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ESCUELA INTERNACIONAL DE DOCTORADO

Sustainability and Internationalization Requirements for Connected Health Services: Method and Applications

Requisitos de Sostenibilidad e Internacionalización para Servicios de Salud Conectados: Método y Aplicaciones

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Requisitos de Sostenibilidad e Internacionalización para Servicios de Salud Conectados: Método y Aplicaciones

A dissertation presented by
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# *Requisitos de Sostenibilidad e Internacionalización para Servicios de Salud Conectados: Método y Aplicaciones*



**Resumen**

Las aplicaciones de salud conectadas son herramientas eficientes para mejorar los servicios de salud. La salud conectada está demostrando ser uno de los promotores más fuertes para la transformación global de la industria del cuidado de la salud. Actualmente, la información sobre salud es verdaderamente omnipresente, pero para garantizar que todos puedan acceder y comprender adecuadamente esta información, es esencial superar la brecha internacional. La diversidad de idiomas y culturas de las personas que buscan información en salud supone que las aplicaciones de salud electrónica deban adaptarse para satisfacer las diferentes necesidades. Los requisitos de sostenibilidad también deben ser considerados en el desarrollo de aplicaciones de salud conectadas para aumentar su adopción a gran escala.

La hipótesis de esta tesis doctoral es:

*Las aplicaciones de salud conectadas pueden mejorarse eficazmente a través de artefactos y métodos definidos desde el campo de la Ingeniería de Requisitos.*

Los requisitos de las aplicaciones de salud dependen mucho del dominio de aplicación. Esta tesis se realiza en el contexto de la donación de sangre. El objetivo principal de esta tesis es desarrollar artefactos que permitan la evaluación efectiva de las aplicaciones de donación de sangre desde el punto de vista de la internacionalización (i18n) y la sostenibilidad.

I18n es el proceso de diseño de una aplicación de software de tal manera que se pueda adaptar a varios idiomas y regiones sin necesidad de cambios de ingeniería. Este aspecto es particularmente relevante en el caso de información extremadamente sensible, como la del ámbito de la salud. La cantidad de información relacionada con la salud difundida en Internet está aumentando rápidamente, especialmente en programas de salud conectados para ambientes multiculturales. Actualmente hay miles de sitios web de salud electrónica en línea que

ofrecen contenido general sobre salud y atención médica, incluyendo cientos de miles de páginas web individuales dedicadas a una amplia gama de temas. Las i18n puede proporcionar un valor añadido a los sistemas de salud conectados, de manera que sean más valiosos para los usuarios de diferentes países. Sin embargo, es necesario disponer de un mecanismo adecuado para comprobar la personalización de una aplicación de salud conectada, en particular con respecto a i18n.

Recientemente, se ha investigado sobre cómo desarrollar software sostenible también conocido como software verde. De hecho, la sostenibilidad de los sistemas sanitarios es uno de los objetivos de las políticas de investigación e innovación financiadas por la UE. Las Naciones Unidas definen el desarrollo sostenible como la capacidad de satisfacer las necesidades del presente sin comprometer la capacidad de las generaciones futuras para satisfacer sus propias necesidades. Esta definición es la más utilizada en la literatura. Según la ONU, la sostenibilidad debe satisfacer tres dimensiones: (i) económica, (ii) social y (iii) ambiental. Por lo tanto, el software sostenible es eficiente en el consumo de energía, minimiza el impacto ambiental de los procesos que soporta y tiene un impacto positivo en la sostenibilidad social y / o económica. El impacto de la sostenibilidad del software pueden ser directo (recursos consumidos como la energía), indirecto (mitigado por el servicio que ofrece) o efecto de rebote. Además de las tres dimensiones antes mencionadas, se han asociado otras dos dimensiones a la sostenibilidad del software: (iv) dimensión individual (o humana) y (v) dimensión técnica.

Las contribuciones clave de esta tesis son: (1) estudiar las aplicaciones de donación de sangre disponibles en los repositorios de aplicaciones, (2) desarrollar un catálogo de requisitos reutilizables para aplicaciones internacionalizadas y sostenibles de salud conectadas, (3) diseñar un método de auditoría basado en el catálogo reutilizable para evaluar la sostenibilidad y la internacionalización de las aplicaciones de salud conectadas, y (4) evaluar empíricamente el método de auditoría.

El primer paso fue estudiar las aplicaciones existentes de donación de sangre. Los siguientes repositorios de aplicaciones se seleccionaron para realizar la investigación: Apple App Store, Blackberry App World, Google Play y Windows

Mobile Store. La población considerada es la de los donantes de sangre, nuestra intervención fue las aplicaciones gratuitas de donación de sangre, y todos los resultados existentes en relación con las aplicaciones de donación de sangre fueron de interés para nuestro estudio. Puesto que el objetivo de este estudio no fue encontrar evidencia sobre las aplicaciones gratuitas de donación de sangre, se excluyó la parte "Comparación" de los criterios PICO. Se analizaron las características de 169 aplicaciones de donación de sangre. Además, se analizó si 133 de estas aplicaciones cumplían con las directrices de usabilidad de un sistema operativo para dispositivos móviles. Se desarrolló un cuestionario de 13 preguntas basado en cuatro fuentes: "Android Design Guidelines", "iOS Human Interface Guidelines", "BlackBerry User Interface (UI) Guidelines" y "Design Library Guidelines for Windows Phone". Además, se analizaron 72 aplicaciones de donación de sangre gratuitas de acuerdo con 12 criterios relacionados con la sostenibilidad individual, social, ambiental y técnica. Estos estudios concluyeron con algunas recomendaciones de interés para programadores, auditores y usuarios de las aplicaciones de donación de sangre. Este estudio tuvo un papel importante en la definición del catálogo de requisitos ISBD-CAT (Internationalized and Sustainable Blood Donation applications CATalog).

