in this Doctoral Thesis.
A.4	The Digital Home is the focus of attention in Information Systems, because it represents an interesting space for the analysis of user behaviour.
New Services and Needs of the Information Society	
A.5	A sensitive service is one whose functioning is based, largely, on the collection and use of sensitive data from its users, such as information relative to their health, daily activities, etc.
A.6	A pervasive service is an ICT service that is geographically delocalised in such a way that the abilities offered to the user persist through various spaces via the adequate adaptation to characteristics unique to their acting context.
A.7	E-Health services, especially Telemedicine, are valid examples of sensitive services that can also be deployed in intelligent spaces to improve acceptance by users.
A.8	Health and wellness systems require a change in the service supply paradigm from a hospital-centred focus to a user activity context-centred focus.
A.9	Users must play a supervisory role within the computing paradigms offered by pervasive technologies. This role allows the user to continue to be involved in the process, though without affecting the functioning of these services, which are generally proactive and imperceptible.
Acceptance of Technology	
A.9	User acceptance is a key factor for the development of new solutions that manage sensitive data in intimate and personal spaces.
A.10	The trust that a user may develop towards a technological development represents an important determiner for managing that development's acceptance. However, a user's trust of a very sophisticated space where an elevated number of entities interact with others is somewhat difficult to achieve.
Interaction Design	
A.11	Interaction Design stands as a valid work discipline for the analysis and design of the user's role in sensitive services implemented via pervasive technology and deployed in intimate and private Intelligent Environments. This is because it acts as a transversal axis of analysis for all of the entities involved: individuals as users, services as a mechanism for development and intelligent spaces as a means of deployment for the implemented solutions and where users carry out their daily life.

From analysing the previously presented assertions, a group of needs has been obtained that must be addressed in order to promote the spread of new technological solutions in society:

N.1	A service that affects personal and intimate aspects of its users requires inclusion of these aspects in its development. It is necessary to find adequate models for efficient
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	inclusion of the user in solution analysis and design processes.
N.2	The inherent complexity of developments based on ubiquitous computing, pervasive technology and Intelligent Environments that affect intimate and personal aspects of their users presents the need for a new conception of the term trust that includes more complex cognitive aspects in its administration and definition. In that sense, the inclusion of a new term in the Engineering and Computer Sciences context demands its operationalization, with the objective of being able to be included in the solution development process as well as its administration.
N.3	Acceptance management of sensitive services must be carried out from their conception, being included in the initial stages of problem analysis and solution design.
N.4	The inclusion of acceptance management in the design stage requires concretion of guides, methods, or models that help the developers to introduce acceptance requirements in this process.
N.5	The pervasive sensitive services deployed in an intelligent environment represent the intentions of a user and, as such, should guide the objectives of the environment and not vice-versa.

3.3 Underlying Hypotheses

The research hypotheses that have made up the basis of the research carried out in this Doctoral Thesis are elaborated upon at length as a concretion of the assertions listed in the prior section and the needs extracted from their analysis. These needs establish that via a focus centred on individuals, more personalised and implanted into their daily lives, the services developed under the umbrella of pervasive technology present a series of benefits that must be taken into account for the future development of critical systems, such as those for health and wellness. However, the inclusion of these new services in individual daily life may generate a lack of trust and rejection in relation to how management of the captured information is carried out and the results obtained from use compared to what was expected.

The utilization of these new services, sensitive and pervasive, for the definition of a new model of health and wellness service provision away from a focus centred on hospitals to a user activity context implies restrictions related to the users themselves. Using ubiquitous computing and intelligent environment techniques as support for the deployment of this type of services implies that spaces generally considered intimate and familiar, such as the home, workplaces, or education and child development centres, may change their perception of security and confidence. As such, acceptance of pervasive solutions that affect information that is highly sensitive for users represents a fundamental aspect in the development of e-Health and Telemedicine services and systems. Because the group of spaces where users carry out their daily lives is large and includes different characteristics, it has been decided to use the space that we know as the most restrictive, the home. Likewise, we believe that the restrictions imposed by the home facilitate the extrapolation of the results obtained in this Doctoral Thesis and the service provision model to the rest of users' living spaces.

Following, the research hypotheses that have been studied in order to resolve the problem addressed in this Doctoral Thesis are listed.

Hypothesis 1: *Confidence is a key factor in promoting the acceptance on behalf of the user of sensitive services deployed in smart domestic spaces.*

The traditional technological acceptance models such as TAM1/2/3 or PTAM indicate trust as a key element for modelling the degree of adoption for a technical solution and its final implementation. However, this concept has been studied from the point of view of binary communication (between two well-defined entities), where the user (one of the entities) interacts directly with one single technological device (the second entity). Scenarios that propose ubiquitous computing and the use of pervasive technology establish contexts for study where the user is immersed in a space composed of an indeterminate group of computational elements, being able to establish the non-binary communication relationships mentioned earlier. In this scenario, the original concept of trust applied to computing systems does not work to transform it within design criteria, since it would be necessary to characterise and adjust the variables that affect this trust for each possible binary relationship.

The evolved concept of confidence, as a psychological state of the user, allows focus on the design and validation of those Intelligent Environments in a systematic manner. The psychological state of the user is the same, independently of the number of agents existing in the intelligent space. Additionally, it allows the inclusion of other important aspects in its study relative to the perception that each user has of the environment where the services are deployed, such as familiarity and intimacy. By studying the concept of confidence as a psychological state, we attempt to facilitate the systematization of the transformation of intimate and personal spaces, such as the home, into Intelligent Environments accepted by the user that favour the deployment of personalised sensitive solutions via pervasive services.

Hypothesis 2: *Understanding, control and intuitiveness are indicators of the level of confidence developed by users and can therefore be used to model and manage the user acceptance of pervasive sensitive services.*

In psychology, variable management may occur via its operationalization into atomic indicators. These indicators represent the group of sub variables that determine the value of the variable studied in a certain context. Confidence must be able to be measured so that it can be included in the engineering process. This implies a knowledge of its sub variables. Through the literature review carried out in the background research, three atomic sub variables were handled in order to determine this confidence: comprehension, control and intuitiveness. In addition, these three sub variables are measurable via classic psychological tools and usability techniques. Here it is attempted to show that, with these three sub variables, the degree of user confidence can be determined in any given situation.

Hypothesis 3: *A smart environment designed from interaction patterns that promote understanding, control and intuitiveness of the sensitive services deployed improved the confidence of users.*

Interaction design has been presented in the research background as a key discipline for addressing the problem studied in this investigation from the initial stages. In that sense, interaction patterns offer a design and implementation

solution to intelligent space developers as a basis for the deployment of sensitive pervasive services.

Interaction patterns, commonly studied in the realm of Web Engineering and user interface development, determine an abstract solution for a concrete problem. This solution is represented by an open design model in the form of a guide for the developers in such a way that they can design concrete solutions for common problems. In general, a design pattern determines how a concrete problem should be addressed in such a way that in addition to being effective, it should be reusable. Thus, design patterns offer reusable design elements in order to avoid repeats in the search for solutions to concrete problems and to standardize, inasmuch as is possible, the way in which the solution design is carried out. Similarly, the use of patterns must not force design alternatives before others and thus eliminate the developers' creative process.

It is attempted to demonstrate that interaction patterns play a fundamental role in determining the minimum group of problems associated with the design of adequate Intelligent Environments for users in terms of acceptance as well as to provide the developers with a design guide for the creation of solutions that promote confidence in end users.

Hypothesis 4: *The design principles necessary for the creation of solutions aligned with fostering user confidence can be embodied in the form of functional software architecture for use in the design of future applications.*

The software architecture of an IT system makes up all of the system's structure, including the description of all of the software elements, their properties and the relationship between them (Bass, Clements, & Kazman, 2003). The object of software architecture is to define a structured solution that complies with all of the functional and operational requirements that are involved in the development of a specific type of service or system (Meier et al., 2009). Other aspects, such as private details of the elements that the architecture is composed of and that are related to internal implementation are not part of the architecture (Bass et al., 2003), and will remain outside of the scope of this research.

It is attempted to demonstrate that the characterisation of the concept of confidence may be reflected in the form of software architecture. This point is important since software architecture, if it is well-defined, becomes a reference point for the implementation of the ultimate solutions. Validation and verification of a software architecture, a process necessary for studying the hypothesis of this research work, is a complex task. A commonly used approximation in the development of these solutions is verification via case studies. Methodologies based on case studies are widely-used in the fields of sociology and psychology, their functioning based on qualitative techniques for result analysis. In this way, it will be necessary to validate and verify the hypothesis presented via a full case study that allows viability analysis of the generated software architecture.

3.4 Objectives

The objectives aimed at evaluating the presented hypotheses are formulated at length. To this end, a primary objective that defines the principal guidelines of the research project has been established as well as some specific objectives that

solidify the primary objective with evaluable results and operative objectives aimed at establishing action plans that are specific to their development.

3.4.1 Main Objective

The primary objective of this research project, which is focused on developing new services in the Information Society, is the following:

Contributing to the promotion of the acceptance of new pervasive and personalized health services and their deployment in smart domestic environments through a design framework that promotes a psychological state of confidence in users.

Use of a design framework to define pervasive sensitive services as much as the intelligent spaces where they will be deployed, attempts to facilitate the development of new health system models from the perspective of technological acceptance by end users. This focus must allow for an optimal degree of adoption for proper implementation in the user's everyday context.

This project has centred on domestic environments as a particular example of users' everyday context, and more specifically, the Digital Home. The Digital Home, due to its capacity to promote individual quality of life and the cognitive restrictions that it has in relation to intimacy and privacy, can be used as a study tool to channel and catalyse access to the analysed pervasive sensitive services. These requirements and characteristics define the Digital Home as a concrete case of intelligent space whose study can be extrapolated to other intelligent spaces.

Lastly, within the group of pervasive and intelligent sensitive services, this thesis will focus on the area of health, since it represents a highly sensitive group of services that directly affect the proper development of people's daily lives. Again, this particular study may be extended to other areas where it is possible to develop sensitive services.

3.4.2 Specific Objectives

The primary objective of this Doctoral Thesis requires greater conceptual concretion in order to allow for evaluation and analysis of results. This concretion materialises in a group of specific objectives:

1. Characterising the feeling of confidence from an engineering point of view for its measurement and modelling. This is an important characteristic for the inclusion of a term unique to other fields of investigation, such as psychology and cognitive sciences, in the process of solution and service development in the Information Society context. This characterisation should be performed via definition of a group of indicators that permit technical administration, as well as for differentiation for the term *trust* commonly utilized in the realm of engineering.
2. Defining and characterising pervasive sensitive services as catalysts for the deployment of Telemedicine and e-Health services in the Digital Home. As such, this objective deals with providing meaning and sense to the pervasive sensitive service concept in the context of development and promotion of the Digital Home.

3. Contributing to the inclusion of Interaction Design in the paradigm of ubiquitous computing and ambient intelligence through the design of models, guides and patterns of Person - Smart Environment interaction. Inclusion of Interaction Design allows matters relative to User-Centred Design to be addressed in the process of sensitive solution development. In particular, the patterns of interaction exemplify a widely accepted design solution for modelling communication requirements between users and computing systems and allow for the inclusion of psychological and cognitive aspects in engineering solution development.
4. Providing development-based software architecture design models focused on activity to ensure proper deployment of sensitive services in smart spaces in a confident way. This architecture represents a design guide for sensitive service developers and operators for acceptance and final adoption management.

3.4.3 Operative Objectives

In order to carry out the previously mentioned specific objectives, operative objectives are defined. These objectives will be listed in the research methodology used for this Doctoral Thesis, expounded upon in the next chapter.

1. *Holistic and functional definition of the concept of confidence.*

This operative objective offers a formal analysis of the concept of confidence from a psychological point of view and centred on individuals, and its translation into a technological context for its use in the engineering field and its differentiation from the concept of trust, widely-used in this context. In order to do this, it is necessary to analyse what factors intervene in confidence generation in terms relative to Interaction Design and provide a minimum indicator group from which this state must be modelled for its direct application in pervasive sensitive service design. The results obtained from this objective will be aimed at verification of hypotheses 1 and 2.

2. *Definition of a design framework aimed at generating confidence in users of the developed service or system.*

The design framework must be of assistance to analysts, designers and developers in such a way that they become a guide aimed at the creation and deployment of pervasive sensitive solutions that are appropriate for users in terms of acceptance. The guide will be focused on health and Digital Home services, even though it will be carried out in the most generic way possible so that it may be reused in other environments and services. This design framework will be materialised in specific design patterns as much as in a reference software architecture. Proper attainment of this operative objective is aligned with research hypotheses 3 and 4.

3. *Verifying and validating the hypotheses using experimentation.*

Experiments will be carried out to found the conclusions obtained in the thesis. These experiments will be of a different nature depending upon the type of result they are applied to. Thus, in the first operative objective, it is necessary to design qualitative experiments that are unique to the field of psychology, though tailored to the aim defined in this research project.

In the case of the operative objective related to design frameworks, developments aimed at satisfying their requirements and showing their technical and conceptual viability will be carried out. The results obtained via execution of the experiments will be validated with combined qualitative and quantitative analysis techniques. To do this, the System Usability Scale (SUS) will be used as a basis for analysis, as well as the existing technological acceptance models.

3.5 Scope of the Research and Areas of Work

The research project presented is aimed at promoting acceptance of the pervasive sensitive services that are deployed in intimate and personal Intelligent Environments. Just as was mentioned in the primary objective, given the impossibility of addressing all possible environments in detail, we have opted to go into the specifics of the Digital Home. Likewise, we have opted to study Telemedicine services and e-Health systems and the use of pervasive technology in their development as a concrete example of pervasive sensitive services. After adequate discussion, updating and modification, the results obtained in this Doctoral Thesis may be extrapolated to other contexts such as workplaces, hospitals, or educational environments.

The previously suggested objectives cover three different areas of action and research, which are commonly addressed independently. These disciplines are:

- Interaction Design. This area encapsulates anything referring to the design of communication relationships between users and devices or systems, with the purpose of generating a pleasant user experience
- Development of Services for the Information Society. The socio-economic characteristics and requirements that services should have for their inclusion in the Information Society, as well as the technology, processes and methods that are most appropriate for satisfying the needs and wants of individuals, are investigated
- Psychology and Technological Acceptance. Study and analysis of the cognitive characteristics involved in the adoption and use of a specific technology by users

This Doctoral Thesis offers a transversal solution to all of these areas of action with the goal of providing solutions that can be effectively integrated into individuals' everyday life and maximise the benefits that they offer a priori.

METHODOLOGY AND MATERIALS

This chapter describes and founds the research method used in the development of the Thesis, detailing the stages that said method is composed of and the kinds of results expected.

4.1 Justification of the Research Method

The study of such a complex problem as promotion of the acceptance of pervasive sensitive systems in users' intimate environments must be addressed from an interdisciplinary focus. This type of focus implies, in turn, the definition of a research method that is aligned with the different disciplines involved. In this Doctoral Thesis, the primary disciplines involved are related to engineering (above all, information system engineering), social sciences (sociology) and behaviour sciences (psychology).

Promoting acceptance, materialised in this thesis as strengthening the user's emotional capacity, implies the study of human behaviour as a user and its relationship to communication with the Information Systems involved. Thus, this knowledge must be applied in a technical and precise way to obtain a viable solution that allows for its application in the everyday life of these users within the framework of a more and more technical society.

The Royal Spanish Academy defines Science as "A knowledge cluster obtained via observation and reasoning, systematically structured and from which principles and general laws can be deduced." In this way, the model presented, as a union of scientific and engineering techniques and methodologies, attempts to take advantage of, and apply the knowledge obtained through, theoretical observation and analysis of the problem in this thesis, in order to define the group of hypotheses and research objectives that guide the development of the a complete and practical solution. The following sections of this chapter go into detail on the method developed for research and the stages that define it.

4.2 Research Method

The intrinsic complexity of the problem being dealt with in this thesis determines the research method that is necessary for its solution. This problem introduces connotations to the research being carried out that are unique to various fields of study, such as engineering and social sciences. This makes it necessary to follow a research method that allows us to join these characteristics in order to achieve the research objectives. Thus, the method created for this thesis, compatible with the scientific method, has been adapted to information system engineering via the inclusion of the development and perfection of devices as a means of validation of said problem. Figure 17 shows the fundamental structure of this method. More specifically, the research method defined for this thesis is founded on the following stages:

1. Observation and analysis of needs and generation of research motivation
2. Theoretical analysis and characterisation of the problem
3. Generation of working hypothesis and research objectives
4. Validation via development of artefacts and experimentation

Figure 17. The research method as followed in this thesis work.

The beginning of the research for this thesis is determined by, and based upon, the knowledge the author has acquired during his work as a researcher in various research groups before beginning this Doctoral Thesis. This initial knowledge has been used in order to contextualise the problem that the thesis attempts to solve.

4.2.1 Prior Knowledge

The first stage of research undertaken in this thesis was founded on analysis of the author's previously acquired knowledge, projects completed by the thesis supervisors, and the background context that frames this project. Specifically, this phase has attempted to observe and put into question the established communication and use relationships between target users and Information Systems developed with pervasive technology and/or ubiquitous computing,

when these are introduced into individuals' daily life. This analysis was formalised in the research project *Autonomía Sugestiva para la Tercera Edad* (Suggestive Autonomy for Seniors [AS3E]), financed by the Cátedra para la Mejora de la Autonomía Personal, Telefónica-Universidad de Alcalá (CAPTA), for which the author of this thesis was codirector.

The AS3E research project developed an Intelligent System for the Home aimed at helping to improve the autonomy of the senior subgroup of the population. The objective of this project was to promote motivation in individuals of advanced age to practice physical and mental activities through suggestions and proposals, as well as a means of assistance in completing daily tasks. With this goal, and by means of pervasive technology and ubiquitous computing, daily objects acquired an important role in generating motivation in end users.

By using an Intelligent System, older individuals can easily access the information services that surround them in the home as well as within the community or the neighbourhood. These services were presented through different information flows adapted to the sensory capacities of each user, while encouraging, through suggestion, activities that would allow these users to be mentally and physically active without imposing any rules or activities, thus maximising its use and efficacy. The system was conceived as a hardware entity where modular and extendible pieces of software could be executed according to the suggested activities. Thus, the system was capable of carrying out basic reasoning at the different and heterogeneous information entrance points, offering exit points personalised to the individual's needs and using interaction channels adapted to their sensory capacities.

Because of the project, it was possible to carry out an acceptance and usability analysis of this type of systems with older (65 and over) users. The study of the analysis performed was founded on a user study centred on three fundamental aspects of old age: needs, habits and abilities. The population group was composed of 17 women and 8 men, regulars at a municipal centre for the elderly (C.M.M. San Francisco, Madrid, and Centro de Jubilados de Cabanillas del Campo [Cabanillas del Campo Retirement centre], Guadalajara). The ideas and observations taken from this study that served as a basis for observation and analysis of the context for this thesis are the following:

- The elderly accept pervasive services independently of their complexity and technology, even if they affect sensitive data, as long as these services are included in their daily lives in an unobtrusive and transparent way.
- Empathy, and specifically, suggestions, are an appropriate way to communicate with these end users.
- Final acceptance is closely linked to the type of technology used to carry out the prevalent services in terms of familiarity and comprehension.
- Confidence emerges as a key factor for promoting user acceptance.

Lastly, the research work carried out in this project was validated by the scientific community in an effective publication and two end of degree projects, for which the author of this thesis was a director.

4.2.2 Observation and Motivation

This stage of research was centred on observation and analysis of the needs related to the results obtained during research experiences prior to the presented thesis and the generation of the motivation for this research. This stage has been presented in Chapter 1 of this dissertation as Introduction and Research Motivation.

4.2.3 Theoretical Analysis and Characterization of the Problem

In this stage, analysis and theoretical review of the concepts and ideas offered from the previous stage is completed. This process was implemented by systematic review of the literature and related research work. Review is focused on three fundamental axes:

1. Theory of human activity and Activity-Centred Design models;
2. Technological acceptance and prediction models for Acceptance of both Traditional and Pervasive/Ubiquitous Information Systems;
3. Challenges and requirements for the implementation of sensitive services in the Digital Home as a specific example of personal intelligent space.

The results of this systematic analysis have been presented as background research performed for this thesis (see chapter 2).

4.2.4 Generation of Hypotheses

Due to the transversal nature of the research performed, it is necessary to define a minimum hypothesis group as a predictive means for the extraction of a series of conclusions for the foundation of the research carried out in this thesis. In addition, the research objectives were defined, unique to the engineering field, to guide and supervise the work carried out and guarantee that the proposed solution is attained, and that it is relevant to society.

The previous stages, outlined in Chapters 1 and 2 of this thesis, have been used to determine the group of working premises used in this stage to generate the working hypotheses as well as the research objectives for this thesis. This work has been outlined in Chapter 3 of the Thesis memory.

4.2.5 Validation Stage

The validation process performed in this thesis has been organized with a cascade development model, as shown in Figure 18. Taking the hypotheses and working objectives obtained in the previous phase as the basis for research development, the artefacts necessary for the implementation of the pursued solution were designed, as well as the validation experiments necessary to evaluate these predictions. Specifically, the following work phases were established:

- Analysis of the hypotheses and objectives in order to operationalise the concepts that must be validated;
- Design the artefacts and technology used as part of the solution for this thesis;
- Design the experiments for verification of the working hypotheses;
- Implementation of the designed artefacts;

- And verification and validation of the results obtained in relation to the hypotheses and objectives indicated in the thesis.

Figure 18. Design of the validation phase.