La contribución más importante de esta tesis doctoral es el desarrollo del ISBD-CAT. La estructura general del ISBD-CAT sigue recomendaciones internacionales, concretamente la norma IEEE 29148. Cada requisito identificado tiene un conjunto predefinido de atributos que proporcionan información adicional sobre él, tales como: identificador único, fuente y prioridad. Las relaciones de trazabilidad se usan para definir las relaciones entre los requisitos identificados, y que facilitan las tareas de reutilización y mantenimiento. En la medida de lo posible, hemos seguido los principios de mínimo acoplamiento y máxima cohesión para reducir el grado de interdependencia (bajo acoplamiento) y aumentar las relaciones conceptuales y funcionales existentes (alta cohesión) entre los requisitos. Los requisitos de este catálogo se han establecido principalmente a partir de los resultados de las revisiones bibliográficas realizadas en este ámbito y el análisis de los estándares relacionados con la ingeniería de software y la salud conectada. Estos requisitos pueden ayudar a los individuos interesados en obtener, especificar y validar los requisitos para aplicaciones de donación de sangre

internacionalizadas y sostenibles. El catálogo se empleó como punto de partida para definir un método de auditoría adaptado para evaluar aplicaciones en el ámbito de la donación de sangre.

Los artefactos involucrados en el proceso de auditoría son los siguientes:

- ISBD-CAT: este catálogo de requisitos es un elemento clave del método de auditoría, ya que este catálogo representa explícitamente los conocimientos sobre sostenibilidad e i18n obtenidos de las normas disponibles y otras fuentes de información.

- ISBD-CAT*: La proyección o adaptación del ISBD-CAT al sistema específico de donación de sangre, y su contexto de trabajo, en el que se aplicará el método de auditoría. Se espera que el artefacto ISBD-CAT* sea un subconjunto de ISBD-CAT y mantenga todas las propiedades de los requisitos reutilizados.

- Lista de verificación: Lista personalizada de ítems que serán verificados en contra del sistema de salud electrónica de donación de sangre bajo estudio. Esto se genera a partir de ISBD-CAT* y puede adoptar la forma que mejor se adapte al equipo de auditoría. Por ejemplo, la lista de verificación puede ser un cuestionario basado en la web, pero cualquier otro formato electrónico o en papel puede ser admisible. Los formularios de lista de verificación deben estar ordenados, y ser fáciles de usar y de rellenar por los participantes en el proceso de auditoría, como es el caso de los proporcionados por estándares como W3C (Checklist of Checkpoints for Web Content Accessibility Guidelines).

- Informes de auditoría: Estos pueden incluir informes intermedios detallados y un informe final con un resumen de los principales resultados de la auditoría y las recomendaciones del equipo de auditoría.

El método propuesto puede combinarse con el catálogo reutilizable para permitir una evaluación sistemática de las aplicaciones de donación de sangre con respecto a la i18n y la sostenibilidad. La versión Android de la aplicación Blood Donor+, una aplicación Android gratuita, ha sido elegida para ilustrar el proceso

de evaluación. La aplicación Blood Donor+ ha sido elegida por alcanzar una puntuación muy alta en Google Play Store (4,7 sobre 5 estrellas). El primer paso de la evaluación consistió en realizar un análisis preliminar del entorno de trabajo de la aplicación y sus principales características y funcionalidad. A continuación, se generó una lista de verificación para evaluar la aplicación del ISBD-CAT. La lista de verificación consistió en un cuestionario que contenía 27 preguntas para facilitar el trabajo del evaluador. Las métricas obtenidas mediante tras realizar la evaluación empírica han demostrado que el método de auditoría es utilizable, ágil, sistemático y repetible, si los responsables de la auditoría tienen experiencia previa en i18n y/o auditoría. En cuanto a la eficiencia del tiempo de la auditoría, la experiencia de los auditores es importante pero no vital, ya que el uso de una lista de verificación puede reducir el tiempo que se emplea en la auditoría, incluso en el caso de auditores con escasos conocimientos prácticos.

A pesar de la innegable relevancia del i18n y del software sostenible en nuestro mundo globalizado apoyado en las Tecnologías de la Información, no se encontraron estándares específicos relacionados con i18n y la sostenibilidad del software en el área de la e-salud. El catálogo presentado en esta disertación es, por lo tanto, muy beneficioso para los individuos interesados en las aplicaciones móviles de donación de sangre. De hecho, los desarrolladores pueden usar todos o algunos de los requisitos de este catálogo para desarrollar aplicaciones de donación de sangre internacionalizadas y sostenibles. Las organizaciones de salud relacionadas con la donación de sangre o las empresas de desarrollo de software pueden obtener y especificar sus requisitos a partir del catálogo ISBD-CAT. Además, los requisitos de i18n y de sostenibilidad son adaptables y pueden ser reutilizados para otras aplicaciones de salud conectadas, tales como aplicaciones para cardiología u oncología. Además, las organizaciones de auditoría o las partes interesadas en las aplicaciones de donación de sangre pueden utilizar ISBD-CAT para evaluar y/o auditar las aplicaciones de donación de sangre. Se puede generar una lista de verificación a partir de ISBD-CAT. Esta lista de verificación debe incluir un conjunto de requisitos que constituirán la lista de ítems que se van a revisar y que pueden ser adaptados a la aplicación de donación de sangre a ser evaluada. Para ello, debe aplicarse un enfoque basado en la reutilización para generar nuevos documentos de requisitos de ISBD-CAT. Este paso

es necesario, ya que los puntos de variación de los requisitos reutilizables, que son básicamente requisitos parametrizados y relaciones de trazabilidad, deben resolverse en el tiempo de reutilización de acuerdo con la evaluación y/o auditoría del sistema. Los documentos de requisitos estarán asociados a los ítems de la lista de verificación para realizar la evaluación y/o la auditoría de las aplicaciones de donación de sangre. El catálogo se puede aplicar en diferentes escenarios y adaptarse para obtener completamente las necesidades y restricciones del desarrollo de aplicaciones de donación de sangre.

El enfoque presentado en esta tesis está sujeto a la mejora continua a través de la incorporación de nuevos conocimientos provenientes de fuentes de información adicionales, como otras normas, estándares o políticas. Como trabajo futuro, se tiene previsto desarrollar una herramienta automatizada que soporte el método de auditoría. Actualmente se está construyendo una herramienta web, ya que el uso de una herramienta automatizada es altamente recomendable para llevar a cabo el método de auditoría, dado que el proceso de auditoría puede ser tedioso y propenso a errores. Además, se deben realizar más investigaciones para mejorar el método y la aplicación de esta disertación. Se espera mejorar el catálogo a través de la armonización de los múltiples requisitos de sostenibilidad e i18n en el ámbito de la e-salud, dispersos en diferentes fuentes, e incorporar nuevos conocimientos provenientes de otras normas, fuentes de información e incluso directamente de los actores involucrados en el método de auditoría. Este procedimiento de armonización se basará en buenas prácticas ampliamente aceptadas. El resultado de la etapa de armonización podría ser un punto de partida para proponer un estándar de sostenibilidad e i18n en el ámbito de la e-salud.

# *Sustainability and Internationalization Requirements for Connected Health Services: Method and Applications*


## Abstract

Connected health applications are efficient tools to improve healthcare services. Connected health is proving to be one of the strongest drivers for the global transformation of the health care industry. Health information is currently truly ubiquitous and widespread, but in order to guarantee that everyone can appropriately access and understand this information, it is essential to bridge the international gap. The diversity of health information seekers languages and cultures signifies that e-health applications must be adapted to satisfy their needs. Sustainability requirements also should be considered in the development of connected health application to increase their large scale adoptability. The hypothesis of this doctoral dissertation is thus as follows:

*Connected health applications can be effectively improved through artifacts and methods defined from the field of Requirements Engineering.*

Health application requirements are highly context-dependent. For this reason, this dissertation is undertaken in the blood donation context. The main objective of this thesis is to develop artifacts that allow the effective evaluation of blood donation applications from the point of view of internationalization and sustainability. The key contributions of this thesis are: (1) studying blood donation applications which are available in app repositories, (2) developing a reusable requirements catalog for internationalized and sustainable connected health applications, (3) designing an audit method based on the reusable catalog to assess sustainability and internationalization of connected health applications, and (4) empirically validating the catalog and the audit method.

The approach presented in this study is subject to continuous improvement through the incorporation of new knowledge originating from additional information sources, such as other standards or stakeholders. Developing an automated tool with which to carry out the audit method should be considered for future work.

# Preface

This doctoral dissertation has been presented in the form of *thesis by publication*. It comprises three already-published journal articles and two conference papers. For this reason, it is not a coherent monograph but rather a collection of research papers. Nevertheless, a comprehensive summary of all the work performed in the thesis has been included in this document. It provides a general introduction in which the works that compose it are presented and the scientific unity of the thesis is justified, together with an overall summary of the research objectives and the final conclusions, unifying the partial results of each work by combining them.

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I lovingly dedicate this dissertation to Mehdi.

*"Fret not where the road will take you. Instead concentrate on the first step. That's the hardest part and that's what you are responsible for. Once you take that step let everything do what it naturally does and the rest will follow. Do not go with the flow. Be the flow."*

Elif Shafak, *The Forty Rules Of Love*

# 1 Introduction

## 1.1 Introduction

There is a need to promote patient-self management, patient education from a very early stage, healthy lifestyle and independence of patients [1]. All of these can be promoted through connected health services. Connected health can be defined as "the collective term for telecare, telehealth, telemedicine, mHealth, digital health and eHealth services" [2]. Connected health technologies are transforming healthcare and empowering patients as they are assuming greater responsibility for their own healthcare decisions [3, 4]. Connected health services provide the potential for: enhanced reach at a relatively low cost; scalability; time efficiency; and the capacity to provide individual patients [5–7] including traditionally underserved populations, patients with chronic conditions [8, 9] and consumers all over the world [10] with tailoring and customization. International collaborations as regards delivering and evaluating connected health applications provide many opportunities but also lead to very substantial chal-

lenges specifically related to different languages and cultures [11, 12]. Developers and researchers should therefore take into account e-health internationalization (I18n) requirements.

I18n is the process of designing a software application in such a way that it can be adapted to various languages and regions without the need for engineering changes [13]. This aspect is particularly relevant in the case of extremely sensitive information, such as that in the health domain. Many stakeholders currently provide cross-country healthcare material and connected health programs for multicultural environments [14]. The amount of health related information on the worldwide Internet is rapidly increasing [15]. There are currently thousands of e-health web sites online offering general content on health and medical care, including hundreds of thousands of individual web pages dedicated to a broad range of topics [16]. The capabilities of i18n can make connected health systems valuable for users in different countries [17]. However, it is necessary to have an appropriate mechanism with which to check the personalization functionality of a given connected health application, in particular with regard to i18n.

Recently, research has begun to be undertaken into how to achieve sustainable software also known as green software [18–20]. In fact, achieving sustainability of healthcare systems is one of the objectives of research and innovation financed by the European Union (EU) [21]. The term 'Sustainability' is widely used and many definitions are proposed in literature [20, 22, 23]. To interpret the concept of sustainability, which in general refers to "the capacity to endure", a context is needed [19]. Sustainable development has been given a popular definition by the United Nations (UN) as the ability to "meet the needs of the present without compromising the ability of future generations to satisfy their own needs" [24]. This definition is the most widely used in literature [25]. According to the UN, sustainability needs to satisfy three dimensions: (i) economic, (ii) social and (iii) environmental [24]. Therefore, sustainable software is "energy-efficient, minimizes the environmental impact of the processes it supports, and has a positive impact on social and/or economic sustainability" [25]. The impacts of software sustainability can be direct (consumed resources, energy), indirect (mitigated by service) or rebound effect [26–28]. In addition to the three aforementioned dimensions, two other dimensions have been associated to software sustainability

[19, 25]: (iv) individual (or human) dimension and (v) technical dimension.

According to [25] five dimensions should be considered when defining sustainability:

- Individual sustainability: refers to the maintenance of the individual human capital, e.g., health, education, skills and access to services [29]. Individual sustainability can be covered by privacy, safety, security, human-computer interaction, usability, personal health and well-being [19].