Just as mentioned in this chapter's introduction, the method presented in Figure 18 for the validation of the research performed in this thesis unifies concepts typical of the scientific method, such as hypothesis verification via experimentation, and the development of solutions via methodologies taken from the field of Software Engineering.

In addition, the cascade focus applied has favoured the evolution and perfection of the developments performed through experimental evaluation. Thus, it has been possible not only to improve each developed technological artefact, but also to include new developments that are necessary to broach and complete the primary objective of the thesis and the solution presented.

The consequences of this stage of research have been grouped into three fundamental types of results: conceptual, technological and experimental, outlined in the following chapter of this thesis memory.

RESULTS OF THE RESEARCH

This chapter outlines the conceptual, technological and experimental results obtained in this Thesis. The holistic definition of confidence, its operationalization into indicators and its application to the promotion of technological acceptance via three typical engineering tools—a guide for requirement definitions, a software architecture, and some interaction patterns for Intelligent Environments—is presented and carefully described.

5.1 Introduction

The results obtained during research for this thesis and their evaluation has been organized into three groups, relative to their practical application: conceptual, technological and experimental. The conceptual results are aimed at obtaining the necessary theoretical basis in order to broach some of the problems presented with guarantees. The technological results obtain software artefacts and tools for direct use by the developers, which can be used both in the context of the thesis as well as in other contexts. Lastly, the experimental results correspond to the application of conceptual and technological results to a previously designed scenario in order to be able to analyse the validity of the initial hypotheses as well as the conceptual and technological results themselves.

The first conceptual result generated from this thesis is based on identifying the acceptance challenges in systems development in the context of pervasive technology and intelligent environments. One of this acceptance challenges refers to the user's confidence. In this way, the rest of conceptual results are focused on provide a holistic definition to this concept and its characterization to be included into engineering processes.

At the technological level, the first result presented is the concretion of a design framework oriented to developers, integrators and service providers to allow them cover all the acceptance requirements mentioned. This design framework is composed by a software architecture based on Activity-Centred Design methods as a support for the implementation of pervasive sensitive systems and set of interaction patterns necessary for defining confident communication relationships between final users and intelligent environments. From the definition of software architecture came the construction of a

demonstrative application that implies the third technological result. This application is a monitoring tool based on everyday objects for early detection of disabilities in children. In addition, this doctoral thesis provides as the last technological result an algorithm for visualization of complex signals that allows better feedback offered by monitoring systems.

Lastly, the experimental contribution has been focused on the validation of the previous results and the evaluation of their impact on the acceptance of a pervasive sensitive solution applied to the Digital Home context. To this end, the conceptual and technological results have been used as a basis for defining various experiments carried out in the Digital Home context and educational centres in Sweden.

5.2 Conceptual Results

This section describes the minimum set of challenges, in the form of requirements, which any development must address in order to promote the acceptance by users of sophisticated applications such as those presented in this doctoral thesis. One of these requirements and is object of study of the thesis is the confidence. Thus, this section outlines a complete holistic definition of the term Confidence used during the research in this thesis, as well as its operationalization. This contribution possesses a double objective. Firstly, to discern between the concept of Trust, widely-used in the computer sciences field, and the term Confidence, related to clinical and psychological areas. Secondly, a complete definition is presented that is based on atomic indicators with the goal to provide a means to manage the concept. Additionally, this definition is specified for inclusion in engineering processes, characterizing the term in a set of atomic indicators with the aim of providing a means of management.

5.2.1 Acceptance Requirements

As it has been previously mentioned in this thesis, the pervasive service on which all of this research is based is an electronic health service, more specifically, Telemedicine. These services are significant examples of the concept of a pervasive sensitive service treated in this thesis.

The development of a Telemedicine service that allows for the effective, secure, intuitive and simple integration of the different roles that come into play in a clinical or healthcare practice is a task that presents serious challenges (Berg, 1999; Brebner, Brebner, & Ruddick-Bracken, 2005; Broens et al., 2007; Huang, 2011). The incorporation of detection and sensor technologies, at times intrusive and incomprehensible for non-technical users, presents additional challenges due to immersing users in highly sophisticated environments such as intelligent spaces.

In the realm of intelligent spaces, this research focuses on the Digital Home. At the academic and industrial level, the home is thought to be the appropriate medium for the development of Telemedicine and assistance solutions (Aarts & De Ruyter, 2009), since one of the fundamental functions of this type of spaces is to allow for continuity of care.

One literature review of Telemedicine solutions and technologies deployed in the home shows that the majority of new contributions have included the adaptation of detection technologies that are used in other applications. However, both sensitive services and the Digital Home possess characteristics

that significantly alter application requirements for technology in other areas of study and application.

Several authors have defined a group of requirements related to the development and deployment of services in Intelligent Environments (Berg, 1999; Brebner et al., 2005; Broens et al., 2007). However, these requirements only refer to the needs of Intelligent Environments and do not provide adequate description and personalisation for the development of pervasive sensitive services, such as Telemedicine services and their deployment in the Digital Home. From the systematic review performed for this thesis, a minimum group of requirements necessary for the deployment of pervasive sensitive solutions in the Digital Home is proposed:

R1. Installation of Devices. Current solutions allow for easy device installation by users. However, the solutions lack the rigour required for medical applications, and due to this, technological integrators must participate in the majority of cases. Technological integrators must verify that the installation functions properly.

R2. Interaction with the User's Home. The patterns of interaction and the logic of the application are closely related in most applications. As such, a change in application logic implies changes in the user interface and vice-versa. However, this model does not fit well with the Telemedicine solutions in a Digital Home. Domestic users are used to learning interaction patterns and do not handle significant changes well. The final design must undo the strong connection between logic and interaction.

R3. Evolution of Solutions. Any ICT-based solution must be considered an artefact that evolves according to the experience of its users. Its evolution must allow the addition of new characteristics to already-deployed solutions and changes in the real behaviour of the application based on the acquisition of technical abilities and user confidence (Woods, Johannesen, Cook, & Sarter, 1994).

R4. Resilience. The final use of a technology depends on the analysis and design of the solution, its foreseen use and how users decide to use it. There are cases where technologies have been used successfully but in a different way than originally intended (Woods et al., 1994). As such, the correct deployment of pervasive sensitive services must take into account the user's experience as much as the possible variations in technology use.

R5. User Confidence. A key aspect is the confidence that users may develop towards the solution. If this aspect is not taken into account, acceptance of the proposed solutions will be limited, especially in cases where real alternatives exists that provide a similar service. This is considered to be one of the primary reasons for the limited impact of current Telemedicine solutions (Broens et al., 2007). As such, solutions must be able to respond to a user's apprehensions with the goal of improving their confidence in the system.

Currently, implementation methods exist that cover some of the requirements established in this result. However, no reference design solutions, such as software architecture or *frameworks*, have been found for developing systems aimed at promoting confidence in end users. Defining a robust architecture that takes the expressed requirements into account could be a huge advance for the development and deployment of Telemedicine services, which not only allow effective use by a specific user at a given time, but also a wide range of users whose abilities may evolve with time. In Annex 3 of this thesis, a comparison between the requirements expressed here and the requirements laid

out by Becker in (Becker, 2008) on intelligent assistance systems appears. The objective of this comparison is to verify the usefulness and viability of the requirements expressed in this result.

5.2.2 Definition of Confidence

As we introduced in the presentation of the requirements for acceptance, User Confidence is a key aspect for the implementation of the sensitive intimate and personal services in intelligent environments such as the Digital Home. This section presents the lexical and functional definition of the term Confidence so it can be differentiated from the term Trust, commonly used in the area of Computer Sciences and ICT. As indicated in section 4.2.3, this study has been carried out with systematic analysis of the related literature and previous comparisons made by other authors.

In general, researchers in the field of Computer Sciences and ICT have used the terms *trust* and *confidence* indistinctly. Despite the fact that the two terms are related, several authors establish key differences for handling them separately and in different contexts. Luhmann explained in (Luhmann, 2000) that the term *trust* may be applied if the subject knows all of the risks that a certain action carries, while *confidence* refers to a context where, in addition to being unaware of these risks, the subject has no way of considering alternative actions. In this sense, Schoorman et al. in (Schoorman et al., 2007) argue that *trust* is only present in cases of possible risk, uncertainty and need for interdependence with another person. Both authors agree that the term *trust* implies a significantly smaller cognitive load than a state of *confidence*, where emotions play a critical role in its establishment, introducing a subjective component to its definition. Thus, E. Chang et al., in their work, (Chang et al., 2008), for the first time indicated the need to broaden the concept of trust to include the user's cognitive state, allowing the inclusion of feelings and perceptions in the study of the user-technology relationship.

This need becomes stronger in the context of pervasive technology and Intelligent Environments. Said context draws a new field of study that does not allow direct application of the traditional functional definitions of trust/confidence without an adaptation. Additionally, the lexical definitions presented in the background chapter of this thesis are unclear from an engineering point of view, because they do not offer a method for concrete administration and measurement.

Figure 19. Representation of the concept of confidence traditionally used in Engineering and Computer Science.

The relationship of communication being studied, represented in Figure 19, commonly used in the field of IT Engineering and information sciences, determines that trust/confidence is directly established between a user and an entity. However, as has already been explained, this communication relationship

is not possible and lacks coherence in the context of ubiquitous computing and pervasive technology. Over the years, computing has based its operations on a bidirectional interaction model between the user and Information Systems, supported and reinforced by technologies such as computers. This technology offered developers a central element upon which to apply the concepts of trust already mentioned, facilitating its study and promotion. The boom of ubiquitous computing and the development of pervasive technologies has generated a new interaction paradigm where this central element disappears in pursuit of a communication space where the user find themselves surrounded by computing elements, that are generally autonomous and proactive.

In this way, and keeping in mind that trust/confidence is still determined by the capacity for comprehension of the relationship established between the user and an entity, the control that the user has over this relationship (Hoffman & Novak, 2015) and the predictability of the actions that the user, as well as entities, may undertake during this relationship (Rowland et al., 2015), may formally represent trust/confidence T_i as

$$T_i = U_i + C_i$$

where U_i determines the degree of comprehension and C_i the control and predictability that said relationship offers for a concrete relationship i .

Thus, in the context of ubiquitous computing and the development of pervasive services, the formal definition of trust cannot be expressed as before. This is because in these environments the total trust is not only an addition of multiple and isolated relationships of trust between the user and each device. It also appears new components related with the total amount of devices, the connection between them and the complete understanding of the interactions as a whole.

This formalisation may be graphically represented for a concrete number of pervasive elements ($n = 8$). As can be appreciated in Figure 20, the number of possible trust/confidence relationship in a pervasive and ubiquitous context grows indeterminately, causing a decline in capacity for comprehension and user control. Thus, this interactive context may cause a situation of uncertainty in the user. This uncertainty may inhibit the development of a state of confidence, generating fear and apprehension about the use of this type of technology, finally leading to its rejection. However, placing the user in a supervisory role, as Tennenhouse indicates in (Tennenhouse, 2000), it is possible to extract the human being from the computing process that ubiquitous computing and pervasive technology perform during a pervasive service. In this way, it is feasible to establish a state of confidence based on the general state of the system, determined by the supervisory action performed by the user. The idea underlying this role change is to provide another type of confidence that is more complex and abstract, which allows the user to trust the system in a general way, without going into detail for each of the possible communication relationships with each of the pervasive entities it is composed of. In addition, keeping in mind that the systems developed with this paradigm tend to affect intimate and sensitive aspects of the users, sensitive services, it becomes of vital importance to guarantee a state of full confidence between the user or users and the deployed system.

Figure 20. Representation of relationships of trust, according to the traditional conception of the concept in the context of ubiquitous computing and pervasive technology.

Because of all of this, and as the first conceptual result of this thesis, a holistic definition of the term *confidence* is presented for its application in the realm of pervasive technology in sensitive contexts, such as Telemedicine in the home. Thus, in this thesis, the term *confidence* is defined as a positive psychological state where the individual can establish a *trust* relationship with all elements involved in a pervasive system, human as well as technological. *Confidence*, as such, is established as a positive feeling because its goal is the acceptance of a solution by its users, centred on all of the possible relationships between individuals and technology. It is necessary to remember at this point that this type of sensitive services generally involve users, service providers, installers and pervasive technological elements and spaces where they are deployed.

Lastly, keeping these considerations in mind, the following holistic definition of the term *confidence* has been solidified for the context of this Doctoral Thesis:

“A psychological state of a person encouraged by a high level of control over and understanding of the behaviour of a system and the feasible relationships among all entities involved.”

5.2.3 Characterisation of Confidence

Once a holistic definition for the term Confidence has been established, it is necessary to characterize such term for its management and modelling. The characterisation of confidence allows for the establishment of indicators and criteria for incorporating the concept of confidence into the development processes of engineering products. The inclusion of the concept of confidence in engineering processes requires precision and operability, due to which the indicators must go beyond the lexical meaning, introducing elements that could be valuable and applicable at the time of design completion or system behaviour analysis.

This conceptual result proposes a first approximation at the creation of these indicators. From the experience of the author and the advisers for this thesis, as well as from a systematic literature review, three basic indicators have been defined: control, comprehension and intuition.

These indicators assume the individuals are only in a state of confidence if they understand and can control the interactions and relationships that may develop between them and the interactive objects that surround them. In general, a pervasive service is made up of a large number of devices and interaction elements, many of them imperceptible to the user, which operate at a higher speed than the human brain. In this situation, users run into difficulties in creating a mental map of the context they find themselves immersed in, and as such in comprehending the way in which said service is carried out. In this way, we propose placing the users a level higher than the computing process in order to simply and comprehensibly supervise all of the activities surrounding them (Tennenhouse, 2000).

The proposed indicators are described at length:

- A. **Understanding.** Comprehension is directly related to user expectations. Users understand an element, system, or technology when they come to know its usefulness, function, or object a priori and can prove the validity of that thought with the obtained results. As such, a pervasive sensitive service, and by extension the intelligent space where it is deployed, which is composed of its users, will behave and generate results that are very close to user expectations, independently of the technology used for this development.
- B. **Intuition or Intuitivism.** Intuition is a human faculty that allows individuals to comprehend things immediately, without the need for reasoning. To apply this concept to the Interaction Design context, it is necessary for the systems and elements of the technology to possess *affordance*, meaning they have the capacity to allow users to perform an action with them in a relatively simple way.
- C. **Control.** Control is users' direct interaction with services or spaces. When a user has a situation under control, it is because the user's intention has a clear repercussion on all of the system's results. Users control a system when they can act upon the system's behaviour directly or via the use of a tool. Certain interactions or uses can cause operational errors, and ideally, the system should adapt to such circumstances. This capacity is called control with recovery or resilience capacity.

The proposed definition for the concept of confidence is based on the observable properties extracted from the author's own and his thesis advisers' experience in the development of Telemedicine systems that are user-centred and deployed in real homes, as well as a systematic study of the related literature. Evidently, this result represents a hypothesis in its own right, whose verification is presented in section 5.4.2.

This result shows the possibility of extending the definition of confidence to the context of information technology and computer science. In addition, this result elaborates on the difference between the concept of confidence and the concepts of reliability and trust, commonly used in the field of engineering. This difference stems from the concept's own definition, which refers to a complex psychological state of the user that is formed and maintained by specific communication relationships between the user and the system in use.

5.3 Technological Results

The technological results presented in this section are an extension of the conceptual results presented in the previous section, providing specific tools within the field of engineering.

5.3.1 Reference Software Architecture

The complexity inherent to the development of Intelligent Environments that directly affect intimate and personal spaces, such as the home, and that must deploy pervasive sensitive services implies the necessity of using tools, models and guidelines for their design and deployment. Specifically, a software architecture or design framework works as a guide for integrators and developers whose goal is to support them in intelligent environment design and the deployment of pervasive sensitive services. In this way, it provides developers with a means of working that is aligned with the acceptance requirements proposed in this thesis (see section 5.2.3) in order to maximise final acceptance by the user/individual/inhabitant. According to (Sharp et al., 2011), a design guide provides an explicit link between how a system should operate, how it is presented to users and, therefore, how it is understood by them. Thus, the issues that a valid design guide must address are established:

- Steps to follow in the design
- Questions to answer with the design
- Definition of concepts involved in the design
- Challenges to cover with the design
- Design principles to follow
- Tactics
- Dimensions or limits of the design

These issues have served as a basis for the definition of the software architecture presented in this technological result. The design phases contemplated by the defined architecture are shown in Figure 21. These phases allow the work of the users involved to be directed during development of Intelligent Environments and the deployment of pervasive sensitive services as long as the previously defined acceptance requirements are accepted.

Figure 21. Design stages for confident Intelligent Environments to promote their acceptance.

The following sections describe in detail each design stage that the software architecture established for defining and building an intelligent environment and maximising user acceptance. The architecture specifics, such as the technological context, background and acceptance requirements, are described in Annex 3, which contains the related article in full.

Definition of Activities

The architecture presented has been centred on the interaction of the user with the environment as a key concept for promoting and facilitating the acceptance of pervasive sensitive services by end users. In that sense, the functionality described in this architecture reflects and agglutinates the previous work developed by the author and the terms presented as conceptual results.

The conception of an intelligent environment must be carried out from the perspective of a group of activities that users must or may perform in it. These activities are closely related to the group of pervasive sensitive services that must be deployed in the intelligent environment and, thus, the services that determine the scope of the environment. In this way, the first design step that the developers must perform is to detect what activities are involved in a sensitive service that will be deployed in an intelligent environment.

According to Activity Theory, which offers a model of human behaviour, every activity can be broken down into a finite group of actions and tasks. Robert Hoekman Jr., in this article (Hoekman, 2008), establishes a system of activity analysis for abstraction to the computing context called an Activity Grid. With this system, Hoekman proposed a simple method for identifying an activity in a system and its breakdown into tasks, actions and operations for processing.

Thus, he proposes analysing the activity "Listening to music while driving a car" as a case study. This activity is broken down into three tasks that the user can perform to reach their goal: select a radio station, listen to a compact disc, or turn on an external music player (cell phone, iPod, etc.). If their goal is to listen to the radio, and as such, the task that they perform is "select a radio station," the actions that they must perform is turning on the radio and looking for the desired station. Lastly, once the radio is on, the action "look for the desired station" goes along with the operation "push the station scanner button," until they find the one they want.

This hierarchical view of the activities a user can perform in a certain context offers a level of abstraction that enables the extraction of timeless requirements for the system to be designed and implemented. In this way, it is possible to determine the behaviour of a system in order to cover the user's needs while in use. If we focus our attention on the case study presented in the article attached in Annex 3 of this memory, control of the consumption of stimulating beverages ingested by a user with high blood pressure, we can define the following grid:

- Supervision of user's hypertensive state
 - Control of caffeine consumption
 - Record the number of coffees ingested by the user
 - Detect coffee machine use
 - Detect the user who uses the coffee machine
 - Record coffees made
 - Warn of greater-than-recommended ingestion
 - Compare number of coffees ingested and the established limit

- Emit a warning to the user

As a design complement to Activity Theory, the definition of this architecture's internal functioning has following the philosophy elaborated upon in the Activity-Centred Design method or ACD.

Formalisation

The formalisation of the activities defined in the previous stage must be performed under the protection of the Contract-Document defined by Iván Pau in (Pau, 2010). A Contract-Document represents a formal structure that specifies each of the activities to be performed by the entities involved, and as such, the communication relationship paradigm used between them. Additionally, all of the information necessary to be able to recover the transaction at any time and to help the user and entity in their decision-making regarding the transaction will also be included. In this way, the Contract-Document defines a contract proposal to be filled by the user as well as the rest of the entities involved in a pervasive sensitive service (installers, service providers, etc.) and that facilitates verification of its validity by the experts involved.

In this way, in addition to the characteristics expounded upon in (Pau, 2010) for correct definition of a Contract-Document, the group of activities that the system must perform will be included. This definition of activities will follow the formal outline presented in Figure 22. This outline not only determines the group of system activities, but also allows visualisation and supervision of each activity, so it is a trace document that must reflect everything that happens during the interaction process. In this sense, the Contract-Document is also used to define communication between entities.

Figure 22. Activity-Action-Process schema.

Following the example used in the article provided in Annex 3, the formalisation of the proposed activity would end up defined with what is shown in Text Box 1.

Text Box 1. Implementation of the “Register Caffeine Intake” activity using XML.

```

<activity>
  <id>001</id>
  <definition>Caffeine consumption register</definition>
  <others>Other information</others>
  <actions>
    <action>Register coffee</action>
  </actions>
  <events max_reg="20">
    <registry>
      <type>Coffee</type>
      <date>13/10/13</date>
      <hour>09:35</hour>
    </registry>
  </events>
</activity>

```

Adaptation

The adaptation stage is a collaborative process that implicates developers and installers with the supervision of operators of the services involved. During this design stage of the intelligent environment, the communication relationship between the devices involved and users of the environment should be established. Additionally, the developers and installers must include the formalisation of the solution carried out in the previous stage in the architecture proposed as the first technological result of this thesis. In this way, it is possible to identify what new devices are necessary to cover the needs defined or the necessary adaptations to combine the devices already used in a previous intelligent space. The proposed architecture design facilitates the adaptation of the pervasive sensitive services that must structure the intelligent environment, as shown in Figure 23.

Figure 23. Graphical representation of the deployment of a Telemedicine service in an intelligent environment using the developed architecture.

The central element of the architecture (CDH) is geared towards completing the service adaptation to the design context or intelligent environment. In order to manage the services deployed in the environment, the CDH performs an exploration of the sensors, actuators and applications in the environment in order to characterise and represent them as processes.