- Social sustainability: aims to preserve the social capital and preserve services and solidarity of social communities [29]. Social sustainability can be handled via computer supported collaborative work [19] that aim to strengthening community building and improve community interaction.

- Economic sustainability: aims to maintain capital assets and added value (interest) assets. Economic sustainability can be taken care of in terms of costs, budget constraints, long-term business objectives and market requirements [19] among other economic requirements.

- Environmental sustainability: seeks to improve human welfare by protecting natural resources, such as: water, land, air, minerals and ecosystem. Any system applied in a real world context is situated within a natural environment which means that it has an impact on the environment [19]. Environmental sustainability can be managed by controlling resource flow: waste management, life cycle analysis and environment impact assessment [19].

- Technical sustainability: refers to software systems longevity and their adequate evolution with changing surrounding conditions and respective requirements. Technical sustainability requirements include all requirements which lead to the longevity of a system such as non-obsolescence requirements and the ISO/IEC 25010 [30] quality characteristics (e.g. maintainability, reliability and transferability). Moreover, energy efficiency is also part of technical sustainability requirements [19].

Green software often refers to the environmental dimension of software sustainability and can be defined as "an application that produces as little waste as possible during its development and operation" [18]. In this dissertation, *green software* means *sustainable software*. Green software can be divided into [25]: (1) *green in* software: produce software in a more sustainable way to achieve more sustainable product to help the environment, or (2) *green by* software: develop software that are more environment-friendly to support sustainability goals. Penzenstadler [19] explains that we should achieve a balance among the five aforementioned dimensions of sustainability in order to achieve the overall sustainability of our daily lives.

To promote a large-scale adoption of connected health services there is a need to promote their i18n and sustainability. Therefore, there is a need for a requirement catalog which provides different stakeholders of connected health applications with different requirements set to develop and/or audit sustainable and internationalized connected health applications. According to the IEEE Standard 1028 [31], an *audit* can be defined as "an independent examination of a software product, software process, or set of software processes performed by a third party to assess compliance with specifications, standards, contractual agreements, or other criteria". Different aspects can be taken into account in a software audit, such as usability, accessibility, reliability or i18n, among others, and many health institutions, such as Pen Computer Systems (PCS) [32] in Australia and eCompliance [33] in Canada are interested in auditing e-health platforms. Furthermore, standardization in the field of connected health is a long ongoing activity in which an attempt is made to use latest technologies for the benefit of patients, health services and other interested parties [34, 35]. When standards are used in the context of software development or auditing, it is very useful to adapt, refine and express their contents in the form of explicit software and system requirements [36]. This implies identifying the principal related sources, extracting the relevant text, and reinterpreting all this information in the form of precise requirements [37, 38]. In spite of the relevance of the problem described, neither specific standards and guidelines for e-health software i18n and sustainability nor e-health i18n and sustainability audit approaches are, to the best of our knowledge, available to date.

Health application requirements are highly context-dependent. For this reason, we have chosen to link this dissertation to the blood donation context. Blood donation is seen as a noble act as it helps save precious human lives. It is vitally important to the correct delivery of healthcare [39]. The sufficiency of blood supplies is still one of the major problems of health services [40]. Hospitals and blood donation centers in many countries confront difficulties as regards ensuring a sufficient and safe blood supply [41]. Patients in need are dependent on a constant supply of blood. There is consequently a need to recruit and retain more blood donors, which has traditionally been done using methods such as brochures or videos [42, 43]. New methods have been used to gain attention from blood donors, such as applications to attract more donors and to raise awareness about blood donation. Blood donation applications are very useful for people in need, particularly in the case of emergencies when it is necessary to identify eligible blood donors. Blood donation applications can provide an insight into and useful information about blood donation types and process. Information on blood donation has been identified as a popular service in smart cities [44].

In order to facilitate dealing with sustainability and i18n of blood donation applications in a rigorous and complete manner, we have collect the existing knowledge on sustainability and i18n, mainly gathered from standards, in a single formal document. The document denominated as Internationalization and Sustainability of Blood Donation applications CATalog (ISBD-CAT), has been constructed according to the best Requirements Engineering practices. Although ISBD-CAT can be used as a conventional requirements document in an ordinary blood donation software development process, in this dissertation we focus on its use for audit purposes. This dissertation therefore provides not only a secretion of the sustainability and i18n sources used and the requirements catalog obtained, but also the outline of an audit method with which to asses this kind of properties.

The rest of this chapter is organized as follows: Section 1.2 presents related work. Section 1.3 shows the thesis hypothesis. Section 1.4 outlines the goals of this dissertation. Section 1.5 summarizes the methodology used in this work. Section 1.6 describes the context of this thesis. Section 1.7 presents the contribu-

tions of this dissertation. Finally, Section 1.8 highlights the conclusions.

## 1.2 Related work

### 1.2.1 Requirements engineering

Requirements Engineering is a multidisciplinary activity of critical importance in software development [45]. Requirements Engineering is a sub-discipline of Software Engineering, focused on determining and managing the requirements of hardware and software systems [46]. The term "Requirements Engineering" is widely used to describe the process of systematic handling of requirements. Research in software development has found that the failures and deficiencies of software systems are often rooted in the requirements activities undertaken [47, 48]. Poor requirements can lead to unstable product, gaps between customers expectations and project contents, imprecise expense estimate and lack of traceability [46]. Requirements activities consist mainly of eliciting, analyzing, specifying and validating requirements [46, 49]. System requirements specification (SyRS) and software requirements specification (SRS) documents play a crucial role in software engineering [50]. Requirements documents are essential to both communicate requirements to stakeholders in an understandable manner and define requirements in precise detail for developers [46]. There are two major processes related to software reuse: (1) building for reuse; and (2) building with reuse [51]. The *for reuse* form concerns the identification of reusable knowledge units, their concise representation in an abstract manner and their storage in a knowledge base. The *with reuse* form, meanwhile, consists of searching for reusable knowledge and modifying it in order to allow it to fit into new situations and to enable it to be combined with the knowledge obtained for a new project.