Once this process is carried out, the environment's Operating Units (HOU) deploy each basic service on the CDH, as shown in Figure 24. Each HOU implements the part of the intelligent environment of each sensitive service in the intelligent environment. In this way, the group of HOU's enriches the capacities of the environment with new capacities represented in the form of actions and processes obtained from physical resources (devices) of the environment itself, or new ones introduced by the installers. It is the work of the installers to carry out mapping, via drivers, between the devices and their abstract representation or processes.

Figure 24. Development of Home Operation Units from real daily objects.

5.3.2 Set of Comprehensible Interaction Patterns

The success of the deployment of generalised services in Intelligent Environments (IE) will be determined by their capacity to support the group of services offered to the user and how these adapt to the corresponding interaction patterns. As such, the relationship between users and IE represents a key factor in promoting final acceptance of new delocalised and personalised Telemedicine services. As such, the objective of this technical result is to define a group of interaction patterns as a new focus for modelling the relationship between users and IE, where sensitive pervasive services are deployed. In this way, this result represents a complement to the software architecture detailed and together, define a complete design framework for developers, integrators and operators of pervasive sensitive services deployed in the Digital Home.

In general, researchers have focused on low-level designs and developments, neglecting the human factors related to psychological aspects of the user. The interaction patterns offer an opportunity to involve users in the first design stages of pervasive services and the IE that will deploy the services. Additionally, interaction patterns allow unification of concepts originating from different areas of study, such as human factors, engineering and Interaction Design, in order to guarantee an optimal level of acceptance. Specifically, a group of interaction patterns offer a design guide for all actors involved in the definition of sensitive pervasive services and the IE for deploying them, including what questions the design should answer, its limits and the principles that will be used for the implementation stage. This technical result completes the framework proposed

in the previous section, providing a basis of Interaction Design for the adaptation stage.

In this way, the communication relationship that is established between the individual/patient/user and the IE, where the sensitive personalised services are deployed, is defined by interaction patterns. In the context of this thesis, interaction patterns are used as a tool to promote an optimal level of user acceptance regarding the sensitive pervasive services deployed in an IE by promoting a psychological state of confidence in the users. In order to achieve this, the interaction patterns presented in this section use the definition of confidence that was solidified in the conceptual results section, based on comprehension, control and intuition.

Classification by Interactions

As mentioned, according to Sharp et al., 2007, interactions can be classified into the following groups:

1. Training Interactions. Users send or give instructions to the system, orders.
 - a. Button presses
 - b. Voice Commands
 - c. Gestures
2. Conversation Interactions. Users establish a conversation with the system and vice-versa. These are QUESTION - ANSWER interactions.
3. Manipulation Interactions. Users interact with virtual or physical objects.
4. Interactions of exploration. Users move around within a physical or virtual environment. A physical environment can be a smart environment.

The following subsections show a more exhaustive definition of these types of interaction used for the later definition of confidence interaction patterns.

1) Instruction Interactions

Instruction interactions describe how users carry out a task by telling the environment how it should work. As such, an instruction represents a concrete action on the environment generated by the resident user. The environment processes said action, providing the resident user with the result in the form of feedback adapted to the restrictions set down in the Contract-Documents (C-D). This process should be recorded in the C-D.

Examples of instruction interactions are turning the system on or off, activating or deactivating a service, using an object in the environment, being involved in events in the environment. In this way, this type of interaction represents a simple and direct interaction that provides the resident user with control over the general behaviour of the environment. Figure 25 defines its sequence diagram.

Figure 25. Graphical representation of a sequence model for an instruction-type interaction.

2) Conversation Interactions

A conversation represents a dialogue between two entities with a concrete objective. Conversation interactions are based on the idea that an individual can converse with an environment in the same way that he or she could establish a dialogue with another person. As opposed to an instruction interaction, conversations involve a communication model in two directions, user to environment and environment to user.

This type of interaction is useful in the development of comprehensible interactions, since they allow the user to clarify any concerns that an activity might generate. In addition, the intelligent environment can use these interactions as a mechanism to personalise the services it holds. In general, conversation interactions are used so that an entity may obtain information from another entity, whether with the goal is supervising an activity or state, or adapting an action to the needs or preferences of the entities involved.

When the conversation is started by the resident user and aimed at the environment, it may be considered a supervision-instruction-type interaction, following the pattern shown in Figure 26. To supervise means to review the general state of the environment in order to determine if said state corresponds with the expectations that the resident user possesses of the service, system, or environment itself. In this way, the user is granted a method for controlling the intelligent environment and the services deployed within it that guarantees and maintains its offered computing capacities. The user cannot act on the internal processing of the services directly, but can manage the functioning of these services to be what they are expecting, to that end, maintaining a direct conversation with the environment.

When the conversation is started by the intelligent environment, the object is to adapt its behaviour to the current state of the resident user, meaning to complete or modify a specific aspect of the C-D. In this case, as shown in Figure 26, this conversation must end with feedback to the user so he or she may verify that it has been updated. The number of questions and answers involved in the conversation will be those necessary to be able to update the C-D, always under the supervision of the resident user. Figure 26 defines its sequence diagram.

Figure 26. Graphic representation of a conversation led by the Intelligent Environment.

3) *Manipulation Interactions*

Manipulating an object in an intelligent environment is a type of action-reaction interaction where the environment processes said action in order to generate a result based on the terms specified in the C-D. To do this, the user performs an action on an object with the goal of obtaining certain feedback. The object establishes a process in the environment that the intelligent space must analyse with the goal of generating a result in accordance with user expectations. This processing may involve an update of the C-D. In the end, the object communicates to the resident user the result of its action in the terms dictated by the intelligent space. As shown in Figure 27, feedback may be offered by the manipulated object, if it has the necessary means, or if not, through the environment.

The objects involved in a manipulation interaction offer the user a choice in how they are used (affordance). In this way, the environment can use said objects to interact with users intuitively, that is, by encapsulating complex actions from the services offered into direct interactions with everyday objects that the users comprehend and accept. In this sense, the objects in the environment are used to the extent of their capacities as interfaces that use the user's experience with them to improve the interaction between the resident user and the environment. Figure 27 shows its sequence diagram.

Figure 27. Process of manipulating an object involved in a service contained in the Intelligent Environment: A) Feedback using the manipulated object
 B) Feedback from the environment when the manipulated object does not have the means to communicate with the user.

4) *Exploration Interaction*

This mode of interaction is related to the way in which the resident user behaves within an intelligent environment. The space analyses the everyday activities its users perform within it with the goal of adapting its behaviour and assisting with their performance. There is no direct interaction between the user and the environment unless the environment is aware of the user's current context via sensorization of his or her activities. As may be observed in Figure 28, the sensor devices deployed throughout the environment capture the user's exploration, providing information to the environment. This information is processed by the environment and depending on the C-D, the intelligent space gives feedback to the user so that they may supervise any changes or events.

Figure 28. Process of contextual analysis in a confident intelligent space.

Patterns of Interaction

The authors in (Sharp et al., 2011) define all of the interactions that users can carry out with interactive elements, classifying them in four basic groups: instruction, conversation, manipulation and exploration. This classification and research work related to design pattern interaction, such as (Folmer, 2014) and (Coplien, 2004) have used the following definition of a group of confident interaction patterns as a basis: To define the patterns of interaction, we have followed the model proposed by Duyne et al. in (Duyne, Landay, & Hong, 2002). These directives establish a group of questions that should be answered by each pattern in order to correctly define it. These questions are:

- What problem do they resolve?
- When is a known solution needed?
- Why is it necessary?
- How is it applied?

Below is each of the patterns that make up this technological result.

1) Definition of the Greeting Pattern

Greeting pattern	
Problem	Users need to know if the intelligent environment can implement a given pervasive service and if they have been identified correctly.
Solution	The IE should inform its users if a pervasive service can be deployed in the environment and if that is not possible, the IE should indicate the reason for its impossibility.
Use when	Users come to an IE and are syndicated to a pervasive service.
How?	The pervasive service starts the conversation with the IE. Then, the pervasive services reports the activity associated with it to the IE, and as such, the actions that the IE should handle. As such, the IE knows what context it should create or what resources it lacks for adequate deployment. Once the IE determines the possibility of deployment, it reports the final decision to the service. If deployment is impossible, the IE informs the pervasive service that it lacks the necessary resources for proper functioning. Lastly, the pervasive service provides the appropriate feedback to users. This communication must be secure and private.

Why?	Users of pervasive services want to use them as much as possible. However, they must decide (control) when to start the service. Likewise, in the event that the IE cannot deploy the service, the user needs to know the reason (comprehension).
Other patterns involved	Depending on the devices used to develop and deploy personalised services, it may be possible to use other patterns of personalisation commonly used in web environments, such as sign-in, registration, or personalised windows.

2) *Definition of Farewell Pattern*

Farewell pattern	
Problem	Users need to know that all of the information gathered and generated by the IE during use of a pervasive service is encrypted and kept for future use, or deleted if not planning to return to the IE.
Solution	The IE should ask users if they want to store or delete the information related to the pervasive service that was collected by the IE. Whatever the response is, the IE should inform the user of stored or deleted data and the state of the process.
Use when	Users stop using pervasive services or leave the IE.
How?	<p>The pervasive service determines if the process is finalised, and as such, initiates the farewell process with the IE. If the users leave the environment, it is the IE that should begin the farewell process.</p> <p>In the first example, the pervasive service informs the IE that it has finalised and the IE should gather all of the related information in order to delete or store it, depending on the user's decision. In the event that the user leaves the environment, IE should ask the pervasive service what to do with the related information. In both cases, the IE should generate a summary of all of the activities involving the pervasive service and the information gathered. Lastly, the pervasive service provides the appropriate feedback to users.</p> <p>This communication must be secure and private.</p>
Why?	A farewell pattern offers users of pervasive services control over information gathering by independent entities. Sometimes, these pervasive services may handle sensitive data and, as such, appropriate storage or full deletion is necessary to assure final user acceptance. Thus, encapsulating this process in a farewell pattern helps users to understand that the process has finished securely and privately.
Other patterns involved	Depending on the devices used to develop and deploy personalised services, it may be possible to use other patterns of personalisation commonly used in web environments, such as log out.

3) *Design of the Action-Reaction Pattern*

Action-Reaction pattern	
Problem	The IE developed with ubiquitous computing, pervasive technology and environmental intelligence techniques hide their points of interaction from users. Sometimes, these points of interaction are encapsulated in everyday objects and remain unnoticed by users. However, users need to control and comprehend their relationship with the environment for accepting deployment of a pervasive service within it.
Solution	When an action performed by the user affects a pervasive service, the IE must provide feedback to the user through the pervasive service related to the action. Otherwise, the action does not provide feedback to the user.

Use when	The user performs an action in the IE or manipulates an intelligent everyday object.
How?	<p>Performing actions or manipulating intelligent objects in an IE means an action-reaction-type interaction, where the environment processes the action in order to generate a reaction based on the terms specified in the pervasive service.</p> <p>To this end, the user performs an action on an object with the purpose of obtaining concrete feedback. The object establishes a communication process that the intelligent space must analyse, with the goal of producing a result in accordance with user expectations. This process may imply an update of the pervasive service. Lastly, the object or environment will communicate the result of its action to its users.</p> <p>The objects involved in a manipulation interaction offer the user an idea of how they are used (affordance). As such, the IE may use these objects to interact intuitively with the users. This is achieved by encapsulating the complex actions associated with the services offered in interaction with the everyday objects understood and accepted by users. In this sense, objects in the environment are used, extending their capacities to create confident interfaces in order to improve interaction between the user and the IE via analysis of the user experience.</p>
Why?	<p>This model is based on Activity Theory, which determined that all activities performed by users are broken down into actions and tasks (Nardi, 1996). As such, the use of actions and tasks as design elements provides a new way to model IE from a point of view that is similar to human behaviour. This allows a better general understanding of interaction to be generated in the IE.</p> <p>Thus, it is possible to increase not only the calculation capacities of the intelligent environment and its objects, but also simulate the habitual physical behaviour of those elements when an action implies a reaction, which is communicated to the user.</p>

4) *Design of Conversation Pattern*

Conversation pattern	
Problem	In general, IE need to gather more information on users than what the pervasive service initially provides and therefore the IE should initiate a conversation with users. However, this process may generate suspicion or rejection from users if not developed transparently.
Solution	The conversation process should end with feedback to the users so they can verify that the information has been supervised and updated. All questions and answers corresponding to the dialogue between the user and the IE will be reflected in an accessible and verifiable document (such as the Contract-Document).
Use when	The IE needs to complete all information from the users that participate in the service with the purpose of adapting itself to the objective defined by the related pervasive service.
How?	The IE should provide the appropriate feedback to the user involved in the conversation, with the purpose of providing all of the information necessary to guarantee process supervision. As such, each question generated by the environment implies processing of the information obtained from the answer and final feedback to the user. The whole process must be recorded so the process information is accessible to users at any time.
Why?	Users cannot make direct decisions about the IE's internal computing process and the services deployed within. However, this pattern offers a control method to supervise the functioning of the environment through a direct conversation with the IE, maintaining the computing capacities it

	offers.
Other patterns involved	Depending on the devices used to develop and deploy personalised services, it may be possible to use other patterns of personalisation commonly used in web environments, such as customisable windows of feedback or visualisation patterns.

5) *Design of Exploration Pattern*

Exploration pattern	
Problem	This interaction pattern is related to how users behave in an IE. The environment analyses the activities performed by users with the purpose of adapting its behaviour and helping to achieve the goal set by the associated pervasive service. Generally, there is no direct interaction between the user and the IE when the IE is conscious of the user's current context via activity detection with sensors unnoticeable to the user.
Solution	All handling of the information collected by the IE sensors should be reported to users via the appropriate feedback.
Use when	Any sensor processes information related to activities performed by users.
How?	When the IE finishes the user information detection process, it provides appropriate feedback to the users with the group of activities analysed. Via appropriate feedback showing a summary of the user activities analysed by the IE, supervision of how the IE backs up the deployed pervasive services is permitted.
Why?	Supervising the invisible behaviour of the IE sensors, using appropriate feedback, increases confidence in User-Environment interaction.
Other patterns involved	In some cases, it may be useful to combine this interaction pattern with the action-reaction model in order to break down the actions involved in exploration activities.

5.3.3 *Confident Game Activity Monitoring*

The technological result presented in this item offers a direct implementation of the framework design presented during the previous sections. Specifically, it presents the development of an everyday object, a set of toys, with the capacity to process and communicate in order to monitor psycho-motor development in children. This toy was developed with fabric sensors incorporated as fundamental parts of the toy. In this way, the idea was to build a support element for the study and analysis of psycho-motor capacities of children and its inclusion in everyday activities, such as playtime.

Playtime represents an activity of vital importance for children's proper development. With the development of this everyday object, it was attempted to introduce a pervasive sensitive service, guided by the acceptance requirements elaborated upon in the previous section in the context of child's play.

Figure 29 shows an everyday implementation of a play activity carried out by children, where they interact directly with toys. The adults that are interested in controlling said activity may supervise it. In general, this supervision has to be direct and all entities must be present at the time of activity. The development of a pervasive sensitive service that monitors this activity offers the option of delocalising said supervision, allowing any entity to be involved in this process.

Figure 29. Playtime activity implemented with everyday objects.

Development of the intelligent toy presented in this technological result facilitates the implementation of the pervasive sensitive service mentioned in the way shown in Figure 30.

Figure 30. Pervasive sensitive service for monitoring playtime activities based on intelligent everyday toys.

Design details, such as physical and logical toy requirements, physical implementation of the fabric sensors and the communication protocol used for processing the information collected, are described in Annex 2, which contains the related article in full.

5.3.4 Confident Visualisation of Complex Outputs

The knowledge generated in this thesis is directly applicable to Telemedicine and e-Health systems. These systems are a representative sample of the group of pervasive sensitive services where personalisation and confidence play a fundamental role in their final adoption. Beyond the advantages that these services offer, this technological result shows how it is possible to generate a communication relationship between the user and the service according to the already-defined confidence parameters.

Feedback techniques traditionally have been used to directly involve the users in a specific system process. In this way, the developers are provided with a useful tool for promoting user compromise in those processes. Specifically, the visualisation of information is the most extensive and widely-used feedback technique in the Interaction Design field.

The visualisation of information represents the direct connection between the state of the system, a specific process, or a service and the user via an abstract representation. This representation should provide the user with the

information necessary to understand what is happening and offer them the option to act in a certain way, according to their preferences or needs. Thus, visualisation offers an ideal means for modelling the confidence that each user can develop against a service through comprehension, control and intuitiveness.

This technological result offers a tool for transforming complex information that is commonly related to services for monitoring physiological signals (respiration, electrocardiography, electroencephalography, etc.) comprehensibly and controllably via intuitive graphic representations. However, this process of signal transformation cannot be a diagnosis of the user's state, but may offer the option to supervise said state. Because of this, the use of colours or explanatory messages is discarded. However, representing the user's state with geometric shapes presents itself as an easily implementable solution that offers the user the possibility of intuitively comparing his or her current state with a previous one. Thus the result presented in this section uses polygons with N sides, where N = number of physiological variables represented, to visualise the current state of the monitored user.

The representation algorithm used presents the user with the monitored data history via mean values and their deviation. In this way, the user obtains a visualisation of his or her current state and a comparison with the values that normally tend to occur. In order to implement it, a mean of X values is obtained, 100 in this case, and typical deviation. With these values, the graphic area corresponding to the mean plus deviation and the mean minus deviation is represented. As the number of variables is 2, the polygon used is a rectangle, where two edges represent one variable and the other two, another. The red polygon shows the current state.

The history is also dynamic, so the mean and deviation are recalculated via the inclusion of the new values. However, when taking all of the values, or the majority of them, into account, the variations obtained in the area of the history are considerably less than the variations undergone in the current state. This allows users to compare their current state with their average historical state. Though it is not possible to diagnose through this visualisation, since that is not the purpose of the visual information, users can control and understand how specific physiological aspects evolve.

The algorithms elaborated upon in Table 4 show how complex data, represented by N vectors transformed into N -sided polygons, is handled. In the presented case, N is composed of two vectors, v and w , one for each physiological measurement being managed. With $N = 2$, the polygon used for confident representation is a rectangle where 2 edges correspond to a vector and the other 2 to another vector. For $N > 2$, each vector is associated with an edge.

Once the vectors are obtained, made up of an indeterminate number of values, they are handled with the *confidata* algorithm in order to extract the following variables:

- a as the mean value of the original vector
- b as the standard deviation of values for the original vector
- c as the normalised value of the mean plus deviation in order to form the exterior reference rectangle
- d as the normalised value of the mean minus deviation in order to form the interior reference rectangle

Table 4. Flowchart representation of the algorithm that transforms complex signals into confident feedback.

In addition, the original vector data is normalised by dividing each one into its values and their means, creating two normalised vectors, v and w . Lastly, three polygons are created, associated with confident feedback in order to visualise them. Figure 31 shows an example representation of two physiological variables, respiration and heart rate, using this technique.

Figure 31. Transformation of complex signals for confident visualisation with a 2-sided polygon.

5.4 Experimental Results

The experiments performed during this thesis for verification and validation of the specific objectives and proposed research hypotheses are presented in this section. First, the initial experiment is described, which was performed with non-everyday intelligent objects, robots, during implementation of interactions between users and sensitive pervasive services for Parkinson patients. The qualitative study is presented below. It was performed with potential users of

pervasive sensitive services deployed in the Digital Home to determine the incidence of potential indicators that should define Confidence. Lastly, the experiment performed in order to analyse the acceptance of pervasive technology for monitoring the psycho-motor development of children during playtime activities on two levels: an implementation level, with analysis of the development of a set of intelligent toys; and design level, via analysis of a group of interaction patterns for modelling user - system communication relationships.

5.4.1 Robot-Parkinson Interaction

This experiment defines an analysis exercise for possible Interaction Design between Parkinson patients and an artificial object such as the intelligent robot AISoy. It intends to determine the usefulness of NON-everyday objects for designing confident interactions between experienced users (not considered children or adolescents) and pervasive sensitive services deployed in an intelligent environment, in this case, the Digital Home.

For this experimental objective, it was settled to determine if robots, as intelligent non-everyday elements, are adequate for developing confident interactions between users of a sensitive pervasive service deployed in an intimate and personal intelligent space, such as the Digital Home. In order to perform the experiment, a three-phase research method was designed, as described in Figure 32.

Figure 32. Research method developed for the AISoy-Parkinson experiment.

The first phase of this experiment centres on the analysis of the requirements for the sensitive pervasive service implemented. In this case, the experiment was aimed at developing a functional prototype for tracking Parkinson patients while they carried out cognitive stimulation tasks and activities. It is a service that supports more complex developments such as DaleMOV (ubiquitous Service of cognitive stimulation accessible to Parkinson patients), in such a way that the intelligent robot AISoy represents each association's patient supervisor's delegated entity in intelligent homes.

The second phase of the experiment focused on the implementation of the sensitive pervasive service prototype, adapted for evaluation of solution acceptance by real users and definition of the qualitative study being performed. The developed prototype did not have complete functionality and was used as a complement to the study. This qualitative study was implemented via individual interviews, the object of which was to determine the degree of usefulness of the proposal, the viability of including an intelligent non-everyday object in the home and, finally, determining general acceptance of the proposal. To this end, 6

interviews with patients from the Asociación de Parkinson de Madrid (Parkinson's Association of Madrid) (N=6). 4 men and 2 women, age between 45 and 68 years old, were carried out. This stage of the experiment was concluded by carrying out the study in the Asociación de Parkinson de Madrid.