### 1.2.2 Reusable requirements catalogs

Many researchers have presented requirements catalogs for different disciplines. Toval et al. [37] have presented a reusable requirements catalog to improve information systems security. Based on this catalog, Martínez et al. [52] have defined

a requirements catalog to audit personal data protection. A reusable standard-based requirements catalog for learning systems development has been defined by Toval et al. [53]. Cos et al. [36] have presented an e-learning internationalization catalog for audit purposes. Filho and Barbosa [54] have proposed a requirements catalog for mobile learning environments. Jensen et al. [55] have presented reusable security requirements for healthcare applications. It is acknowledged that the use of reusable requirements catalogs like the aforementioned catalogs yields improvements in the quality of the software product and the productivity of the software development process [56]. Recent case studies [57, 58] have, in fact, evidenced that reusability provides greater benefits when it is applied during the initial processes of the software development life cycle.

As far as we know, there is no complete and well-defined set of requirements for blood donation applications. This dissertation is a step forward in this direction. The activities that led to the development of the ISBD-CAT were carried out in the context of *building for reuse*, whereas the application of the ISBD-CAT is related to *building with reuse*.

## 1.3 Hypothesis

Connected health concerns "patient empowerment" [59], and connected health solutions such as personal health records in fact promote patient-self management and patients' independence. Other solutions promote patient education from a very early stage, healthy lifestyle and improve access to supportive care. However, and regardless of the linguistic and cultural barriers in connected health tools, "persons who could benefit most from additional empowerment tools will continue to be left behind" [60]. The key to ensuring inclusion in connected health is to address these barriers with linguistically and culturally appropriate tools in a manner that allows the inclusion of all users [61] and promote their sustainability. The current trend as regards auditing a system or an organization is to comply with standards [62, 63]. IT audits, including e-health sustainability and i18n audits, are, however, still not well regulated [64], principally owing to the lack of standards dealing with sustainability and i18n.

The hypothesis of this doctoral dissertation is as follows:

*Connected health applications can be effectively improved through artifacts and methods defined from the field of Requirements Engineering.*

## 1.4 Goals

In order to test the previous hypothesis, the following overall goal was defined for this dissertation:

*Develop artifacts that allow the effective evaluation of blood donation applications from the point of view of I18n and sustainability.*

This general objective is broken down into the following specific goals:

- **Goal 1**. Study mobile blood donation applications which are available in app repositories.
- **Goal 2**. Develop a reusable requirements catalog for internationalized and sustainable connected health applications.
- **Goal 3**. Design an audit method based on the reusable catalog to assess sustainability and I18n of connected health applications.
- **Goal 4**. Validate the audit method through an empirical evaluation of a blood donation application.

## 1.5 Methodology

A systematic review has been used to address the search for free mobile blood donation applications. The search has followed the quality reporting guidelines set out by the Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) group [65]. The objective of the PRISMA Statement is to help authors improve the reporting of systematic reviews and meta-analyses. A review protocol was adopted in which each step of the systematic review, including eligibility criteria, was described before beginning the search for applications and the data extraction.

For requirements elicitation, requirements have been identified from literature reviews on blood donation applications [9, 66] and from previous research dealing with software quality [67–69], i18n [36, 70] and sustainability [19, 25]. Moreover, requirements from the following standards were also extracted:

- ISO/IEC 25010 standard [30] for system and software product quality requirements and evaluation
- ISO 9241-151 standard [71] for ergonomics of human-system interaction
- ISO/TR 18307 standard [72] which is for interoperability and compatibility in trusted health information interchange between software applications and systems in health care
- ISO/HL7 27931 standard [73] for data exchange in health care environments
- ISO 21090 standard [74] for information interchange in health informatics
- ISO/TR 14292 standard [75] for the definition, scope and context of personal health records
- ISO/TR 20514 standard [76] for the definition, scope and context of electronic health records (EHRs)
- ISO/TS 14265 standard [77] for processing personal health information
- ISO 27799 standard [78] for information security management in health
- The W3C standards [79] for web and mobile devices

Requirements based on Health Insurance Portability and Accountability Act of 1996 (HIPAA) recommendations [80, 81] have been included in the catalog. Furthermore, usability guidelines from app repositories [82] have been taken into consideration in addition to requirements from software engineering for sustainability (SE4S) project [83]. After identifying the standards and the other information sources, the corresponding parts of text relevant to functionalities

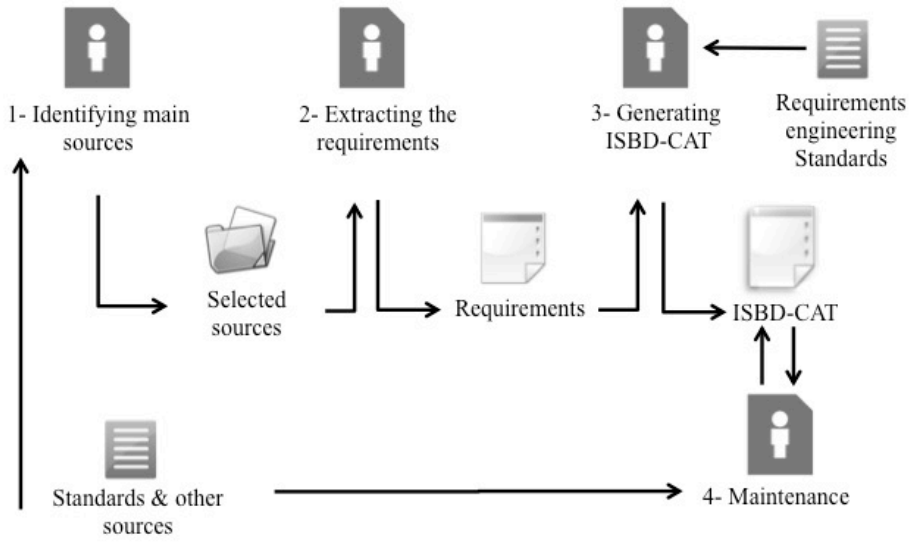


**Figure 1.1:** The reusable requirements catalog generation process

of blood donation applications and i18n and sustainability of connected health applications have been identified, analyzed and specified.

For the catalog development, guidelines from the IEEE 29148 standard [50] to develop the SRS and from SIREN (SImple REuse of software requiremeNts) [37] to develop reusable catalogs of requirements have been followed. The quality of SRS documentation, which serves as an input to the design, coding and testing phases, is critical to the success of any software project [84]. SIREN, which is developed by the Software Engineering research Group (GIIS) at the University of Murcia, is a practical approach that can be used to create, select and specify the requirements of a software system on the basis of reuse and Software Engineering standards. Fig. 1.1 presents the generation process of ISBD-CAT. The catalog maintenance is an important task as it concerns the adaptation of requirements which are changed due to regulations, policies and standards changes or modifications in the connected health applications, in general, and in the mobile blood donation, in particular.

For the empirical evaluation, a checklist is generated from ISBD-CAT that contains a list of items that will be checked against the e-health system under study. A checklist approach is increasingly being adopted in order to perform external

and internal IT audits [85]. In fact, an audit checklist is one of the auditor's basic tools. It is a highly appropriate technique to use, given that it helps to ensure that the audit addresses all the necessary requirements, guarantees that the audit process is systematic, and provides uniformity between different auditors, among other benefits [86].

## 1.6 Context of the thesis

### 1.6.1 Research projects and technology transfer contracts

This dissertation has taken place in the context of the following research, development and innovation (R+D+i) projects and technology transfer contracts:

#### GINSENG-UMU

GINSENG (*Green in Software Systems and Software Engineering*) (TIN2015-70259-C2) is a national research project funded by the Spanish Ministry of Economy and Competitiveness and is coordinated between the Alarcos group of the University of Castilla- La Mancha, and the University of Murcia. The University of Murcia is in charge of the GINSENG-UMU (Green in Software Systems and Software Engineering) (TIN2015-70259-C2-2-R) subproject. In the GINSENG-UMU project, research is focused on the research about the sustainability of the software itself. In this sense, its goal is twofold: (i) to contribute to the knowledge of software sustainability both at national and international level with validated and automated methodological proposals, which will help companies to incorporate sustainability practices in their software systems and (ii) to contribute, actively and from the beginning, to raise awareness of the software impact on the environment, in society in general, and in the IT field in particular. The principal investigators (PI) of the GINSENG-UMU project are Dr. Ambrosio Toval and Jos◎ Luis Fern◎ndez Alem◎n from the University of Murcia. The project has a duration of three years (2016-2018).

Through this project, the doctoral candidate was able to undertake the sustainability aspects of this thesis and to be in direct contact and collaborate with both national and international researchers and research groups.

### GEODAS-REQ

GEODAS (*GEstiOn para el Desarrollo globAl del Software*, in English *Management for Global Software Development*) is also a national research project funded by the CICYT and coordinated between the Alarcos group of the University of Castilla-La Mancha, the Lucentia Group of the University of Alicante and the University of Murcia. In particular, the University of Murcia is in charge of the GEODAS-REQ (*GEstiOn para el Desarrollo globAl del Software mediante ingeniería de REQuisitos*, in English *Management for Global Software Development through Requirements Engineering*) subproject.

In the GEODAS project, the main objective is to optimize the quality and productivity of software factories in GSE environments, starting from mechanisms to improve the management of their processes. The PI of the GEODAS project is Dr. Mario Piattini from the University of Castilla-La Mancha, while the PI of the GEODAS-REQ subproject is Dr. Ambrosio Toval from the University of Murcia. The project had a duration of three years (from January 2013 to December 2015).

Through this project, the doctoral candidate was able to deal with the i18n aspects of this thesis, discover the SIREN process and the basis of the definition of requirements catalogs, and collaborate with researchers specialized in the field Requirements Engineering, particularly with Dr. Juan Manuel Carrillo-de-Gea.

### Mobile Personal Health Records in Morocco

Mobile Personal Health Records in Morocco (*MPHR-PPR1-2015-2018*) is a research project funded by the Ministry of Higher Education, Scientific Research and Professional Training in Morocco. The main objective of this project is the development of a system that consists on: (i) a set of medical sensors and (ii) a mobile application. The PI of this project is Dr. Ali Idri. The project has a duration of two years (from January 2016 to December 2018).

Through this project, the doctoral candidate was able to maintain and extend its established collaborations with Dr. Ali Idri and Mrs. Manal El Bajta.

### 1.6.2 Doctoral program

The doctoral candidate has been working on her thesis within the International Doctorate School of the University of Murcia (*EIDUM*).

### 1.6.3 Scholarships and research stays

During the execution of this dissertation, the doctoral candidate has benefited from a research stay financed by the Mobile Personal Health Records in Morocco project and a research grant offered by Erasmus+ program of the EU, which followed a scheme of subsidies awarded on an open and competitive basis. These grants allowed the doctoral candidate to complete a research stay in location outside Spain, which were useful to intensify collaboration with international researchers and research groups.

#### Research stay financed by the Mobile Personal Health Records in Morocco project

The doctoral candidate has performed a research stay in the Software Projects Management Research Team, ENSIAS, Mohammed V University in Rabat. During this period of time, Sofia Ouhbi worked in software engineering and e-health. This research stay has been financed by the research project entitled "Mobile Personal Health Records in Morocco". The doctoral candidate has worked under the supervision of Dr. Ali Idri, Full Professor at the ENSIAS (*Ecole Nationale Supérieure d'Informatique et d'Analyse des Systèmes*, in English *National School of Computer Science and Systems Analysis*) of the Mohammed V University in Rabat, Morocco.

*Duration*: from 1st of July 2015 to 31st of May 2016, one year.

#### Research grant offered by Erasmus+

Erasmus+ is an international mobility program between the University of Murcia (Spain) and international partner universities. The program managed by the International Relations Service of the University of Murcia (Spain) and funded by the Erasmus+ program of the EU has awarded the doctoral candidate a six-

month international mobility scholarship to carry out a research stay at ENSIAS, Mohammed V University in Rabat, where the doctoral candidate worked under the supervision of Dr. Ali Idri.