The last phase of the experiment was aimed at the analysis of the results obtained. These results showed that use of intelligent NON-everyday objects as a means of interaction between pervasive sensitive services and experienced users does not represent a valid option. To this end, experienced users must be understood as users whose life experience has created specific patterns of behaviour, such as adults. In this way, 100% of study participants did not show interest in the intelligent NON-everyday object used to implement the interaction. 80% of the subjects considered use of the AISoy robot interesting as a test element, but did not accept the idea of introducing it into their homes. Some of the most interesting reasons provided by these experienced users were the following:

- The intelligent NON-everyday robot or object does not go with the user's home furnishings;
- The intelligent NON-everyday object could be seen as a toy by the users' grandchildren, and as such could be broken during playtime activity;
- The intelligent NON-everyday object is implemented using cameras in its eyes, and as such the users felt watched at all time (loss of privacy).

5.4.2 Evaluation of the Characterisation of the Term Confidence

The experiment described below details the method of research designed and implemented for the verification of the operationalization of the concept of confidence already-defined in section 5.2.2 as a conceptual result. The main objective of this experiment is to determine the direct and real impact of the indicators Understanding and Control, largely related to confidence in the literature, in the context of ubiquitous computing and pervasive technology. In particular, this experiment is put forth to determine how Understanding and Control that users can develop on a pervasive sensitive service deployed in a smart environment affects the final acceptance of the solution on user's behalf.

The implementation of a pervasive sensitive service not only implies the management and processing of sensitive information but it also involves, in general, the use of invasive technology as support. An example of a pervasive sensitive service could be any number of services within the context of Telemedicine or telehealth. The technology that these systems use for the deployment of the associated services represent, in most cases, invasive elements that must monitor or observe the daily activities of people, such as example cameras, motion or fall sensors, etc. This technology not only captures sensitive information about users but also introduces psychological components about how they are perceived by the users themselves, such as a fear or rejection of surveillance. However, the reliability that this technology offers the efficiency and effectiveness of the system is high and can justify their use. Therefore, for the experiment described in this section a scenario composed of a Telemedicine service has been used, since it used technology that is highly intrusive for the deployment of a pervasive sensitive service in the private and intimate environment of the home.

The use of the home as a place for deploying the system used in this experiment represents, in addition to the restrictions imposed by the technology used, adding psychological connotations related to the perception that users have of their homes. The home represents a safe, reliable, controllable and predictable context for activity for its inhabitants. The acceptance of a sensitive solution, that deploys pervasive sensitive services in the home and that uses highly intrusive technology, must be complete in order to ensure correct operation. This means that users must not only adopt the system but also behave naturally, i.e. they have to continue their daily activities normally during the use of the system and the associated services. Thus, the construction of an evaluation scenario based on highly intrusive pervasive technology for the deployment of a sensitive service in an intimate and personal context, such as the home, offers a set of restrictions sufficient to develop the objective of the experiment.

A three-phase investigation method was put forward for the experiment, as described in Figure 33. The first phase focused on the definition of the scenario and the questionnaire used for the qualitative assessment. In addition, both the scenario and the questionnaire were perfected iteratively through group interviews (n=20) carried out on potential users of the experiment. These interviews provided improvements concerning the type and number of questions in the questionnaire, grammar and the definition of the scenario to reliably and faithfully represent a home's living space. The second phase of the experiment focused on the implementation of the study on a long scale with a set of users N=160 via the Internet. For this, an on-line interactive questionnaire was implemented to make it easier for the largest number of potential users to take it. Lastly, during the third phase, a deliberative study was carried out with a set of N=10 users, experts in the field of developing pervasive services aimed at Telemedicine in the Digital Home.

Figure 33. Graphical representation of the research method defined and used in the work presented.

Definition of the Scenario and Questionnaire

The experiment defined in this section is based on qualitative research implemented by means of a questionnaire that must be completed by each target subject. Through the presentation of a real-world scenario, the subjects are immersed in a real context that must allow users to determine and explain how and why they decide to behave in a specific way. In this way, the scenario defined for the experiment is used to place the target subject in a context of actual

deployment of a pervasive sensitive service in the Digital Home. To do this, specific places in the household, such as the bedroom or bathroom, were considered, since they represent the two most restrictive rooms in terms of privacy within the home.

The defined questionnaire has been used to present the subjects under study with the implemented scenario, dividing the questions into two distinct parts. During the first part, the scenario is explained and presented to the subject in an evolutionary way, i.e. as they go through the questions more information relevant to the user is presented, as described in

Table 5. In this way, the idea is to provide users with resources to facilitate the understanding of the behaviour, need, privacy, utility and legality of the service to analyse the evolution of the responses obtained about whether they feel confident to perform their daily activity in the scenario presented. Thus, it is feasible to analyse how user confidence develops as Understanding and Control of the service increases.

Table 5. Confidence and Safety questions from User-Centred point of view.

Understanding and Control over Level	Question
P1	Picture yourself in your bedroom which is considered an intelligent environment and there is a camera in the ceiling. Could you carry out your daily life into this room?
P2	Picture the same situation. In this case, ensure the camera will only be used by the Intelligent System and the information obtained/recording is not visible to any other person. Would you be comfortable, now, to carry out your daily life?
P3	Again, imagine the same room. The above is guaranteed and protected by law. Could behave normally in this room?
P4	Lastly, imagine the same situation. Completing the above assumptions, it is explained that the camera is used only to detect a possible scenario of falling and/or unconsciousness. This is a mechanism with which you have enough control to “see” what is being monitored at any time. The system aim is to save, in extreme cases, your live. In this way, would you feel confident in performing your daily task in that room and could you behave normally?

Thus, the description of the scenario is organized in four states of confidence (P1 - P4), according to the Understanding and Control that is offered to the user by using the description of the scenario through the questions. Each state provided the subject interviewed with new information in the following way:

- P1 describes a private and intimate room in the house that has been transformed into a smart space through the use of intrusive technology which can be seen and located: a camera in the ceiling;
- P2 completes the information offered to the interviewee in P1 with data on the privacy that the solution offers, ensuring the user that all data extracted during the operation of the service will not be used for any other purpose other than that defined by the service integrators and providers;

- P3 provides additional information on current legislation and the legal guarantees available to the user if faced with any problem arising from the use of the service;
- Finally, P4 explains the usefulness and benefits of the developed system and the services deployed in the bedroom. To ensure full understanding of the scenario, there is a concrete example of a typical telecare service for detecting of falls and situations of unconsciousness of users in the Digital Home.

The goal of the second part of the questionnaire is to eliminate the possible tendency of respondents to answer questions in a way that will be seen favourably by other subjects, i.e. social desirability bias or SDR. These questions are organized as term ordering that define the indicators under analysis, i.e. Understanding and Control in relation to the confidence status of the subject interviewed. To facilitate and monitor users' possible responses, a set of terms that the interviewed subjects must sort according to their wishes and beliefs were provided, as shown in Table 6.

Table 6. Definition of operationalised confidence.

Question	Target aspect of Confidence	Sorting terms
The concept of confidence, beyond linguistic meaning, has different connotations depending on the scope of application. In this sense, could you sort the words that best define, in your opinion, the aforementioned concept of confidence?	Perception of Usefulness	<i>Utility</i>
	Understanding and Control	<i>The environment does what I expect it do</i>
	Usability	<i>Ease of use or usability</i>
	Affordance	<i>Cost</i>
	Quality	<i>Quality</i>
Applying the above concept of confidence, could you order the following terms depending on the confidence that contributes to an intelligent environment?	Control	<i>The environment does what it must</i>
	Understanding	<i>The environment does what I have understood it will do</i>
	Dependability	<i>It does not have any problems or mistakes</i>
	Intuitiveness	<i>There are no elements with functions or utilities I am not familiar with</i>

As a complement to these questions issues related to gender, level and field of study and technological skills were added to the questionnaire, with the aim of being able to perform a detailed analysis and filtering of the answers obtained.

Lastly, both the questionnaire and the implemented scenario were refined by two group interviews conducted with 20 target subjects (two groups). These interviews served to improve both elements iteratively concerning grammar, number of questions and technical aspects of the scenario, such as the most intrusive technology to be used or the room in the house with the best privacy -

feasibility of the proposal relationship, choosing the bedroom over the bathroom.

Results

The experiment was carried out by a total of 160 people, who fully completed the questionnaire offered via the Internet through the tool *Obsurvey.com*. The results of the experiment show that 25% of those interviewed accepted, and therefore agreed with, carrying out their daily routine in a normal way from the outset, replying affirmatively to the questions associated with state P1. Differentiating between technical users, those who have a high culture and knowledge of ICTs, and non-technical users, the affirmative responses for P1 vary from 29%, for technical users, to 23%, for the non-technical users. In the state P4, where users had all the information necessary to understand and be able to control the pervasive sensitive service, the level of acceptance reached 72%. However, the differences between the responses provided by the technical users and non-technical user are significant on this point. While 78% of the technical users accepted the scenario presented in state P4, only 69% of non-technical users replied affirmatively. Full results are shown in Table 7.

Table 7. Responses about if one could develop a normal life in a smart space such as a smart bedroom, even though the technology used to make this space. The results are filtered in people who describe themselves as developers and others as simple users.

State	Overall		User		Developer	
	No	Yes	No	Yes	No	Yes
P1	74.81%	25.19%	76.67%	23.33%	71.11%	28.89%
P2	53.33%	46.67%	53.33%	46.67%	53.33%	46.67%
P3	48.15%	51.85%	51.11%	48.89%	42.22%	57.78%
P4	28.15%	71.85%	31.11%	68.89%	22.22%	77.78%

The chart presented in Figure 34 shows how the psychological state of confidence of users evolves depending on the amount of information provided in each stage of the questionnaire.

The results of the first phase of the questionnaire show that the confidence that users have in the scenario presented increases as they gain more information on its usefulness and operation. It is striking that the increase between States P2 and P3 does not follow the trend observed in the other state changes (+5%). Specifically, state P3 adds information about current legislation stating that sensitive information handled by the pervasive sensitive service must be protected. As explained in the background, the current trend of user confidence towards the data protection laws and programs has suffered a progressive deterioration during the last 5 years. However, the use of an external entity, such as installers or service providers, to ensure the privacy of the information managed (information provided in state P2) is shown as a necessary and sufficient condition to obtain a higher degree of confidence (+21%), by both technical and non-technical users. Lastly, general comprehension and a guarantee of supervised control of the solution (as presented in state P4), offers an increase in confidence similar to that offered by direct intervention by external entities

(20%), and must be taken into account to guarantee an optimal level of confidence.

Figure 34. Evolution of the feeling of confidence on the users' behalf increases as more information to improve the Understanding and Control of the user over the solution presented is presented (states P1 to P4).

Figure 35 presents the responses provided to Control Question 1 about the definition of confidence in relation to a pervasive sensitive service deployed in a smart environment that affects a vital space for the user, the bedroom. This chart shows the distribution of terms selected as first priority. As you can see, 62% of the subjects interviewed selected the term "Understanding and Control" as the item that best defines their confidence status for the scenario presented.

Figure 35. Graphical representation of the definition of confidence using one term.

Figure 36 presents the data as ordered by the interviewed subjects, the first choice being of greater importance and the fifth term being the one of lesser significance. In this way, it is noted that the Understanding and Control of the Scenario was selected as the first and second most important term for 80% of respondents. The utility and the quality of the solution presented themselves as the alternative terms with a ratio of 44% and 40% respectively. However, the cost of the solution represents the less representative term, being placed last by 77% of users and first by 0%.

Figure 36. Ordering terms for the definition of Confidence.

Lastly, the second Control Question showed the results shown in Figure 37. These results show that the most important aspect of a pervasive system affecting an intimate and personal space is that it meets the expectations that the user had placed in it from the outset (84%). However, if you only consider the findings from the first election, you can see that, in addition to the above, the use of familiar artefacts, everyday objects, as elements for developing the smart space represents a fundamental aspect, with 67 per cent of users agreeing. This means that for a correct adoption of pervasive sensitive services, whose operation are conditioned to the deployment of their services in smart spaces that affect personal and intimate instances of users, it is necessary to fulfil two premises: that users can understand and control the system in a simple way, and that the technology used for their development is not a disconcerting element, meaning that as far as possible, intuitive objects with which users feel familiar and safe should be used.

Figure 37. Definition of confidence in the context of smart spaces.

5.4.3 Experiment with Smart Toys

The goal of the observations carried out during this experiment was to determine the feasibility of the development of pervasive sensitive service for monitoring some key aspects of psycho-motor development in children aged 3 to 6. The service that was analysed was developed using an everyday object, toys, with processing capacity using intelligent textile sensors equipped to measure two basic motor skills in children: squeezing and releasing. The viability analysed in this experiment refers not only to the possibility of physical development of the object, already presented in the technological results of this chapter, but also to determine its acceptance by children.

Acceptance of a technified object that replaces an everyday object, in this case toys, is conditioned by its ability to offer a user experience similar to the object replaced. This user experience refers to the playability the object offers. Therefore, the assessment of a smart everyday object or Smart Toy has been aimed at analysing the playfulness it offered, so that users can understand this object as a toy and thus decide to use it. Playing represents the most important activity that children perform and where more information about their development can be extracted in a way that is natural and hardly invasive.

To perform this experiment a method of investigation was developed, summarized in the Figure 38, based on the development of a functional prototype and qualitative observation through 10 individual interviews. The description of this experiment, as well as the results obtained have been listed in Annex 2, which presents the related scientific article in full. Supervision of this experiment was carried out by two education professionals, responsible for the group of children involved in the study.

Figure 38. Graphical representation of the research method defined and used in the work presented.

5.4.4 Evaluative Research of the Set of Interaction Patterns

As defined in the background of this research, pervasive services are ICT services whose persistence must be total, i.e. that regardless of the context in which the user is located, they must be operational and present. In the case of pervasive services aimed at studying and monitoring the psycho-motor development of children, they must accompany the users in their daily lives and be involved in their daily activities. Usually this the developmental control process is carried out in specialized centres, schools or health centres through specialist supervision. However, the inclusion or use of sensors for monitoring development offers advantages over this supervision when specialists are not present to generate information about the behaviour of users during their daily activities, which, in the case of children, is during play activities.

There are several types of possible services that can be developed: from services for simple monitoring to services that provide a specific diagnosis when faced with specific events. In the context of children, these services must be transparent and imperceptible in order to not affect the monitored activity. However, parents or legal guardians of these users should be aware of their deployment and use and therefore, accept such developments.

The set of patterns proposed in the previous section aims to promote this acceptance through generating optimum confidence states. The experiment presented below aims to assess the merit and value of this set of patterns in relation to the level of confidence generated in the supervising users, i.e. the parents.

Research Method

For this experiment an evaluative investigation based on semi-structured interviews has been designed for a group of parents ($N=10$) of children aged between 0 and 6. The evaluative investigation represents a qualitative tool suitable for assessing how a policy of action has an impact on an object of study. In this case, the policy of action is represented by the defined set of patterns of interaction and the object of study is defined as the generation of confidence in the parents. Which is to say, through this experiment, the aim was to assess the capacity of the patterns of interaction to generate Understanding and Control in an intuitive way in parents at the time of use a pervasive sensitive service for monitoring their children.

Evaluation of Confidence Interaction Patterns

The first phase of the experiment was focused on the extraction of the concepts under analysis based on the problems that each pattern of interaction seeks to solve. These concepts were associated variables related to the definitions of the terms of confidence and pervasive sensitive service. Lastly, statements were generated, in the form of cards, which were to be presented to the subjects of the experiment. The aim of these cards was to abstract the user from technicalities through colloquial language that would give rise to a group discussion. Table 8 shows operationalization of the evaluated patterns of interaction.

Table 8. Operationalization of the set of confidence interaction patterns for the Digital Home.

Greeting Pattern		
Problem Detected	Service users must know if a pervasive service can be deployed in a smart environment in optimal conditions for its development	
Variable	Concept	Card
Prevalence	I use the service where and when I decide.	<i>Using the service where and when I want.</i>
Persistence		
Customisation	The service works only with me (my daughter) and is not affected by other people interfering in its operation.	<i>Only I can use the service.</i>
Control	If I do not want to use the service, it is not activated/not running.	<i>Only I decide when to use the service.</i>
Understanding	The service tells me and justifies the reasons why it does not work. In addition I know that the service is not running at all times.	<i>The service explains why it does not work and I understand the reasons:</i> <ul style="list-style-type: none"> - No battery - No Internet Connection - Broken Toy - Many people in the room
Farewell Pattern		
Problem Detected	Users need to have a record of the information collected by the smart environment, where the information is encrypted and stored or deleted as the user chooses.	
Variable	Concept	Card
Privacy	I can use the service wherever I want/can because when I stop using it all data and information captured is deleted.	<i>There are regulations and/or laws that protect my privacy and the service tells me so.</i>
Safety	The data generated are protected both by regulations/laws and computer security techniques.	

Privacy		No one has access to the information obtained by the service.	<i>The space where I use the service is adapted so that the information is private and informs me of the fact.</i>
Control		The service stops working when I decide, without objections.	<i>I can stop using the service when I decide and the environment informs me that the service has stopped.</i>
Understanding		Once stopped, the service confirm that it has stopped working.	
Action-Reaction Pattern			
Problem Detected	The points of interaction between the service and the user are transparently immersed in the environment through the use of everyday objects that have been augmented with computational capabilities.		
Variable		Concept	Card
Suitability		The use of service favours my development and I can see the improvements that I have been promised.	<i>I am able to see improvements in myself/ my child when using the service.</i>
Intuitiveness		I don't need anyone to explain how the objects in the environment work and can I use them normally.	<i>Learning how to use the service doesn't take long.</i>
Understanding		I fully recognize the objects used by the service: toys, electrical appliances, Smartphone, tablets, etc.	<i>Before using the service I had already handled the devices involved.</i>
Privacy and Transparency		The objects used by the service do not produce shame/embarrassment because they are familiar and the rest of the people in my environment also have/use them.	<i>The people around me use the devices associated with the service and not I am ashamed of/ by using them.</i>
Conversation Pattern			
Problem Detected	The points of interaction between the service and the user are transparently immersed in the environment through the use of everyday objects that have been augmented with computational capabilities.		
Variable		Concept	Card
Customisation		Due to the fact that I am somewhere different than where I usually use the service, I understand that the service will ask about how to perform specific actions.	<i>The service/environment asks me questions. I understand them and being asked or answering does not make me uncomfortable.</i>

Privacy	Only I receive the questions, and nobody else is part of the dialogue.	<i>I am aware that the conversation with the environment is between it and me, and nobody else.</i>
Reciprocity	I can communicate with the environment when I want and it answers me.	<i>The questions that arise are answered correctly by the environment, discretely.</i>
Exploration Pattern		
Problem Detected	The pervasive service typically uses analysis of the actions and activities that a user performs in a smart environment to adapt and improve. The environment, through sensors, collects this type of information and adapts its behaviour to assist the user in achieving the goal set out by the service. In this process, there is no direct User-Environment/Service interaction, since the monitoring/sensing process is usually transparent to the user.	
Variable	Concept	Card
Privacy	The activities that I carry out in a space are not communicated to anyone outside the service.	<i>Nobody outside the service knows what I am using without me explaining it.</i>
Privacy	Only the service and I know what activities are analysed.	<i>The objectives of the service are defined privately with experts and nobody else.</i>
Resilience and Adaptability	My daily activity does not interfere with the service. I can perform other actions without generating errors and also, if I decide to carry out an activity in a different way, the service behaves correctly.	<i>If I use the devices involved in the service in a different way they still work properly.</i>

Development of the Interviews

The strategy followed in this qualitative experiment was based on a semi-structured interview with 10 parents of children between the ages of 0 and 6, grouped in two discussion groups. This division allowed comparison of the results obtained with the purpose of determining the objectivity of the responses and their validity.

The interview was organized with an initial presentation of a case study, a scenario that the group was to discuss for 15 minutes. After the discussion, participants were asked to individually select the 5 cards that best define the subjective ideas that they had processed during the discussion. Subsequently each set of selected cards was presented to the rest of the members of the group and the selections were discussed. At the conclusion of the experiment, each member of the group, through a dialogue with the other members, had to associate each selected card with a pattern of interaction. Each pattern was presented to the

group indicating its name and the problem it was designed to resolve as well as how it solves it.

The scenario presented at the beginning of the interview was defined thus:

"The developed pervasive service offers the possibility to monitor the development process of children during their play activities. This service is oriented at constantly monitoring children's play activity, provided it is accessed, i.e. while it is operating. In this way, the professional supervision extends to unsupervised contexts such as the home."

For this experiment, we can imagine the following situation. We have a monitoring service that is going to be implemented in the home, specifically in each child's bedroom. This service monitors uses toys. Their appearance is identical to traditional toys but they include sensing and computing capabilities."

The service must be operational when the child is playing. Through interaction with each toy, it is possible to detect actions involved in the study of the user's psycho-motor development. In addition, the toy or set of toys must be able to be used in other situations where the service is not operational."

Results and Conclusions

The results were organized according to the selected cards for each subject, with a maximum of 5. These 5 cards represent the concepts of most importance according to each subject after having discussed them with the other members of the group. Each card gives a weight to a variable and each variable affects a particular problem, collected in each one of the patterns of interaction defined. Figure 39 graphically displays the distribution of the weight given by participants.

Figure 39. Graphic representation of the distribution of the weight given by participants.

As can be seen, the analysed variables can be grouped according to the aspects that they affect in a pervasive sensitive service. The variables related to the protection of information, represented with the colour blue, are privacy, security and transparency. The variables shown in yellow are related to the acceptance requirements exposed as a first conceptual result of this thesis. Lastly, in green, the group of variables that refer to the nature of a pervasive and sensitive service that affect the correct deployment of the latter, i.e. the persistence of the service, the capacity of adaptation to user or customisation and its suitability or utility.

The analysed results show that privacy and security and the associated feeling of intimacy play a crucial role in developing pervasive sensitive services. The associated variables collected a total of 23 votes, 40%. Intimacy, in this

group, represents the variable with the greatest weight for interviewees. Privacy and security, commonly understood as synonyms (and thus recorded by the subjects) are also key aspects in developing this type of services. In general, the results show that the patterns of interaction must meet the needs of users regarding the protection of their activities that are affected. To do this it is necessary that each one of the actions that the user takes are covered by regulations or laws.

The variables related to the requirements of acceptance and confidence-building represent 34% of the selections, with a total of 20 votes. In this set of variables, resilience obtained 0 votes out of a total of 10 possible. As has been analysed from the discourse obtained during the experiment, users did not contemplate the possibility of using the technology involved for their development, smart toys, with a different purpose than the one offered by the service. However, and as we have analysed in the acceptance experiment described in section 5.4.2, this feature is very important when it comes to elements of interaction with children. Children represent a very variable target subject, whose behaviour is unpredictable and therefore, developments must withstand different uses to those planned.

The remaining variables represent 26% of selections by the subjects interviewed. It should be noted that the score obtained by suitability, with 8 votes out of 10 possible, was the most important variable if it is analysed independently. It is clear that for a service to be fully accepted, the results obtained when used must be the ones expected. For that to happen, the patterns of interaction must provide the necessary information so that the user has a record of its evolution, without it detrimental to the correct development of the service.

Figure 40. Graphical representation of the distribution of votes for the operationalised variables corresponding to a pervasive service in the Digital Home.

As shown in Figure 40, the results establish that trust and management of the information and activity in a private and secure manner are the most important features for users. This means that the patterns must be able to provide a design solution that allows modelling the communication relationship between users and services in two directions. They must promote a psychological state of confidence, through clear and precise dialogues, easily understood by the users, with the aim of providing control over the behaviour of the system. In

addition, they must ensure the protection of the information about users and their activities gathered during the use of the system, either through confident channels of dialogue or the involvement of trusted entities, such as doctors, installers, etc.

DISCUSSION, CONCLUSIONS & FUTURE WORK

This chapter provides an analysis of the results of the research in the form of discussion and conclusions, in relation to the defined assumptions and objectives. As part of the above analysis, the main original contributions made are included, explaining the scientific and technological innovations they contain. Lastly, indications of current and future lines of research that are particularly relevant to the achievement of continuity and transferral of the results are given.

6.1 Discussion of the Conceptual and Experimental Results

Throughout the development of this thesis, the validity of the solutions adopted and possible alternatives have been technically compared and discussed. This section provides a specific discussion of the validity of the results in response to the working hypothesis raised and its consistency with the objectives pursued.

6.1.1 Validity of the Working Hypotheses

<p>Hypothesis 1: <i>Confidence is a key factor in promoting the acceptance on behalf of the user of sensitive services deployed in smart domestic spaces.</i></p>
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This hypothesis establishes that, in addition to the constructs analysed and assumed in the traditional acceptance models, confidence is a new construct necessary and not properly analysed for the promotion of acceptance of new ICT services. The need to treat *confidence* is exacerbated with pervasive technologies and ubiquitous computing since the amount of existing communication relationships between the user and the system rises dramatically. The approach to dealing with confidence in this thesis is based on the definition of the concept in cognitive terms related to user psychology.

The experiment carried out with 160 potential users of smart environments for the deployment of sensitive pervasive services has facilitated the verification of this hypothesis. This qualitative experiment has allowed verification of the personal vision of a significant set of users (Pearson = 0.97) on the incidence of confidence developed during the use of these intrusive systems. As shown by the results presented in the corresponding section, acceptance of the proposed solution based on a set scenario that is representative of this type of technology increases depending on the degree of confidence generated in users.

Hypothesis 2: *Understanding, control and intuitiveness are indicators of the level of confidence developed by users and can therefore be used to model and manage the user acceptance of pervasive sensitive services.*

This hypothesis is related to the possibility of operationalising the concept of trust proposed in this thesis through atomic indicators for their management and processing. The three indicators identified in this hypothesis, understanding, control and intuitiveness, have been studied and analysed extensively in the literature, a fact that facilitates individual processing in the context of computer science and engineering. Their relationship with the acceptance of a technological or technical solution as variables in the concept of trust has been analysed in this thesis.

The experiment carried out for the verification of hypothesis 1 was also used for the verification of this hypothesis. As shown by the results of the experiment mentioned, over 60 per cent of users interviewed agree on the importance of understanding and controlling the technological solution analysed. Moreover, the experimental results obtained during the analysis of sensitive pervasive services implemented through pervasive technology, in this case intelligent toys, show the possibility of applying these variables in the design of these solutions.

Hypothesis 3: *A smart environment designed from interaction patterns that promote understanding, control and intuitiveness of the sensitive services deployed improved the confidence of users.*

The research work exposed in this thesis determines that the capabilities that a smart environment offers users are identified by the set of pervasive services that surround the user at a particular moment in time. The intelligent environment must provide these services a means of confident deployment, i.e. one that fosters a communication relationship with the user that is understandable, controllable and as intuitive as possible.

In this regard, working hypothesis 3 establishes that the design of the deployment of this type of services in a smart environment can be modelled using a finite set of patterns of interaction. These patterns pose general solutions to problems related to communication between the user and the environment. The verification of this hypothesis is conditional to the viability of the definition of the set of patterns and working hypothesis 2. The technical result presented in section 5.3.3 shows the set of patterns defined, according to the results obtained in the experimentation phase for the verification of hypothesis 2. In addition, these design patterns were used for the definition of the technological result related to the development of intelligent toys presented in 5.3.2. Lastly, the

acceptance of this solution was evaluated qualitatively by the experiment presented in 5.4.4.

Hypothesis 4: *The design principles necessary for the creation of solutions aligned with fostering user confidence can be embodied in the form of functional software architecture for use in the design of future applications.*

A sensible solution that negatively affects both intimate aspects of the user and private spaces where they dwell must ensure a state of confidence that will allow for the use of the defined solution in a natural way. Addressing this premise from the source makes it possible to achieve an acceptable level of acceptance of the final solution, a fact that should ensure the adoption of such a solution by target users. To promote the concept of trust from the beginning of the creation of a solution it is necessary to provide tools to developers and operators. These tools can conveniently guide the processes of analysis, design and development by ensuring that the requirements of acceptance are covered from the conception of the system until its final deployment. One of the most widely-used tools as a guide in the processes indicated are software architectures.

Working hypothesis 4 assumes that it is possible to adequately guide solution developers through a software architecture in terms of trust established in this thesis. To verify the hypothesis an architecture with the objective of satisfying the acceptance requirements identified during the investigation (section 5.2.3. In chapter 5) has been developed. Its technical correction and its functionality have been verified through specific usage scenarios (see Section 5.3.1. Chapter 5 and Annex 3). After the checks carried out it is considered that the hypothesis is also adequately met.

6.1.2 Research Objectives and Results

This section will discuss the extent to which the results of the thesis have met the objectives established.

The main objective of this thesis was defined as follows:

Contributing to the promotion of the acceptance of new pervasive and personalized health services and their deployment in smart domestic environments through a design framework that promotes a psychological state of confidence in users.

This objective provides for two distinct ideas in its formulation. The first determines that final acceptance by users of highly sophisticated and sensitive technology is strongly linked to cognitive aspects concerning the relationship that is established between them. The second specifies that these cognitive aspects should be addressed from the time the problem is put forward and the solution is designed, up to its final deployment, based on a framework of design as a useful and effective means to do so. Achievement of this overall objective is based on the fulfilment of the specific objectives and operations that comprise it.

Analysis of Specific Objectives

In this thesis, a total of four specific objectives that allow pinpointing the problem adequately in terms of engineering have been defined. Below, the analysis of compliance of each one of the specific objectives is presented.

1. To characterise the feeling of confidence from an engineering point of view for measurement and modelling.

Treatment and management of a concept defined in a holistic way, made concrete by its deconstruction into atomic elements. To do so, in this thesis an operationalization of the concept of trust proposed has been made by generating the minimum set of indicators that have been used to manage and include in the technological solutions presented. Thus, the characterisation of the concept of trust has materialised in the following indicators: understanding, control and intuitiveness. These indicators have been used in all artefact development and experimentation processes with real users carried out in this thesis.

2. Defining and characterising pervasive sensitive services as catalysts for the deployment of Telemedicine and e-Health services in the Digital Home.

Because there is no specific definition for the concept of pervasive sensitive service, it has been necessary to carry out a synthesis of the concepts involved in its composition, i.e. sensitive service and pervasive service. Thus, and through the work done in this thesis, it has been possible to determine that the usefulness of smart spaces is subrogated to the deployment of the services associated with a user. This work, in addition, has allowed the development of the rest of the objectives put forward.

3. Contributing to the inclusion of Interaction Design in the paradigm of ubiquitous computing and ambient intelligence through the design of models, guides and patterns of Person - Smart Environment interaction.

A pattern represents a design approach for a solution to a particular problem. In this regard, when the problems analysed refer to the relationship of communication between a user and a concrete technological solution, they are defined as patterns of interaction. The set of issues drawn from the analysis of the relationships that are established between users of sensitive pervasive services and the intelligent environment where they are deployed have determined the set of minimum interaction patterns for the promotion of their acceptance by end users. In this way, it has been possible to introduce the design of interaction in the process of development of services in the Information Society. In addition, these patterns have completed and concreted the rest of the technical developments (software) and the conceptual architecture for the definition of a design guide for sensitive pervasive services and the Intelligent Environments where they are to be deployed.

4. Providing development-based software architecture design models focused on activity to ensure proper deployment of sensitive services in smart spaces in a confident way.

This research addresses the current problem of the acceptability by end users of smart technologies for the home through the definition of a software architecture. This architecture meets the challenges inherent in the development of sensitive services, such as Telemedicine and assistance systems, as well as user acceptance and, specifically, user confidence. The proposed solution provides a framework to deploy sensitive services in the Digital Home based on ensuring greater acceptance by all types of users who participate in these services.

Additionally, this work has yielded a set of requirements for the acceptability of sensitive services, both from the user interaction and from the technical point of view. These requirements include, in addition, a new approach to the needs of services in relation to the capabilities of the Digital Home by using templates in activities and a model of confident communications.

Analysis of Operational Objectives

To carry out the specific objectives three operational objectives that gave rise to the strategy of development carried out in this thesis were defined. What follows is an analysis of the degree of implementation of these operational objectives:

1. Holistic and functional definition of the concept of confidence.

This operational objective has been achieved during this thesis by providing a complete definition of the term *confidence* through a systematic review of the related literature. In addition, a functional definition has determined, based on its operationalization in sub variables, to be included in engineering processes. This definition and characterisation has allowed a differentiation of the concept Trust to be established, which was traditionally used in the field of Engineering, giving rise to an analysis more oriented to the psychological aspects of users.

2. The definition of a framework of design aimed at building confidence in users of the service or system developed.

This objective has been addressed in the first instance with the definition of a set of requirements aimed at promoting a state of confidence in users of sensitive pervasive services deployed in Smart Home environments. Once these requirements have been defined, a design guide was developed that determines the steps required for developers and operators of sensitive pervasive services to address these requirements. This design guide has been based on the construction of a reference software architecture and the definition of a set of patterns of interaction that facilitate the task. Using software architecture, it is possible to model, at the functional level, how pervasive sensitive services deployed in a smart environment should behave, while the patterns of interaction offer a design guide for the communication relationships between these environments and the users that inhabit them.

3. Verifying and validating the hypotheses using experimentation.

The validation of the technical results obtained and the verification of hypotheses established as the basis of the research of this thesis have been carried out through a strategy of experimentation, detailed in depth in Figure 41. To carry out this strategy, four projects and experimental artefacts were developed. The validation of the software architecture defined in relation to working hypothesis 4 has been carried out by means of a case study where a home assistance system for the control of high blood pressure and its relationship with the consumption of drinks such as coffee was developed.

Figure 41. Organization of the results obtained during the execution of the research for the Doctoral Thesis and its relationship with the defined working hypotheses.

Table 9. Comparison between the proposed architecture and the solutions related with this research.

Req.	ATLAS	S3OiA WSO2	(Scherpbier universAAL -de Haan et al., 2013)	(Esser & Goossens, 2009)	(Dabbs et al., 2009)	(Jara, Zamora- Izquierdo, & Skarmeta, 2013)	
1	own devices	✓	✓	X	X	X	✓
2	X	✓	X	X	X	✓	X
3	its context	✓	✓	X	X	X	✓
4	X	X	X	X	X	X	X
5	programmers	X	programmers	X	X	X	X

✓: Requirement covered; X: Requirement uncovered.

In case of software architecture, its verification was conducted by the implementation of a study case (detailed in the Annex 3) and its validation was made by a comparative study with related works. This study was based on the analysis of each related work used to establish the background of the software

architecture development and how each one meets the acceptance requirements. Table 9 shows the comparative between the software architecture presented in this Doctoral Thesis and related works. This comparative study is detailed in deep in the Annex 3.

6.2 Original Contributions of the Thesis

This thesis has given rise to several scientific and technical contributions. This section presents a summary of each contribution for their identification, evaluation and consistent use in future investigations.

1. *Holistic definition of the term confidence and its operationalization in three core indicators: understanding, control and intuitiveness*

This definition offers the scientific community a new application of the term *Confidence*, for differentiation from the concept of *Trust* already in use and its applicability in the context of the development of sensitive pervasive services and Intelligent Environments. It also provides a separation into atomic indicators for processing and management.

2. *Redefining the concept Smart Space*

Traditionally, smart spaces represent a technological development with capabilities that are offered to the user in the form of services. This thesis has offered another conceptual approach to the definition of a smart space, in such a way that services are deployed in spaces that define their own capabilities. This change of vision determines that smart spaces are designed and built to house pervasive services associated with a user, independently of which or what services are used. Therefore, it is the users that customise and determine the behaviour of space, using services, as opposed to adapting to them.

3. *Reference software architecture*

This thesis provides a template of design and implementation for the development of smart spaces that must accommodate pervasive sensitive service with the objective of promoting final user acceptance. Built from a set of requirements of acceptance, the proposed architecture determines the minimum modules that a system of these characteristics must contain, as well as both the internal and external communication interfaces. In this way, not only a model for the design of technological systems is proposed, but also a model of communication relationships is put forward for the entities involved in the definition of sensitive pervasive services: service providers, integrators, developers and of course, the end users.

Lastly, the design of the architecture offered is based on a model of design focused on human activity, which has allowed the internal processes of to be organized and managed according to the Theory of Activity. This has sought to provide the resulting and implemented systems, under the architecture, with a logic and functionality similar to how people conduct their everyday activities. In this way it covers not only the set of requirements of acceptance proposed but also models the behaviour of the architecture according to the vision presented in this Doctoral Thesis.

4. *Set of confident interaction patterns for the design of Intelligent Environments*

The set of patterns of interaction defined offer a technique of design to encourage a state of confidence in users of pervasive sensitive services through

modelling communication relationships between them and the Intelligent Environments where the services are deployed. Through these patterns, it makes it easier for developers, installers and operators to deal with the issue of acceptance of pervasive sensitive solutions from the initial stages of development. It is therefore a complementary tool to the reference architecture that allows the already exposed optimal level of acceptance to be ensured in the construction of this type of solutions.

6.3 Conclusions

The results obtained in this thesis have led to the following conclusions:

- Technological Acceptance

As has been reflected in the approach of this thesis, the need for new models of service provision for society that are more efficient and sustainable represents a key aspect for development. The evolution of services in the Information Society has been aimed at addressing this issue through the construction of new ICT services that affect different areas of the daily lives of people.

However, the inclusion of sophisticated technology and advanced computational paradigms in daily life generates fears that must be taken into account for successful adoption. In this context, acceptance of technology presents itself as a key aspect for the development and implementation of these new pervasive and sensitive services in the Information Society.

- A new role for technology and users

The enabling technologies of new, more personalised and efficient, services have given rise to the need for a reassessment of the relationship between the user and these technologies. In a context where the user is surrounded by proactive and imperceptible computational elements, it is not possible to maintain the centralist vision in which users control and manage the computational process completely. The overcrowding of interaction elements causes users to not be able to establish a mental pattern of the relationships that are established between these elements, which disables their ability to intervene directly in the computational process. It is therefore necessary to furnish users with a supervisory role to enable them to continue in the centre of attention of the new services and systems developed, while at the same time not undermining the computational capacity that they offer. Technology must, therefore, adapt to the intentions expressed by users, aiming to satisfy a particular need or desire.

- Interaction Design

Interaction Design is an appropriate discipline to develop tools that enable designers to create appropriate solutions in terms of confidence. The concepts studied and developed by this discipline, which in turn integrates different academic disciplines, design practices and interdisciplinary fields of application, have facilitated the management of acceptance requirements defined for inclusion in developments. Lastly, the utility of the inclusion of Interaction Design for the management of pervasive sensitive solutions acceptance has been verified at the experimental level.

- Multidisciplinary Approach

Addressing such a complex problem as the promotion of acceptance of sensitive solutions deployed in personal and intimate spaces, such as the home, must be broached from a multidisciplinary approach. The solutions to this problem are a challenge at both the technological level, concerning what technology or development offers greater benefits from a technical point of view, and a psychological and social development level, where the personal restrictions related to users are taken into account. It is therefore necessary that disciplines such as cognitive sciences, psychology and Interaction Design work closely with engineering to generate a complete result and an effective tool for proper development of the Information Society.

6.4 Future Lines of Work

This section lists the lines of future work aimed at evolving and deepening the concepts, technologies and case studies presented in this thesis.

A. Interfaces for accessibility

Research on the design of user-guided multimodal interfaces has been a breakthrough in the promotion of the usability and accessibility of many technological developments for the benefit of people. However, despite these advances, there are still social groups that are at a disadvantage due to the lack of accessible and usable systems. In particular, people with diseases and neurological disorders, as well as cognitive disabilities lack the means to access the new services promoted by the Information Society on equal terms.

The investigation carried out in this thesis can be applied in this field of research for the development of more effective solutions. These solutions are designed to improve the communication experience for people with any kind of disability and the development of technologies aimed at improving accessibility, which promote user's cognitive attention, executive functions, knowledge acquisition, communication, perception and reasoning. In this way, the results obtained in the thesis submitted can help formalise the capabilities of users (cognitive and motor) as well as the capacities of each of the interaction elements in an environment. This would make it possible to adapt, customise and improve the communication relationship between users and ICT services developed.

B. The Toy of the future

Toys represent an interesting and powerful technological tool for the development of physical and psychological capacities in children. The use of pervasive technology and ubiquitous computing to increase the computational capabilities of these objects may allow better analysis of the personal development that they offer. In this way, it would be possible to develop sensitive services acceptable from the point of view of children and girls, more efficient and present in its daily activity, the game. However, the inclusion of this technology can turn these objects into invasive elements, generating problems with parents, so that a detailed study of the acceptance of this technology is very important for final implementation.

C. Confident display systems

Although this issue has been treated in this thesis, a detailed study of its usefulness and impact is necessary. The display, using both visual and haptic

interfaces, represents an important means of communication, if not the most, between the user and a system. In a context where the user must be relocated to a supervisory role, this means of connection and communication assumes greater importance. No longer just to display complex data in a way that is understandable, but also to expedite the process of interaction with smart spaces and pervasive services. The rise of the deployment of Intelligent Cities or the inclusion of ubiquitous computing for transport and natural resource consumption organization means that the possibilities offered to users grow uncontrollably. This situation can overwhelm users, preventing proper adoption as valid solutions. Therefore, visualisation systems based on confidence may represent a useful tool to manage the acceptance of these developments.

D. Security systems based on the state of a person

The multidisciplinary work defended in this thesis can be concreted in the development of safety and access control systems to restrictive computing environments where the state of a person is taken into account. By *state of the person*, we must understand the psychological state of a person prior to performing a task and that complements the competencies and skills acquired by them in the past. Currently both the author of this thesis his supervisors are conducting research focused on the study of this line.

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SCIENTIFIC PRODUCTION

This annex describes the scientific contributions obtained from the research work carried out during this Doctoral Thesis and detailed in the beginning of this document. Finally, a chronology which place temporarily and contextualize each contribution is presented in the Figure 42.

Journals

- [J1] Vega-Barbas, M., Pau, I., Ferreira, J., Lebis, E., & Seoane, F. (2015). Utilizing Smart Textiles-Enabled Sensorized Toy and Playful Interactions for Assessment of Psychomotor Development on Children. *Journal of Sensors*, 2015. (JCR, IF = 1.182).
- [J2] Vega-Barbas, M., Pau, I., Martín-Ruiz, M. L., & Seoane, F. (2015). Adaptive Software Architecture Based on Confident HCI for the Deployment of Sensitive Services in Smart Homes. *Sensors*, 15(4), 7294-7322. (JCR, IF = 2.245).

Book Chapters

- [B1] Vega-Barbas, M., Valero, M. A. (2013, July). Intentions: A Confident-Based Interaction Design for Smart Spaces. In 1st International Conference on Human Factors in Computing & Informatics (SouthCHI13). July 01 - 03, Maribor, Slovenia.