During her stay in ENSIAS, the doctoral candidate carried out research in ongoing papers about the analysis of the impact of sustainability and i18n in m-health applications, and the empirical evaluation of the audit method of e-health applications

*Duration*: 15th of September 2016 to 14th of March 2017, six months.

## 1.7 Contributions

The contributions of this doctoral dissertation are presented in the following paragraphs. Section 1.7.1, Section 1.7.2, Section 1.7.3 and Section 1.7.4 include the contributions related to **Goal 1**, **Goal 2**, **Goal 3** and **Goal 4** respectively. The contributions in which the doctoral candidate has been involved are listed in Sections 1.7.5-1.7.8. Finally, Section 1.7.9 elaborates on the matching between the goals of this doctoral dissertation and its contributions.

### 1.7.1 Goal 1: Study mobile blood donation applications which are available in app repositories

The first step was to study existing blood donation applications. The following app repositories were selected to perform the research: Apple App store, Blackberry App World, Google Play, and Windows Mobile store. The PICO (population, intervention, comparison and outcome) [87] criteria were used to define the search string. The population considered is that of blood donors; our intervention was free mobile applications for blood donation; and all existing outcomes regarding blood donation applications are of interest in this study. As the aim of this study is not to find evidence about blood donation free application, the "Comparison" part of the PICO criteria was excluded. The following types were identified from the description in the repository of each of the blood donation applications selected:

**Find donors.** Applications which help the user find donors

**Find centers.** Applications which help the user to find centers/hospitals where he/she can donate blood

**Records.** Applications which record the donation history of the user

**Blood types.** Applications which explain information about blood types to the user

**Blood calculation.** Applications which estimate the blood type of a user by using the blood types of relatives

**Related to a center.** Applications which provide the user with information related to a center or centers such as blood transfusion services, hospitals, or laboratories

**Eligibility.** Applications which calculate the date on which the user may donate blood based on the date of her/his last donation of blood

**General information.** Applications which provide general information about the blood donation process

Characteristics of 169 blood donation applications have been analyzed. Moreover, the compliance of 133 of these applications with mobile OS usability guidelines has been studies. A questionnaire based on the Android Design Guidelines [88], the iOS Human Interface Guidelines [89], the BlackBerry User Interface (UI) Guidelines [90], the Design Library Guidelines for Windows Phone [91] and composed of 13 questions was developed and used to assess the compliance of the 133 applications selected. Furthermore, the greenability of 72 free blood donation applications has been studied according to 12 criteria related to individual, social, environmental and technical sustainability.

These studies concluded with recommendations for blood donation applications stakeholders. They have also played an important role in the definition of requirements for the ISBD-CAT.

### 1.7.2 Goal 2: Develop a reusable requirements catalog for internationalized and sustainable connected health applications

The most important contribution of this dissertation is the development of the ISBD-CAT. This catalog is partially based on the e-healh Internationalization Catalog (eHI-C) developed by Ouhbi et al. [92] and on the Sustainable Connected

Health Catalog (SCH-C), presented in a paper *under review*. The general structure of the ISBD-CAT, as recommended in IEEE 29148 standard [50], is shown in Table 1.1.

**Table 1.1:** Table of contents

| |
|---|
| 1. Introduction |
| 1.1 Purpose |
| 1.2 Scope |
| 1.3 Product overview |
| 1.4 Definitions |
| 2. References |
| 3. Specific requirements |
| 3.1 External interfaces |
| 3.2 Functions |
| 3.3 Usability Requirements |
| 3.4 Performance requirements |
| 3.5 Logical database requirements |
| 3.6 Design constraints |
| 3.7 Software system attributes |
| 3.7.1 Reliability |
| 3.7.2 Availability |
| 3.7.3 Security |
| 3.7.4 Maintainability |
| 3.7.5 Portability |
| 3.7.6 i18n |
| 3.7.7 Sustainability |
| 3.8 Supporting information |
| 4. Verification |
| 5. Appendices |
| 5.1 Assumptions and dependencies |
| 5.2 Acronyms and abbreviations |

In order to facilitate the search for and reuse of i18n and sustainability requirements, along with their integration into current instantiated requirements documents for blood donation application that is already under way, two new subsections dedicated for i18n requirements (i.e., Section 3.7.6) and for sustainability requirements (i.e., Section 3.7.7) were added as shown in Table 1.1. Each requirement identified has a predefined set of attributes that provide additional information on it, such as: unique identifier, source and priority. Traceability relationships are used to define relationships between the requirements identified which facilitates both reuse and maintenance tasks. As much as possible,

we have followed the principles of minimal coupling and maximal cohesion in order to reduce the degree of interdependency (low coupling) and increase the existing conceptual and functional relationships (high cohesion) among requirements.

Requirements of this catalog have been primarily established from the results of literature reviews conducted in this domain and analysis of standards related to software engineering and connected health. They can assist blood donation stakeholders in eliciting, specifying and validating requirements for internationalized and sustainable connected health applications, in general, and blood donation applications, in particular.

### 1.7.3 Goal 3: Design an audit method based on the reusable catalog to assess sustainability and i18n of connected health applications

The i18n and sustainability catalog was taken as a starting point to define an audit method adapted to assess connected health applications, in general, and blood donation applications, in particular. The audit method is similar to the eHIA-M (e-health Internationalization Audit METhod) defined by Ouhbi et al. [92]. Fig. 1.2 shows the main elements of the audit method, ISBD-AUDIT.