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Figure 42. Chronological list of scientific production.

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**Utilizing Smart Textiles-Enabled Sensorized Toy and Playful Interactions for
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Research Article

Utilizing Smart Textiles-Enabled Sensorized Toy and Playful Interactions for Assessment of Psychomotor Development on Children

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Emerging pervasive technologies like smart textiles make it possible to develop new and more accessible healthcare services for patients independently of their location or time. However, none of these new e-health solutions guarantee a complete user acceptance, especially in cases requiring extensive interaction between the user and the solution. So far, researchers have focused their efforts on new interactions techniques to improve the perception of privacy and confidence of the people using e-health services. In this way, the use of smart everyday objects arises as an interesting approach to facilitate the required interaction and increase user acceptance. Such Smart Daily Objects together with smart textiles provide researchers with a novel way to introduce sophisticated sensor technology in the daily life of people. This work presents a sensorized smart toy for assessment of psychomotor development in early childhood. The aim of this work is to design, develop, and evaluate the usability and playfulness of a smart textile-enabled sensorized toy that facilitates the user engagement in a personalized monitoring healthcare activity. To achieve this objective the monitoring is based on a smart textile sensorized toy as catalyzer of acceptance and multimodal sensing sources to monitor psychomotor development activities during playtime.

1. Introduction

Healthcare, as we know it, is changing; the continuous trend of increasing cost associated with the increase in elderly population and the success in managing chronic diseases demands a paradigm change towards personalized and pervasive healthcare. Although advances in all technological fronts, for example, *material, sensors, electronics, information, and communications*, indeed allow the development of almost any e-health solution for pervasive monitoring, the complexity of such healthcare monitoring scenarios increases, making its exploitation more difficult, especially when a specific patient/user interaction is required.

The interactions represent reciprocal relationships established between users and different technological developments. That is, the interactions represent the convergence of interactive and physical contexts [1]. Thus, the main objective of the proper interaction design is to maximize the use of technological development and the satisfaction that the users obtained during this activity, reducing the negative aspects of the experience (frustration, discomfort) at the same time improving the positive (enjoyment, happiness) [2]. In the case of complex developments like e-health services, a design of a concrete interaction can influence the final acceptance of service by users.

The study of technology acceptance determines the probability of success of a technological development prior to use by the target users [3]. This issue is particularly interesting when developing ICT services under study are directly affecting sensitive aspects of users [4]. Moreover, in the case of fragile and vulnerable users such as children, this acceptance involves the study of a complete ecosystem of users, which includes parents and caregivers. Therefore, this acceptance extends from a technology-user relationship to a supervised relationship where there are several types of user with a broader set of requirements.

Previous work on how to promote acceptance in the context of sensitive service determined that by promoting a state of confidence it is possible to increase the final acceptance. Trust is ensured through the use of intuitive elements, easy to understand, and guaranteeing an optimal degree of control by users [5]. The use of smart textiles presents an interesting option for the development of sensitive services. The ability to integrate smart textiles with everyday objects (clothes, toys, etc.) leverages the familiarity and intuitiveness of the objects in which they are integrated enabling them as friendly interfaces for the deployment of ICT services.

When targeting the assessment of child development in the specific scenario of children smart textiles-enabled sensors empowering augmented toys seems to be the precise combination to monitor the key parameters required to assess child development while the child is in playful daily and accepted activity. In this study, a sensorized solution encapsulated in a toy using smart textile technology has been designed and deployed. The sensorized smart toy intends to provide a playable interaction and user experience to ensure optimal acceptance by all users involved in a daily activity like playing. Thus, the aim of this work is to design, develop, and evaluate the usability and playfulness of a smart textile-enabled sensorized toy that facilitates the children engagement in a personalized monitoring healthcare activity. Since the toys will be customized to specific applications in later stages, the toys need to have a general processing platform to change their behavior according to the final application requirements. The technical details of the processing platform including the textile sensors, digital processing, and light and sound actuators are also presented. The paper also presents a technical validation demonstrating the capabilities and feasibility of this processing part. The technical validation demonstrating the capabilities and feasibility of this processing part is another aim of this paper.

The rest of this work is organized as follows. Section 2 presents an overview of previous research efforts oriented to design and develop sensors based on toys and architectures to support sensitive services. Then, Section 3 describes the design and development of the smart toy and the communication between it and the smart space. The evaluation of playfulness and acceptance by users is analyzed in Section 4 and, finally, Sections 5 and 6 summarize the discussion and conclusions of this work.

2. Background

Child development in the early years is characterized by the progressive acquisition of important functions such as postural control, autonomy of movement, communication, body language, and social interaction [6]. Early detection of warning signs, which are potential indicators of problems in child development, is a key issue because it offers greater guarantees to prevent added pathologies, achieving functional improvements, and enable a more adaptive fit between a child and his environment [7, 8]. Thus, telemedicine not only offers the possibility of providing health services to children who live in isolated areas [9], but also can provide novel monitoring and diagnostic methods that may be beneficial for the children's health.

An interesting trend related with the scope of this research work in telemedicine and telepediatrics is providing pervasive services and ubiquitous solutions that enable experts to observe and treat children in their natural environment, preferably homes or childhood centers [10, 11]. However, the potential of telemedicine in concrete telemonitoring in smart spaces has not yet been reflected in a significant implementation [12–14]. Besides challenges not only are related to current status of the technology but also are associated with other factors related to the inclusion of technology in areas such as organization and coordination of providers, updating healthcare processes, or acceptance of health services by users [15, 16]. This last factor, the acceptance, is especially critical due to the characteristics of health services: privacy, safety, reliability, and intention of use.

Also, an important amount of researchers involved in technologies for physiological measurements and personalized healthcare monitoring focuses their efforts on developing sensors based on smart textile materials [17–20]. Smart textiles offer benefits related to the intuitiveness ensured by the use of known interaction and accepted elements by all human beings. For example, in [21–23] the authors develop and use different set of clothes for recording measurements for different applications of assessment of fluid distribution in the body. In [24] researchers attempt to include monitoring of daily activities of people using smart textiles; specifically this research shows how to assess the stress in real time on workers under extreme conditions. Finally, [25] shows an overview about the usefulness of developing textile interfaces as a means of interaction. However, when the target set of users are children, the use of clothing presents problems related to the unpredictable behavior of these.

In this sense, the creation of playful interactions presents a potential and interesting method to get children involved in some telemedicine and healthcare monitoring activities [26–28]. Currently, part of the research in this field is aimed at developing serious games that use smartphones and tablets as a tool (Bring Your Own Device or BYOD) [29]. In case of children, especially aged between 0 and 6 years, toys represent the most intuitive BYOD. The development of smart toys seems to be a useful tool for monitoring their daily activity because they are safe and enjoyable for very small children [30]. In this way, a smart toy represents a target element which connects children with the telemonitoring

service and in which we can deploy playful interactions to improve the engagement of such specific type of user.

As we present below, the literature related to the development of intelligent toys shows two clear trends. First is toys and smart spaces designed for the treatment of chronic diseases such as autism. Furthermore, the research focuses on the educational field, developing environments, and interaction elements based on toys to improve learning processes.

Some examples of efforts related with the first trend are found [30–32]. In [31] the researchers present a complete development of a toy system based on smart textiles for general use. Such work represents a first approach to the use of smart textiles for the development of interactions that promote free play, that is, that simulate traditional toys, encourage creativity in children, offer interactivity, and encourage social interaction. The work in [30] shows a comprehensive solution for identifying and monitoring recording activities related to the game in order to identify possible developmental disorders of children. In that work, authors define three elements, a set of intelligent toys that make up a wireless sensor network, a recognition patterns system of behavior, and a query interface for further analysis of the data obtained. The last two elements of the system employ direct recording of the activities of the children. Complementing this work, [32] offers the possibility of inclusion of a robot in child domain. This robot provides facilities for communication and social interaction for children with certain types of disabilities. This robot has the ability to organize games that encourage social skills of children associated with social relationships.

Finally, relevant research works related with the second trend are analyzed in [33–35]. These articles studied how toys computationally enhanced can provide improvements in learning and psychomotor development of children. The system proposed in [33] is designed to create a sixth sense of health through pervasive components located around to detect information about the welfare of children. The novelty of this experiment is to provide a pervasive ecosystem component plug-and-play that is geared towards health education and children's autonomy through an approach of "Do-it-Yourself." Authors in [34] show how the interaction with toys can help to promote and support the psychomotor skills of children during their development. Using kinesthetic methods, that is, toys and materials that use the movement to support communication and learning through computational physics interaction, it is possible to establish healthy and profitable relationships between children and technology with an educational or therapeutic target. Finally, in [35], soft toy design is presented, using conductive fabrics and pressure detection circuits. The system is a highly sensitive deformable controller, which can be flexibly used in a range of settings for the continuous or discrete control. The controller is wireless and can be used to expand the interactive possibilities of mobile computing devices. Multiple controllers can also be networked in collaborative scenarios.

3. Sensor-Toy Design

The development of toys for children aged between 0 and 6 must provide interaction of free play. As the authors of [31] exposed, this interaction should favor four factors:

- (i) it should simulate a traditional toy,
- (ii) it should encourage creativity in children during use,
- (iii) it has to be interactive,
- (iv) it encourages social interaction.

In this sense, smart textiles gain importance because they allow design and build toys with a traditional shape and texture. Furthermore, the design of a smart toy should have a clear functional objective, which in this case is to record a set of physiological measurements to allow the assessment of children's psychomotor development through the use of the toy. Again, this goal is carried out with the use of smart textiles utilizing their potential to create textile sensors, which can be integrated, in the smart toy in a seamless way.

3.1. Set of Physiological Measurements. The set of physiological measurements that can be evaluated for a correct assessment of psychomotor development of a child from birth to an age limit of 6 is varied [36]. As aforementioned, one of the objectives of the presented work is to provide a sensor that can be encapsulated in a toy. In addition, the smart textile sensor intends to provide a playable interaction and user experience to ensure optimal acceptance by all users involved in a daily activity like playing.

The behavior of a child during a playing activity with traditional toys shows that an objective measure is the force that children develop in their hands [37]. This force can be decomposed into force of compression and stretching. It is also interesting for children developmental experts to know if children react to reactive stimuli such as sounds or lights [38, 39]. These stimuli are easily relatable to the above-mentioned movements, establishing a feedback interaction between the detection of force on the toy and the production of sound and light effects.

3.2. Sensing Toy Shape and Materials. The first result of this research work is a sensorized prototype toy based on interaction design foundations and build using smart textile sensors and the *lilypad arduino* platform. The toy was designed to measure two psychomotor abilities, handgrip and stretch force.

The previous analysis of the background and related literature gathered the initial requirements to develop this smart toy.

- (i) Cloth texture is preferable than a plastic or wire texture.
- (ii) The interaction must report a feedback to the children in order to attract them to use the toy repeatedly, using lights, sounds, and vibrations.
- (iii) The battery must be hidden and well protected.

FIGURE 3: Smart toy developed in its final version. (a) The ball toy. (b) The monster toy.

FIGURE 4: Graphical representation of data gathered by smart textile sensors included in the smart toy: (a) handgrip measure output data gathered from the press sensor and (b) stretch measure output data gathered from stretch sensor. In both cases the data is produced by the output of the *arduino* internal ADC available in the *lilypad* bounded between 0 and 1023. The red line represents the threshold that determines the existence of activity or not. The value of the threshold was defined by direct observation during the child-toy interaction.

As we can observe in Figure 5, the communication process is organized as follows. The smart toy transmits the gathered information to a receiver formed by an *arduino* UNO with a wireless *Zigbee* communication module and an Ethernet module. Once generated, an information packet is sent to the database in the server at school. The information stored in the database at school is replicated via Internet to a database at the supervision center allowing experts to have access to all data gathered if they need.

4. Evaluation of Playfulness

To achieve an evaluation of the sensorized smart toy, a field observation based on questionnaires to measure the user experience was designed. The aim of this observation was to validate the use of the toy from a final user point of view in order to know if the produced sensorized smart toy meets the design requirements, in other words, if the sensorized smart toy can record a set of physiological measurements while providing a playfulness experience for the children.

FIGURE 5: Overall deployment diagram that specifies the communication process.

With such purpose in mind, a user experience experiment (UX-experiment) was designed with the specific purpose to observe if the smart toy fits our previous expectations according to children use, understanding, acceptance, and,

TABLE 1: Structure of the questionnaire.

Evaluation area	Target aspect of the smart toy	Question
Playfulness	Acceptance	Children want to use the toy
	Understanding	Children understood the smart object as a toy
	Intuitiveness	The smart toy seemed intuitive
	Environment cohesion	There were many differences of shape with other toys in the playground
Caregiver confidence	User comfort	Children used the smart textile sensors in the smart toy
	Caregiver confidence	Teachers felt confident with the use of the toy by children
Social interactions	Innovation capabilities	Children discovered new ways to play with the toy
	Smart toy integration	The toy was integrated successfully in the playground

therefore, playfulness. This experiment started with the definition of a questionnaire to conduct the field observation. Next we carried out a direct observation in a nursery school involving the teachers in this process.

4.1. Questionnaire Definition. The questionnaire used in this experiment was based on previous work such as the IBM Computer Usability Satisfaction Questionnaire (CUSQ) and rules proposed by the System Usability Scale (SUS). To obtain useful information about how the toy seems interesting for children, the questions were adapted accordingly in these methods. The number of questions was reduced to 8 in order to ease the experiment and avoid a boring experience for both teachers and children.

The questions defined were organized in 3 evaluation areas, which included the functional objectives of the research work. Playfulness defines if any children could use the smart toy as a toy. The caregiver confidence refers to requirements from a medical point of view; that is, the smart toy can be used for physiological monitoring. Finally, the social interaction area includes questions about how the smart toy provides ways of interaction among children in a gaming environment and encourages creativity in the children. Table 1 summarizes this organization.

4.2. User Experience Test. The questionnaire was used to conduct the user experience test (UX). The test was filled out with the collaboration of 10 children ($N = 10$) at the age between 3 and 6 years (mean = 4.5, SD = 0.69), always under supervision of their teachers. The experiment was carried out in a real playground environment.

Each child played with the toy during 20 minutes under supervision of the teachers and a researcher. Along this time the teachers filled out the questionnaire marking the previous questions with a grade between 1 (strongly disagree) and 5 (strongly agree). Finally, the test was anonymous and balanced in gender (5 girls and 5 boys).

4.3. Evaluation of UX Experiment. The UX experiment gathered data from the observation of 10 children, 5 boys and 5 girls, playing with the smart toy prototype in a playground at the school. Also the teachers contributed to the experiment supervising the entire process and providing comments to each question. Next Figure 6 shows the general results of this

FIGURE 6: Graphical representation of the global results of the UX experiment.

FIGURE 7: Graphical representation of the girls' results of the UX experiment.

experiment and the results per gender are shown in Figures 7 and 8.

The results show that 100% of children understood the smart object as a toy (understanding) without any extra explication (intuitiveness) and wanted to use it to play

FIGURE 8: Graphical representation of the boys' results of the UX experiment.

(acceptance). However, boys encountered problems to use the toy in the way that it was designed (user comfort) since only in 64% of the chances the textile sensors were used while girls discovered the function of the textile sensor more often, with a ratio of usage of 96%. Also, boys found some problem in integrating the toy with their other toys (environment) but not the girls. Finally the ratio of discovering new ways to play with the toy (innovation) was 66%, similar in boys and girls. The teachers explained that the children wanted to play with the sensorized smart toy only but some child invented new games such as creating new melodies. In this way, the teachers felt a grade of confidence of 84% with the use of the toy, with a strong difference between boys (68%) and girls (100%).

In addition, it was observed that the children played individually and in group with the toy but not for a long period of time (20–25 minutes). The girls used the toy exactly the way it was designed, using the smart textiles sensors, whereas the boys accidentally discovered the smart functions. Amongst all children the hair of the toy and the lights were the most appealing feature to them.

Finally, from the discussion with teachers, information about the confidence of the informal caregivers was obtained. The teachers noted that the toy was a useful tool to integrate children with special need. For example, they tried to include a shy child into the group through the smart toy and succeeded. However, the teachers felt uncomfortable letting the toy out of their sight because some children, boys, played too rough and therefore they were worried about the possibility that children could break the sensorized smart toy. The observation ended when the children started watching a movie. The toy was placed at the end of the mattress with its eyes facing towards the screen.

5. Discussion

The reported work shows that is possible to develop a sensorized smart toy based on emerging technologies as smart textile sensors facilitating personalized healthcare

FIGURE 9: Electrical circuit equivalent of the sensors implemented in the smart toy. Notice the presence of R_{junction} and its contribution to the voltage sense at the analog input of the Arduino. The dynamic range of the ADC can be adjusted to voltage change expected on the sensor by software. In addition the ADC digital output X and its complement $\bar{X}$ can be selected also.

monitoring and increasing the acceptance of the solution by transforming such activity in a playful interaction. In particular this research presents a smart toy, which can monitor activities related with specific aspects related to childhood development using smart textiles and electronics as well as information and communications technologies.

Both textile sensors developed use a very straightforward electronic implementation with a simple voltage divider and a pull-down resistor. The direct connection of the analog input of the Arduino to the textile sensor implies that the sensing input of the Arduino will sense not only changes in the resistance of the textile element but also changes in the impedance of the junction; therefore none of the sensors will be able to produce precise readings. See Figure 9.

The intended purpose of these specific smart sensing toys was not to obtain a precise representation of a physical magnitude per se, for example, pressure, elongation, or force, but the detection of a specific activity directly related to the change in the sensed physical magnitude. Therefore since such simplistic sensor implementation provides handgrip and stretching data useful for assessing the existence of activity and the length of the given activity, we concluded that actual implementation of the sensors is adequate for the targeted application.

Any other electrical implementation would increment the number of passive and active component increasing the cost and the complexity unnecessarily, but, in case that the monitoring application required better sensing performance, there are other textile-enabled solutions for sensing pressure [41] and stretch [42] currently available.

In short, developing enhanced toys using smart textiles sensors makes it possible to establish a link between the virtual world represented by pervasive technology and the physical world where children live, a key factor in Early

Childhood Intervention [7]. That means we can take advantage of benefits of a complex and abstract technology such as ubiquitous computing without renouncing to usability, acceptance, and confidence offered by everyday objects such as toys [43]. This way, the use of textiles to develop this type of smart objects fosters technology acceptance enabling novel e-health applications.

Finally, we consider that there are several applications that could benefit from the use of sensorized smart toys ranging from rehabilitation activities to support treatment of children with autism [44] in a similar manner to what robotic toys do [45].

6. Conclusions

New computing paradigms such as ubiquitous computing and emerging technologies as smart textiles offer potential ways of interaction that favor the creation of new types of services that directly affect complex tasks such as e-health processes, making them simpler and more accessible. However, this type of technology, useful and necessary, is often rejected due to implications of confidence, privacy, and security. More often this rejection happens when users involved are children and the services offered use sensible and private data such as medical monitoring.

Thus, smart toys provide an interesting way to generate the necessary confidence to ensure the use and acceptance of these solutions. Toys represent an intuitive mode of communication and interaction with children in young ages. A suitable use of these tools could make easy other processes that are presumptively complex and critical. In this sense, the smart toy shows us how to orchestrate these types of tools to ensure the children acceptance and, therefore, the use of the implemented services.

This research line aims to evaluate the usefulness of smart toys to improve the user acceptance of critical e-health services. Aligned with that aim this work proves that it is possible to develop and deploy a sensorized smart toy that supports and increases the confidence of the final users involved in the monitoring for assessment of psychomotor development during early childhood.

Conflict of Interests

Mario Vega-Barbas, Iván Pau, and Evelyn Lebis declare no conflict of interests regarding the publication of this paper. Fernando Seoane and Javier Ferreira are both founders and partly owners of Z-Health Technologies AB.

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Article

Adaptive Software Architecture Based on Confident HCI for the Deployment of Sensitive Services in Smart Homes

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Abstract: Smart spaces foster the development of natural and appropriate forms of human-computer interaction by taking advantage of home customization. The interaction potential of the Smart Home, which is a special type of smart space, is of particular interest in fields in which the acceptance of new technologies is limited and restrictive. The integration of smart home design patterns with sensitive solutions can increase user acceptance. In this paper, we present the main challenges that have been identified in the literature for the successful deployment of sensitive services (e.g., telemedicine and assistive services) in smart spaces and a software architecture that models the functionalities of a Smart Home platform that are required to maintain and support such sensitive services. This architecture emphasizes user interaction as a key concept to facilitate the acceptance of sensitive services by end-users and utilizes activity theory to support its innovative design. The application of activity theory to the architecture eases the handling of novel concepts, such as understanding of the system by patients at home or the affordability of assistive services. Finally, we provide a proof-of-concept implementation of the architecture and compare the results with other architectures from the literature.

Keywords: telemedicine sensor software architecture; assistive services; digital home; activity centered design; confidence

1. Introduction

Ubiquitous computing presents an interesting scientific practice in which the computing capacity increases significantly due to the large number of technological elements that are integrated seamlessly into the environment and our daily lives. The Internet of Things (IoT) represents the next step in this concept and offers the opportunity to arrange these physical objects into communication-actuating networks in a way that is similar to how digital information is organized on the Internet [1,2]. In this way, both concepts in conjunction with ambient intelligence form a novel scenario that provides a customized view of the physical world [3] and thus offers interesting options to develop new interactive services for assisting people in performing certain tasks.

The interaction model that this scenario offers is of particular interest in the definition of smart spaces that are used for the deployment of critical and sensible services, such as the promotion of personal autonomy or telemedicine and e-health solutions [4]. In particular, this scenario is being studied as a new concept of development in the field of Ambient Assisted Living (AAL) and homecare because it facilitates the care of patients in their usual environments [5]. It also provides socio-economic benefits that must be taken into account, such as the promotion of user autonomy, reduction of costs in the management of chronic patients and the possibility of establishing a more direct relationship between primary and specialized care [6].

However, although the current trends in health care and the actual needs of society clearly justify the inclusion of pervasive technology and wireless sensor networks in the development of new types of personalized healthcare applications and assistive services [7,8], unresolved issues and challenges prevent the final implementation and adoption of such pervasive healthcare solutions. The sensors and actuators that are used in smart spaces represent a vague and strange concept that hinders their acceptance by final users. Researchers often encounter serious complications when attempting to deploy this technology in real homes, which is the *location of choice* for the implementation of assistive environments, mainly due to the difficulty of residents in understanding its operation and internal behavior [9,10]. In addition, when assistive environments are applied to clinical practice, strict medical and safety standards must be met, and the services must be administered often and always be supervised by medical personnel, such as doctors, nurses, and therapists, who are commonly referred to as caregivers. These caregivers, as well as the other users, usually have limited knowledge of the technology involved; therefore, the implemented systems must be simple, intuitive and effective. Finally, the integrators that install the devices and certify their proper functioning often encounter difficulties when trying to use components from different manufacturers that utilize proprietary communication protocols.

The Smart Home is a particularly interesting case of assistive environment. Many studies have defined the home as the suitable place to perform certain clinical treatments and assistive therapies [5,6]. Information and Communication Technology (ICT) can effectively facilitate and even

enable novel applications. However, even at home, users may not feel comfortable or confident with these technologies, particularly in areas related to their own health [11]. Therefore, the proper integration of ICT and the home would allow taking advantage of the communication and automation capabilities of ICT with the customization and acceptance advantages of home environments. In this regard, the main objective of the smart home is the correct integration of technologies at home to facilitate the deployment of useful services and maximize user acceptance.

This paper presents a set of requirements for the future development of confident sensitive solutions at home using physical and daily smart objects as sensors. Because the requirements are not easy to fulfill for all services, we propose the development of a smart home platform to address most of the requirements and support the deployment and running of sensitive services. The smart home platform is thought of as middleware for services that is supported by heterogeneous sensors. In this way, the service designer can use the smart home platform as both a development platform, which allows focusing on the specific logic of the service, and a deployment platform that controls the life cycle of the service.

We present a software architecture as a novel design method to support the transformation of common spaces into smart spaces. The architecture emphasizes user interaction as a key concept to facilitate the acceptance of sensitive services by the end users. In this sense, the functionality described in the architecture reflects the research on confident Human-Computer Interaction (HCI) that has been developed by the authors [11]. In addition, this software architecture is based on the theory of activity concepts in that all of the activities of the users are decomposed in actions and tasks [12,13]. Thus, the use of actions and tasks as design elements provides a new way to model smart spaces for assistive services, such as from a point of view that is similar to human behavior, to allow a better overall understanding of the implemented system. In this way, the Activity Centered Design method [14] provides a guideline for the software architecture to obtain an adaptive and robust solution. The research presented in this paper uses this concept to design the internal behavior of the software architecture and to model the interactions between users and the system.

This paper is organized as follows. After this introduction, the state-of-the-art of the software architectures that are related to this topic is presented and analyzed in Section 2. Section 3 describes the major challenges for HCI architectures in the context of telemedicine and assistive services. Such challenges were identified based on the analysis that was performed in the previous section and a systematic literature review. Section 4 describes the proposed software architecture, and Section 5 verifies the architecture with a case study. Finally, Sections 6 and 7 discuss the results and the conclusions drawn from this study.

2. Related Work

The design and construction of software architectures for the deployment of sensible services, such as telemedicine and assistive solutions, have historically focused on both patients and the clinical environment close to home. However, these solutions pose problems of user acceptance due to the use of the home as the means of deployment. For example, studies such as [5] have shown that the actual use of such solutions for medical consultations is low.

From a computational point of view and as a result of the emergence of the ubiquitous computing paradigm, including the IoT and Ambient Intelligence, researchers have attempted to apply the advantages offered by the construction of smart spaces to clinical and assistive practice. This paper focuses on general architectures to support the deployment of heterogeneous services in the smart home. In the following sections, current solutions that are aligned with the objective of this paper are detailed.

2.1. Current Commercial Solutions

Nowadays the market is offering to advanced users several solutions based on the IoT concept to implement services related to visualization of health data, e.g., Apple Health, Google Fit, Fitbit, to easily develop connected applications, e.g., IFTTT, or to access to automate home activities, e.g., SmartThings. These solutions are focused on very specific user needs following the Do-it-Yourself (DIY) approach and are usually deployed on wearable, mobile, tablet or computer devices.

IFTTT (IFTTT Inc., San Diego, CA, USA) presents an action-reaction middleware that allows users to interconnect web services by chains of conditional statements. This technology enables users to capture changes in the state of web services and trigger their own applications according to those changes. Users need some knowledge about web environments and must be getting familiar with web applications in order to take advantage of this powerful solution. Like IFTTT, AppleHealth (Apple Inc., Cupertino, CA, USA) offers users an interaction solution to centralize health mobile applications oriented to manage their health information.

SmartThings (SmartThings Inc., Samsung, Washington, DC, USA) GrandCare Systems (GrandCare Systems, West Bend, WI, USA) and BeClose (BeClose, Vienna, VA, USA) are examples of complete IoT solutions. SmartThings offers final users to control and monitor their home from one usable mobile phone application. This home platform allows interconnecting several home elements such as furniture, doors and some electrical appliances by sensors and actuators (owner and third-party) in order to automate usual human tasks in a home. GrandCare System and BeClose are similar to SmartThings but strong oriented to the elderly home care. Both solutions try to reduce healthcare costs and improve healthcare outcomes by providing a hub point where all stakeholders of these services are involved.

2.2. ATLAS

The Mobile Computer Laboratory of the University of Florida has developed a scalable framework architecture for pervasive computing systems. This architecture allows for abstracting the sensors and actuators that are deployed to a smart home as services [15] from the points of view of developers and programmers. The architecture is oriented at integrators and suppliers, and the solutions that can be developed are limited to a particular type of sensor. Those sensors, which are developed by the same research group, cannot communicate with third party devices transparently. Moreover, this solution omits the computational process to the home users, who are the residents of the intelligent environment.

2.3. S3OiA and WSO₂ Reference Architecture for the IoT

S3OiA [16] presents a research study that is intended to contribute to the standardization and interoperability of the future Internet through an open and scalable solution. It is a syntactic and semantic service-oriented architecture that allows the integration of any object or device, regardless of its nature, into the IoT. Additionally, the architecture enables the use of devices that are deployed in smart environments as a substrate for the automatic composition of complex applications through a triple paradigm semantic space. Thus, the creation of applications is dynamic and adaptive because they can evolve according to the context in which they are executed. The architecture also accounts for the possibility of dealing with different types of users that provide a suitable model of interaction based on their characteristics. However, its global approach, which is oriented towards the DIY concept, prevents it from offering solid solutions for security and reliability in telemedicine and e-Health applications.

Recently, WSO2 presented their reference architecture for the IoT [17]. This white paper introduces the requirements for interacting with and managing devices in the context of the IoT. The reference architecture is focused on architects and developers of IoT projects with the aim of providing them a starting point that covers the major requirements of IoT projects and systems, which include connectivity, device management, data processing, scalability and security. As with S3OiA, this reference architecture presents an overview of the needs of the IoT and attempts to provide a global solution for any type of service that is developed in the context of the IoT. However, it lacks the user's point of view and prevents any requirement about user acceptance or user confidence, which is another key concept for the development of sensible services.

2.4. Smart Daily Objects

Smart daily objects are a usable and understandable interface between people and the environment in which they operate. These elements provide contextual information, such as physical location, origin, and condition, while supporting a model of interaction that is familiar to the person who interacts with them. This requires virtually augmenting the daily objects using information technology and allowing integration into an intelligent environment to obtain the maximum benefit from joining the physical world with the digital world [18]. The goal of using this type of element as a means to create smart spaces is to ensure an optimal level of confidence and acceptance of ambient intelligence systems. Lopez-de-Armentia *et al.* [19] provide an example of how an everyday smart object, such as a coffee maker, can bring about social change towards energy efficiency.

The main problem with the use of these elements is the need for a high degree of design and development expertise, which excludes non-technical people. Although there are initiatives for the development of DIY platforms to solve this problem, the services that are developed in the field of telemedicine and e-health involve a high level of security and reliability.

2.5. Telemedicine and Assistive Experiences in the Digital Home

In [20], the authors present a web-based application for a consultation process solution. The authors claim that this work represents a correct solution from the points of view of usability and the number

of derivations to primary care. However, this study lacks a detailed assessment of user satisfaction and potential acceptance.

The work presented in [21] provides a framework for user-centered design for conducting teleconsultation systems through appropriate communications channels between patients and doctors. This study focused on maximizing the acceptance of the service by users via an initial study of the ecosystem of users and technology acceptance models. The work described in [22] provides a series of recommendations for telemedicine services and e-Health to ensure the proper levels of usability and acceptance. In both cases, the solutions are based on a user-centered design that associates the sustainability of the system and the evolution of the user who is experiencing it; both parameters are highly dynamic and unpredictable.

Finally, in [23], the authors propose a complete solution that combines the concepts of ubiquitous computing and telemedicine. This solution uses an architecture that is based on the IoT to enter the patient environment in the clinical setting and provides a high level of connectivity between clinical devices (interoperability) and telemonitoring systems. However, this research is unclear as to the role that non-technical users should play in the solutions and how this work addresses the problem of final acceptance by those users.

2.6. *UniversAAL*

The *universAAL* (uAAL) project attempts to define and produce an open platform to provide a standardized, reliable and economic approach to develop AAL solutions [24]. To achieve this, uAAL defines logical environments (AAL spaces) that are composed of embedded networked artifacts (software and hardware) that are oriented to a specific human user or a set of users. The core part of uAAL is the middleware, which ensures that all *universAAL* elements (uAAL nodes) in a space can interoperate. The logical execution of the middleware is organized as containers, and there are different containers depending on the type of device in which it is deployed. Thus, the middleware can run as OSGi bundles and Java applications in computers or embedded systems and as APKs in Android smartphones. The pairing communication between each node is performed by defining specific-purpose busses. Finally, a uAAL application is any piece of software that can run on the container and uses the uAAL buses to provide an AAL service.

This project defines a correct AAL solution for developers, but it is limited in the user-system interaction. uAAL uses common graphical user interfaces (GUIs) as interaction elements, and the architecture can only use artifacts that can integrate and develop GUIs. Additionally, uAAL requires introducing new technology into houses, such as smartphones, smart TVs, computers, and other elements, which might not be present in every home or be challenging for the elderly to use.

3. Architecture Challenges of the HCI for Telemedicine and Assistive Services at Home

The development of a telemedicine or assistive service that allows the integration of the different roles that are involved in clinical or healthcare practices in an effective, safe, intuitive and simple manner is a task that poses serious challenges [25–29]. The addition of sensing technologies, which are sometimes intrusive and can be incomprehensible to non-technical users, raises additional challenges from immersing users in highly sophisticated and often intimate environments such as smart spaces.

Within smart spaces, this paper focuses on the digital home. In an academic and industrial context, the home is considered as the appropriate environment for the deployment of telemedicine and assistive solutions [9] because one of the fundamental functions of this type of space is to enable the continuity of care, and the home is a natural space to accommodate this requirement.

A literature review of telemedicine solutions and technologies that are deployed at home shows that most new contributions have included adaptations of sensing technologies that are used in other applications. However, both sensitive services and the digital home have characteristics that significantly alter the requirements that are imposed on the technologies in other application areas.

One of the fundamental issues in defining a solution is the proposal of a functional architecture. The architecture formally models the requirements, so the solutions should follow the patterns that are described in the architecture to fulfil those requirements. Moreover, the architecture must be adapted to all of the actors and users that are involved in the solution and take into account the evolution in the behavior of those actors. The proper choice of elements determines the architecture and, critically, the chances for the success and acceptance of the proposed solution over time.

A requirements gathering process is needed to define an appropriate architecture. Other authors have described several of these requirements [25–27]; however, novel requirements are only described for sophisticated environments and are not properly described and customized for telemedicine solutions at home and vice-versa. The novel requirements are as follows:

- C1. *Installing devices.* As we presented in Section 2, current solutions enable easy device installation by users. However, these solutions lack the rigor that is required for medical applications, so technology integrators must be involved in most cases. Technology integrators must verify the proper operation of the deployment. Therefore, the architecture cannot ignore the role of the integrator.
- C2. *Interacting with the user's home.* The interaction pattern and the application logic are closely related in most applications. Thus, a change in the logic of the application implies changes in the user interface and *vice-versa*. However, this model does not fit well with telemedicine solutions in a digital home. Home users usually learn patterns of interaction and do not properly handle meaningful changes. The final design must disengage the strong connection between logic and the interaction pattern.
- C3. *Evolution of the solution.* Any solution that is based on information and communication technologies should be considered an artifact that evolves with its users. The evolution must allow both the addition of new features to those that are already deployed and a change in the actual conduct of the application based on the acquisition of technical skills and confidence by the users [30].
- C4. *Resilience.* The final use of a technology depends on the analysis and design for the solution, the intended use, and how the users decide to use it. There are cases of technologies that have been used successfully but in different ways than what was initially intended [30]. Thus, an architecture that is oriented to sensitive services must take into account both the user experience and possible variations of use of the technology.
- C5. *User confidence.* A key aspect is the confidence that users can develop towards the solution. If this aspect is not accounted for, the acceptance of proposed solutions will be limited, especially

in the case of real and existing alternatives that provide a similar service. This is considered as one of the main reasons for the limited impact of telemedicine solutions today [25]. The architecture must be able to respond to the fears of users that are trying to improve their confidence in the system. In this research, the term confidence is defined as an arrangement of two key human abilities, understanding and control [11].

While methods are available to develop solutions that take into account several of the challenges described above, reference architectures for defining design patterns for solutions that account for user confidence were not found. The definition of a robust architecture that accounts for these requirements may be a breakthrough for the development and deployment of telemedicine services that allow not only the effective use by one type of user at a given time but also by a wide range of users whose skills can evolve over time. Table 1 compares the challenges presented above with the set of system and service qualities that an assistive system should possess according to Becker [31].

Table 1. Challenges of telemedicine architectures vs. Becker's assistive requirements.

Challenges	Affordability	Usability and User Exp.	Suitability	Dependability	Adaptivity	Extensibility	Resource Efficiency	Heterogeneity
(1)	✓	✓	✓	-	✓	✓	✓	✓
(2)	✓	✓	✓	✓	-	-	-	-
(3)	✓	✓	-	-	✓	✓	✓	✓
(4)	✓	✓	✓	✓	✓	-	-	-
(5)	✓	✓	✓	✓	-	-	-	-

Becker *et al.* [31], in addition of quality requirements of AAL Solutions, also reports several architecture models with potential utilization for implementing solutions based on the mentioned quality aspects. Nevertheless no functional requirement is specified in any of the mentioned architectural models in Becker *et al.* [31]. As shown in Table 1, there is a straightforward relationship between the quality requirements defined in Becker *et al.* [31] and the functional challenges introduced in this work.

Considering integrators as part of the system (C1) ensures that only required and proper devices are integrated into the system (heterogeneity and extensibility) keeping down the cost of deployment (affordability). At the same time integrators provide a human interface between assisted people and the system (usability and user experience), ensuring that the system meets all demands of the final user (suitability). The integrators also verify that each device and element of the architecture work properly according to the requirements of the system in a way that the final deployment of the architecture will be able to support most of the required quality features (adaptivity and resource efficiency). In addition, the proper installation of new devices allows the solution to efficiently evolve (C3) (heterogeneity and extensibility) by increasing the capabilities of the system according to the evolution of the assisted users (adaptivity) to cover both new needs but also new skills (usability and user experience). However, such evolution is subject to the available resources to the final users, e.g., cost and the service providers, e.g., human assistance (affordability and resource efficiency).

The improvement of the confidence of the final users is a key factor of acceptance [11]. The user confidence challenge (C5) implies an increase of both understanding of the operations and behavior of the services deployed in the smart space and the control capacity by users. To promote users'

confidence, a common strategy is to avoid adding unfamiliar elements in the smart space and provide computational capacity to the daily objects. This way, since users already have a good understanding of daily objects, they will be more comfortable with this approach (usability and user experience, and suitability). In addition daily objects will be used for current activities in the smart space allowing the reuse of those objects and consequently reducing the final cost (affordability). Finally, user confidence is related with the availability of services, which must be robust and minimize any unexpected results (dependability).

Resilience (C4) guarantees that devices introduced in a home can be used to support users in additional ways than the initially planned (dependability and suitability). This should be done without affecting the behavior of the system or the users' expectations (usability and users experience). In addition, by addressing this challenge, the amount of devices installed in a home can be reduced because the possibility of using them in different contexts or purposes (affordability and adaptivity).

The evolution of user's capabilities usually implies the change of the interaction requirements (C2) obtained in the first stages of the solution analysis and design. Due to the evolution of the users' knowledge, the interaction system can be unaligned with the users' expectations affecting directly to the user experience or the robustness of the system (dependability and affordability). The proper addressing of this challenge will avoid frustration to users and substantial changes of the solution (usability and user experience, and suitability).

4. Definition of the Software Architecture

The software architecture of a computing system represents the entire structure of the system including the description of all software elements, their properties and the relationship between them [32]. The objective of the software architecture is to define a structured solution that meets all of the functional and operational requirements that are involved in the development of a specific type of service or system [33]. Other details, such as the private details of the elements that make up the architecture and are related to the internal implementation, are not architectural [32] and are outside the scope of this work.

The challenges and requirements that were discussed in the previous section guide the development of the software architecture that is presented in this paper. To define this architecture, we characterize the services that are treated and implemented and their method of deployment in the digital home. We then explain the information exchange model between the entities and describe the modules of the architecture.

4.1. Characterization of Sensitive Services

The guidelines that are imposed by assistive and AAL spaces are related to the increase of people's autonomy and their confidence to enjoy their favorite environments for longer periods of time. To comply with these guidelines, solutions must adapt the environment to people and promote access to basic services for development, social integration and health. A basic service represents the mechanisms that are required to meet the needs of society in matters related to health, education and social participation. These services must also be provided according to criteria of solidarity and social cohesion. ICT provides essential tools for a successful deployment of these services and enables

greater efficiency in implementation, closer cooperation between social partners and the satisfaction of the needs of vulnerable groups.

This study considered telemedicine and assistive services as key services to meet the requirements of the proposed smart home platform because of their extensive requirements and challenges. Therefore, services that do not align with these guidelines have not been taken into account in the definition of the smart home platform, although, as discussed later, they may be functionally integrated if they meet the requirements of the communications architecture.

4.2. Service Deployment Model

A service deployment model defines the way in which the service is offered to users within an environment. In home environments, it is common for different models, such as those based on personal computers (PCs), to be on appliances or on the network. However, we considered that the digital home should have its own approach to provide the advantages described above. Thus, the model of the digital home must allow for the efficient and dynamic deployment of services based on PCs or networks but also have the reliability and ease of installation of appliance-based models.

Figure 1. Graphical representation of the deployment of a telemedicine service in the digital home using the developed architecture.

Figure 1 shows the deployment scheme of telemedicine and assistive services in the digital home. The core of the digital home (CDH) is a central element. The CDH is the base element that allows for the creation of the ecosystem of applications within the household. To do this, the CDH ensures:

- The proper integration of all of the devices and applications that are enabled at home;
- The deployment of basic services in the digital home that can make use of embedded devices as well as applications, and;
- Efficient and confident communication with external entities.

To manage the deployed services, the CDH is responsible for conducting an exploration of existing sensors, actuators and applications in the home, characterizing them according to their specifications and representing them as processes. Then, the Home Operation Units (HOU) deploys each basic

service in the CDH as Figure 2 shows. The HOU implement the house side of a basic service; thus, in the context of this study, we have defined a telemedicine-assistive HOU (it is also possible to deploy other types of HOU, such as electronic voting and telecare examples). The set of deployed HOU enriches the capabilities of the home, and these acquired skills are represented in actions. To deploy these actions, the architecture uses household resources, which are represented as processes, so there must be a mapping or a standard agreement between the actions and processes. This mapping can be performed through standardization during the integration or by semantic associations in the case that there is low uncertainty and they are easily verifiable.

Figure 2. Development of Home Operation Units from real daily objects.

The Provider Organization Unit (POU) is defined to complement the HOU. POUs are within the organizations that provide the service, so they are a representation of the resources and capabilities of the service provider. In this way, the CDH is the entity that manages the life cycle of each HOU and its internal components.

4.3. Model Information Exchange between Entities

The information exchange model is a complete definition of the rules of information transmission as well as the language, including syntax and semantics, which is used in the development of telemedicine and assistive services. The full specification of the model is beyond the scope of this paper, but the fundamentals that are needed to understand the architecture are presented.

Because the CDH is designed to offer sensitive services to users with security and acceptance guarantees, the information exchange model must provide the necessary mechanisms to meet all of the requirements related to this type of service. The challenges presented in Section 3 are of special interest, especially challenges 3, 4 and 5, which depend on external entities such as the healthcare center in addition to the homes.

Given these requirements, the information exchange model uses the concept of the Contract-Document (C-D) that is described in [34]. The C-D is an incremental information record that is filled out by the actors involved in a sensitive activity. The actions of all users are reflected in the document with appropriate security safeguards. This allows knowing the status of the transaction at any time for any entity as well as how it was completed.

At the end of the transaction, both the telemedicine service provider and the patient will obtain a copy of the transaction that was carried out, in which the content of the transaction and the list of actions taken by each entity are clearly reflected (Figure 3). The entities that are involved in this process must show all of this information in a usable and accessible way to achieve a full understanding and correct use by the users. Thus, the interaction between entities is controlled by the document itself through the content that must be refilled by them. However, a C-D is just a generic exchange model that establishes rules for all of the entities that share the same information about a transaction. To implement a specific model for the services discussed in this study, it is necessary to define syntax, semantics and specific implementation rules.

Figure 3. Contract-Document exchange.

To do this, we used the activity theory and the concept of Activity Centered Design. An activity is composed of a set of operations that are performed to meet the needs of people, and the provision of any basic service will be composed of activities. For example, the telemedicine service could be made up of multiple activities, such as “routine check”, “emergency detection and management”, and “teleconsultation schedule”. All of the exchanges of information between different entities in a given organization should be based on activities, which in turn are governed by the rules reflected in the C-D.

Every activity is always guided by goals that satisfy a user need. The activities are divided into actions, which are divided into processes (Figure 4). The actions specify how to execute activities and who will perform each activity. In the case of telemedicine, the actions reflect the clinical procedure that is performed and the organizational health system. The implemented clinical procedure (Figure 5) includes actions that take place within the home, those that are performed by the CDH and the related HOU, and those that are carried out on the premises of the service providers, which are conducted by a POU.

Figure 4. Activity behavior in a telemedicine service deployed in the digital home.

Finally, the processes develop activities under real conditions that are imposed in a given environment. Depending on the resources that a user has, the actions are divided into different processes. Thus, in two different homes, you might deploy the same activity in different instances if they have adequate HOU. The two activities have the same actions, irrespective of the housing, so each action to be taken at home will be sent to the appropriate HOU. However, because each home has different configurations, each action is composed of different processes. The action “to obtain confirmation from the user” does not have to be the same in two houses because the context of each can vary significantly; for example, *in a house adapted for blind people, the feedback can never be visual*.

Figure 5. Example of an activity model applied to this study.

Figure 6 shows and specifies every significant type of data that defines an activity, such as syntax, labels, required fields, descriptions of the activity’s actions, the conditions for an action to be performed, and the activity life cycle.

Figure 6. Activity-Action-Process schema.

This schema shows which entity is in charge of a particular action. Thus, depending on the activity that must be completed, the architecture knows whether the activity should be active at home, in the POU of a service provider, or even in the home of a different user because the identification HOU is unique for the entire application domain. In summary, this information exchange model reflects user activities within the system in the C-D and collects every interaction between users and the system so the users can evaluate the behavior of the system in an understandable way at any time.

4.4. Functional Architecture

The software architecture is based on the modules presented above. These modules, except for the HOU, are generic and occur in all implementations. Because the software architecture presents a design model and the resulting middleware platform, we consider a detailed description of the operation of each HOU to be unnecessary.

Thus, the architecture uses the model defined in Section 4.3 to exchange information at all levels of interaction, both internally between modules and externally between the system and users. The design of activities, actions and associated processes not only defines the behavior of entities when conducting transactions and interactions but also defines the expected behavior by establishing internal communications between modules. This approach is used to determine the advantages offered by the theory of activities to allow the adaptation of this architecture to external changes in functionality or use. In the case of telemedicine, the clinical protocols that are exemplified through activities, actions and processes will be shared by the architecture itself, so there will be no ambiguity or misinterpretation.

As shown in Figure 7, six modules are defined, which must exist in all implementations of the CDH, as well as a set of modules that depend on the services that it can support, which are represented by the HOU. Each action to be taken within the CDH is referred to a module, as shown in Figure 7. A central module, called the Activity Manager, is responsible for managing the documents that represent the activities to be carried out. Any other module can send processes to this module on its own initiative. From these processes, the Activity Module verifies which actions may be involved and which specific module can perform the action.

Figure 7. Graphical representation of the architecture's modules.

Two modules handle outside communications. The Communications Module is responsible for sending and receiving activities through data networks, and the Device Module is responsible for direct communication with the users through compatible devices.

The CDH and its modules will be developed on a middleware that provides the necessary messaging facilities and monitors the status of each of the modules, the lifecycle management, and quality of service. The functionality of each module is described in the following sections.

4.4.1. Activity Manager Module

As previously described, this module uniquely manages the content of the activities. The activities have an internal language that this module interprets to determine what actions can be performed and what modules can perform them. To perform this procedure, this module receives internal processes from the other modules. These processes are identified inside each action, so the Activity Module can determine that a specific process is related to an action. The Activity Module then sends the received process to the module that is able to complete the action. Once completed, the receiver returns the updated action, and the Activity Module completes the activity with that action. This update can in turn lead to further actions because of interdependencies. Figure 8 shows a graphical representation and internal interactions of this module.

The HOU's perform specific operations of a specific service. To create an adaptive design that is understandable by different actors, each HOU represents its capabilities in the form of actions. These actions are stored in the Persistence Module. Thus, the designers of an activity and the Activity Module can know the capabilities of a house and determine if it is possible to deploy a complete activity. Finally, the service integrator addresses the processes-to-action mapping because they depend on the configuration of the home.

Figure 8. Graphical representation of the Activity module.

4.4.2. Device Management Module

A device is any element that processes or provides information, such as *physical location, origin, condition, or use*, that extends the concept beyond the sensors and actuators that are offered by the current market for assistance or telemedicine. This means that it should be possible to use everyday objects, such as clothing, furniture or building materials, as devices. To be used in the context of clinical care, these devices must both ensure an optimum level of security, privacy and control and be installed and manufactured by specialized agencies or service providers and integrators.

This module is in charge of standardizing a set of devices from different manufacturers or entities. Its function is to operate each device on standard processes that are understood by the other modules. This module provides the translation of every device that is compatible with the CDH and HOU to the processes and their storage in a repository. Thus, this module represents the interface between the architecture and the users' world. Figure 9 shows how each device is translated to a set of actions in the digital home.

Figure 9. Abstraction layers: model of device-to-process transformation.

A driver is required for each type of device. Drivers gather the data from the device and build the element of information that is aligned with the process. The relation between the devices and processes is stored in a database that is configured during the integration/installation stage of the CDH deployment. It is then possible to update the database to reflect the changes in the home or users' devices.

4.4.3. Persistence Module

The information that is generated and managed by the architecture and systems must be tightly housed and stored. The Persistence Module provides a unique address space and model to access all of the information that is handled by the rest of the CDHs. All of the activities, in the current state, will be stored in this module. It also stores the databases that are needed to map the devices to processes or to announce the capabilities of a specific module as actions.

4.4.4. Interaction Module

The ubiquitous systems and highly sophisticated environments that are necessary for the deployment of complex services, such as telemedicine or assistive services, include a large number of items that are usually imperceptible and limit the direct involvement of users. Actively involving humans in the computational processes of these types of environments is difficult without limiting and degrading their potential. However, it is easy to define a global view of these environments by abstractions and determine if the operation and the results are expected. The Interaction Module attempts to define the most appropriate, simple, intuitive and understandable model for each type of user interaction based on the set of activities that the deployed system has defined. Together with the Device Manager Module, this module manages feedback to the users and the communications interfaces that are used for such interactions.

We define a four-actor view of the user ecosystem that characterizes all of the users that are involved in an assistive system from the point of view of smart environments and sensitive services, including:

- End-user;
- Relatives and other informal caregivers;
- Service provider, such as health professionals and healthcare entities; and
- Integrators.

4.4.5. Communications Module

This module manages the communications between remote systems. Telemedicine and assistive solutions have a distributed topology that includes communications between every location that is involved, such as the home and the healthcare center. The communication is based on the exchange of activities using the C-D.

4.4.6. Security Module

Security is a critical aspect, so it is necessary to define security in a way that is comprehensible for all of the stakeholders that are involved in providing the service. Several authors have proposed the

implementation of security profiles that are more understandable for users and other stakeholders and also independent of the implemented application or the provided service.

Including security as an independent module of the CDH forces us to define the protection capabilities of the CDH in terms of specific actions. Given their intrinsic nature, such actions would be more intelligible than the descriptions of security mechanisms that are currently used.

The Security Module also manages the users' credentials and performs data encryption as well as verification and digital signature tasks as required to ensure the correct handling of the service information in terms of both service assurance and privacy.

5. Case Study and Verification

The analyzed software architecture has been verified by means of a case study that uses the challenges posed in Section 3 as requirements. The goal of this case study is to demonstrate that the functional description of the architecture is correct. Therefore, the case study presents a partial implementation of the necessary components to show that the proposed approaches meet the identified challenges. The work environment is focused on the digital home, so this implementation uses elements that are associated with this case, such as using *smart daily objects as sensors*.

Figure 10. Overall deployment architecture for the case study of assistive services to control the caffeine consumption of hypertensive patients.

The case study presents the deployment of an assistive application whose main objective is to control the consumption of stimulating drinks by patients suffering from hypertension in the digital home. We follow an agile modeling method in which the contents are more important than the representation. The deployment diagram shown in Figure 10 specifies the initial requirements for this development.

5.1. Device Installation

First, the elements for the deployment of the defined service are installed. The selected devices are:

- (a) A smart coffee maker, which is an example of an everyday object that is endowed with computing capacity, and
- (b) Visualization and interaction devices, such as monitors and smartphones.

The installation of these devices is based on the definition of a bundle and the storage of syntactic information following the data model that was defined in Section 4.3. Figure 11 shows the deployment of the software components that are required for this implementation.

Figure 11. Component diagram.

This example uses a proprietary device, which is the Social Coffee Maker (SCM) [35] from the University of Deusto. This device records the energy consumption of the electric coffee maker and detects the user who performed the action by RFID technology. This information is stored in a document-oriented database (CouchDb). The installation of the SCM into our architecture is performed by the implementation of two bundles: one to access the stored information into CouchDb and one that is related to the action “Register Coffee Consumption”. Figure 12 shows the relationship between the components during the execution of the service.

Figure 12. Sequence diagram of the case study.

Access to the information that is recorded by the SCM was implemented using HTTP methods (REST), and the reader class encapsulates that functionality. The information that the SCM stores is related to the energy consumption, but the target of this case study is to offer the action “Register Coffee Consumption”. Thus, the related bundle can filter data to look for this action.

Finally, we developed a bundle to manage the interaction with monitors (or TVs) and smartphones to show relevant information. This bundle provides a REST API that uses a HTTP packet to show its content on a visual interface. We reused an intelligent multi-device user interface service that was previously developed by the authors in [36].

5.2. Interaction and User Confidence

Activities define the interactions between the users and the services that were designed with the software architecture. An activity is defined as an XML document within the C-D that specifies a set of actions that the system has to perform. The main activity of this case study is focused on controlling the coffee intake by a user at home. In the case study, we only take into account the first level of definition for an activity, which includes the *activity parameters and the set of actions that are required to deploy this action*. The following Box 1 shows a piece of code that programs this activity:

Box 1. Implementation of the “Register Caffeine Intake” activity using XML.

```

<activity>
  <id>001</id>
  <definition>Caffeine consumption register.</definition>
  <others>Other information</others>
  <actions>
    <action>Register coffee</action>
  </actions>
  <events max_reg="20">
    <registry>
      <type>Coffee</type>
      <date>13/10/13</date>
      <hour>09:35</hour>
    </registry>
    <registry>
      <type>Coffee</type>
      <date>13/10/13</date>
      <hour>11:21</hour>
    </registry>
  </events>
</activity>

```

The action “Show information” is used to isolate the interaction and the application logic. The activity shown in Box 1 makes a record of each consumed coffee that is transparent to the user. This action indicates to the system that the registered information has to be displayed by an interaction device. The system uses monitor screens as display devices to perform this action. The new activity within the C-D is composed of the actions showed in Box 2.

Box 2. Implementation of a new action to the “Register Caffeine Intake” activity.

```

<actions>
  <action>Register coffee</action>
  <action>Show relevant information</action>
</actions>

```

This model of interaction is implemented through two different bundles. One bundle is associated with the activity whose goal is to process the information that is stored in the XML document, and the other manages the actions. Actions represent simple or complex services that are offered by the installed devices and other applications to the system and to the users.

The case study uses the OSGi tool ServiceTracker to implement the latter bundle. The aim of this class and the related bundle is to be certain about every service and action that is deployed in the

system and provide access to its information. In this way, we know the actions that are registered by the installed devices. Figure 13 shows the new sequence diagram that models the analyzed interaction.

Figure 13. Sequence diagram of the case study updated with the “Show relevant information” action.

In summary, this interaction model that is based on activities and C-D takes into account all of the users that are involved in an assistive application. Using XML documents and suitable XSLT, our architecture provides an acceptable level of understanding for all user roles. It is then easy to transform the information that is managed by the system into understandable messages, as is shown in Figure 14.

We can then create a mobile application to provide feedback to users in an understandable manner, as is shown in Figure 15.

Finally, the service providers and the final users, including informal caregivers if necessary, define the C-D, while the integrators have a syntactic description of the actions that can be used in the assistive home.

Caffeine consumption register. - Register coffee

You've consumed a Coffee at 13/10/13 (09:35)

You've consumed a Coffee at 13/10/13 (09:35)

Figure 14. Transformation of an activity in an understandable message.

Figure 15. Mobile application to control the user's caffeine consumption.

5.3. Evolution and Adaptation

The adaptation and evolution of the presented architecture is based on several aspects. From a theoretical point of view, we used a development method that is based on activities called Activity Centered Design (ACD). This method suggests using activities that define the product as analysis and design elements instead of the users' requirements. Thereby, changes in the user profile, such as user experience or role, are easier to accept and manage.

From a practical point of view, this architecture is guided by the OSGi's versatility as a tool to effectively manage the lifecycle of the hosted services. OSGi provides mechanisms to evolve the architecture and its applications by including new services or reusing components from other systems without a complex reimplementaion.

5.4. Resilience

The architecture makes it easy to adapt the system to this new behavior. The RFID tags that are provided by the SCM under the coffee cups are used for this purpose. The SCM assigns registry IDs to each coffee consumption; therefore, with a small improvement (adding a new method) to the associated bundle, it is possible to identify the target user (Box 3).

Box 3. Example of resilience of the software architecture illustrated by adding a new action to the main activity.

```
<actions>
  <action>Register coffee</action>
  <action>Identify Manolo as 55677786</action>
  <action>Show relevant information</action>
</actions>
```

6. Discussion

Software architecture represents a functional model that collects all of the requirements that must be met by a system and defines the necessary communications interfaces to ensure that the elements of the different systems can interact [33]. In a sense, software architecture defines a design template that guides and validates the developments arising from it [32].

From the point of view of the occupants of a home, transforming the space into a smart space raises serious doubts about approval and acceptance. These spaces are often intimate and personal and have emotional connotations that hinder modifications through technology because they seem strange, non-aesthetic and/or complicated to manage. However, the work presented in this paper demonstrates that it is possible to design a software architecture that encompasses technical and theoretical restrictive requirements that allow the design and deployment of sensitive solutions in the digital home. In addition, this software architecture pays special attention in the interactions between the users (the entire ecosystem) and the smart space to promote understanding and control of the deployed systems and therefore the environment. These features have been addressed through the definition of five acceptance challenges, which were defined in Section 3: installing devices (C1), interaction with the user's home (C2), evolution of the solution (C3), resilience (C4) and user confidence (C5).

The acceptance of the proposed solution has been addressed at two levels: internal (related to the behavior of the entities that are defined in the architecture) and external (the user's point of view).

To foster the acceptance at the internal level, the software architecture was developed using patterns based on the activity theory and its related Activity Centered Design model. The resulting architecture forms a robust solution that is focused on activities that simplify its evolution with the users' experiences. As Norman explains in [14], Activity Centered Design achieves better results in terms of efficiency and adaptability, which makes the system more stable and nurtures the familiarity of the user with the system, which will undoubtedly affect the final acceptance.

C1: Installing devices. The installation of new devices is reduced to defining its proper use with a portion of a text file, which is transformed for a specific process by the architecture. The inclusion of

the integrator guarantees that the devices that are included and used in the deployed services are well defined and installed. The Device Manager Module and the Interaction Module support the integrators by providing them a guide to adapt the device logic to the system.

C3: Evolution of the system. New user requirements are addressed by changes in the activities files that the software architecture can perform. These files are accessible by integrators and service providers to ensure the fitting of the user's needs.

C4: Resilience. Resilience is one of the objectives of the application of activities in the solution design. With other approaches, different components that are part of the solution partially meet objectives that are set previously by the developers (albeit closely agreed upon with users). With an activity-based approach, different components can be used in ways that the user requires. Whether its use contributes to the development of one or more activities will depend on the degree of customization of the system but will not be limited by the design itself. This achieves a greater ability to adapt to changes introduced by the user.

In the case of the acceptance at the external level (C2, C5), the software architecture considers the interaction process to be an independent element.

C2: Interaction with the user's home. The architecture presents an abstract interaction that is customized to the specific setup of the house. This enables each person to tailor the interaction to their preferences by simply engaging devices for it.

C5: User confidence. The logic of the software architecture is planned in the same way that users would perform their daily activities, which nurtures the understanding of the behavior of the system. Understanding is a key factor of user confidence, but so is the control over the system. For this, the software architecture reflects in the C-D all of the activities that users perform within the smart space. This document attempts to reduce the fears that a user could develop in interacting with sensitive services because they are presented to users in a manner that is readable, understandable and accessible at any time (C5).

The related work that was discussed in Section 2 indicates that there are numerous options for the development and implementation of telemedicine and assistive solutions. A detailed study of the literature about the deployment of telemedicine and assistive services at home shows that the challenges presented in Section 3 must be satisfied to ensure a proper solution. Nevertheless, the research efforts that were reviewed in Section 2 only partially address the identified challenges. The implementation of the case study showed that the proposed software architecture meets the challenges posed in Section 3, which justifies its use as a means for deploying confident telemedicine and assistive services in digital homes. Table 2 compares the presented architecture to the related studies. In general, the architectures and middleware solutions shown in Table 2 are strongly oriented to programmers and specify the interactions between users and systems by graphical user interfaces. However, the interaction should be designed to create a user experience that is enjoyable for all users regardless of their technical level or capabilities [2]. The feeling of confidence that can be generated during its use and the final acceptance depend strongly on the design and implementation of such interactions.

Table 2. Comparison between the proposed architecture and the solutions analyzed in Section 2.

Challenges	ATLAS	S3OiA/WSO2	universAAL	Scherpbier-de Haan <i>et al.</i> [20]	Esser <i>et al.</i> [21]	Dabbs <i>et al.</i> [22]	Jara <i>et al.</i> [23]
1	Only own devices	✓	✓	X	X	X	✓
2	X	✓	X	X	X	✓	X
3	Only in its context	✓	✓	X	X	X	✓
4	X	X	X	X	X	X	X
5	Only for programmers	X	Only for programmers	X	X	X	X

✓: Challenges covered; X: Challenges uncovered.

Only OSGi-based tools guarantee the possibility of evolving and adapting the developed services to new features without degrading the system's capabilities. From the point of view of design, all of the tested tools follow a user-centered model and are defined to meet specific user requirements. Thus, only installing new devices and implementing new applications can perform the system evolution generated by this model. Some authors believe that User Centered Design is not the correct approach [14] to designing long-lasting systems in which the user experience is expected to change.

7. Conclusions

The possibilities for human-computer interaction offered by personal and private smart spaces, such as the digital home, makes them of special interest in fields in which the acceptance of novel technologies is limited and restrictive. The integration of the digital home as a smart space with sensitive solutions can increase user acceptance. However, to be accepted as a valid solution, systems that are based on ubiquitous computing, ambient intelligence and IoT must solve challenges that have not yet been adequately addressed.

This research addresses a current problem of end-user acceptability of smart home technologies by defining a software architecture that meets the typical challenges of sensitive services, such as telemedicine and assistive systems, as well as user acceptance and specifically user confidence. The proposed solution provides a framework to deploy sensitive services into the digital home based on ensuring greater acceptance by every type of users that is involved in these services.

An innovative element of this work is the design methods that are focused on activities to address the development of the software architecture. These methods are widely recognized as key elements for developing user-oriented solutions that allow their evolution with the users' experiences [14]. The activity theory facilitates the definition of a solid basis for designing a software architecture to specifically address the challenges of evolution, resilience and user confidence.

In addition, implementing the contract document makes it possible to capture the activities that users perform daily and include them in the system. The C-D is a key element of the architecture that allows organizing sensible services according to user behavior; therefore, it provides intrinsic knowledge about how the services are running for the user and provides the user understanding and control. Thus, this research addresses a set of acceptability requirements for sensitive services from both the user interaction and technical points of view, including a novel approach of matching service needs to the smart home's capabilities via activity templates and the contract-document-exchange

communications model. Finally, this paper provides a case study of the software architecture and compares the results with other architectures from the literature to verify that the functional description of the architecture is correct.

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Author Contributions

M.V.-B. and I.P. defined the architecture challenges and designed the software architecture; M.V.-B. and M.L.M.-R. defined the theoretical background and conceived and designed the case study. M.V.-B. performed the case study; F.S. and I.P. supported and supervised the research work; M.V.-B. wrote the initial draft and F.S., I.P. and M.L.M.-R. have contributed in the writing of the manuscript. All the authors have contributed in the revision process of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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