The artifacts involved in the audit process are as follows:

- *ISBD-CAT*: this requirements catalog is a key element of the audit method, since this catalog explicitly represents the knowledge on sustainability and i18n gathered from the available standards and other information sources.
- *ISBD-CAT**: The projection or adaptation of the ISBD-CAT to the specific blood donation e-health system, and its working context, in which the audit method is to be applied. The ISBD-CAT* artifact is expected to be a subset of ISBD-CAT and maintains all the properties of the reused requirements.
- *Checklist*: The customized list of items that will be checked against the blood donation e-health system under study. This is generated from ISBD-CAT* and can adopt the form that best suits the audit team. For instance,

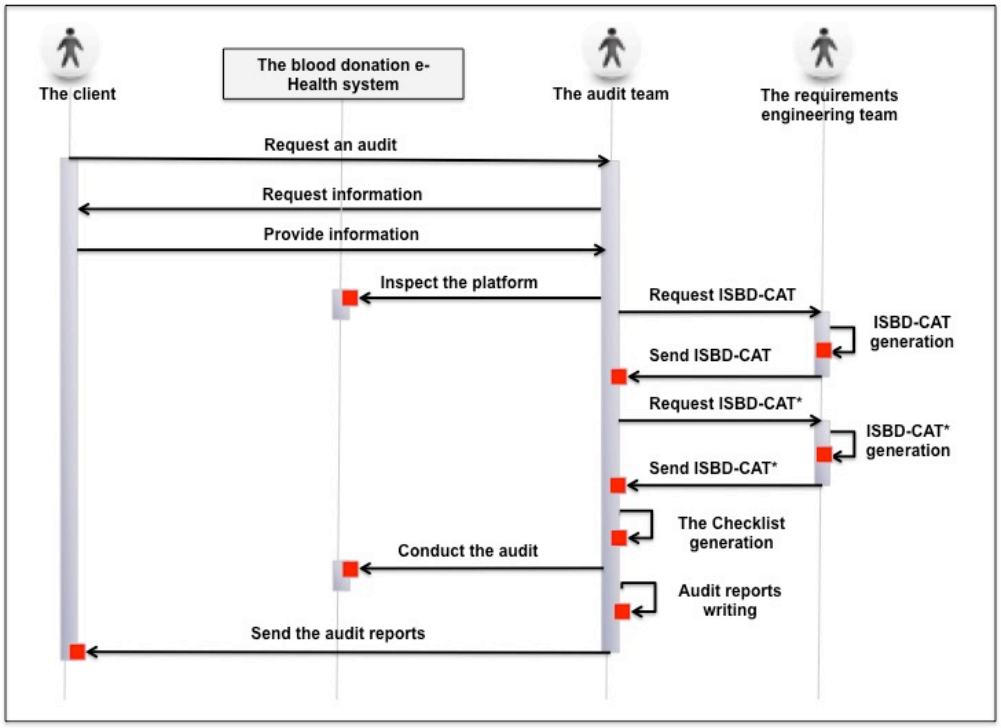


**Figure 1.2:** The Internationalization and Sustainable Blood Donation Audit Method

the Checklist can be a web-based questionnaire, but any other electronic or paper-based format may be admissible. The Checklist forms must be ordered, user-friendly and easy for the participants in the audit process to fill in, as is the case of those provided by standards such as W3C (Checklist of Checkpoints for Web Content Accessibility Guidelines).

- *Audit reports*: These may include intermediate, detailed reports and a final report with a summary of the main results of the audit and the audit team's recommendations.

The proposed method can be combined with the reusable catalog to enable a systematic assessment of blood donation applications with regard to i18n and sustainability.

### 1.7.4 Goal 4: Validate the audit method through an empirical evaluation of a blood donation application.

The Android version of the *Blood Donor+* app (https://goo.gl/LOeDNS), a free app, has been chosen to illustrate the evaluation process. The app *Blood Donor+* has been chosen because of its very high review score in *Google Play Store* (4.7 out of 5 stars) given by 34 real users. This number may appear as relatively small, however, by taking into account Nielsen's finding that small groups can provide enough usability information [93], this score can be used as an indicator of this application's quality. The first step of the evaluation consisted of carrying out a preliminary analysis of the app's work environment and its main features and functionality. Then, a Checklist to evaluate the app was generated from the ISBD-CAT. The Checklist was in the form of a questionnaire containing 27 questions so as to facilitate the work of the evaluator [94]. We have discarded requirements from ISBD-CAT that are not applicable to this app. The questions can be answered by "Yes", "No" or "Partially". Total questions: 27. Yes (+1): 12. No (+0): 13. Partially (+0.5): 2.
$Coverage = 13 * 100/27 = 48.15\%$ To improve this app, a list of recommendation has been proposed.

The metrics obtained through the use of the empirical evaluation has proven the audit method to be usable, agile, systematic and repeatable. If the people in charge of the audit have previous experience of i18n software and/or auditing. With regard to the time efficiency of the audit, the auditors' experience is important but not vital, as the use of an audit checklist can reduce the time that they spend, even in the case of auditors with low levels of practical knowledge.

### 1.7.5 Journals indexed in Journal Citation Reports (JCR)

- **Contribution 1**. Sofia Ouhbi, José Luis Fernández-Alemán, Juan Manuel Carrillo-de-Gea, Ambrosio Toval, and Ali Idri. "E-health internationalization requirements for audit purposes." *Computer Methods and Programs in Biomedicine* 144 (2017): 49-60. doi: 10.1016/j.cmpb.2017.03.014. JCR Science Edition 2015 impact factor: 1.862; Q1 (16/105): *Computer Science, Theory & Methods*.

*Summary*: Presentation of an e-health software audit by using i18n requirements, specified in the form of a reusable requirements catalog.

- **Contribution 2**. Sofia Ouhbi, José Luis Fernández-Alemán, José Rivera Pozo, Manal El Bajta, Ambrosio Toval, and Ali Idri. "Compliance of blood donation apps with mobile OS usability guidelines." *Journal of Medical Systems* 39, no. 6 (2015): 63. doi:10.1007/s10916-015-0243-1. JCR Science Edition 2014 impact factor: 2.213; Q2 (7/24): *Medical Informatics*; Q2 (31/88): *Health Care Sciences & Services*.

  *Summary*: Analysis of the usability compliance of 133 free blood donation applications with the guidelines of Android, iOS, Blackberry and Windows Phone.

- **Contribution 3**. Sofia Ouhbi, José Luis Fernández-Alemán, Ambrosio Toval, Ali Idri, and José Rivera Pozo. "Free blood donation mobile applications." *Journal of Medical Systems* 39, no. 5 (2015): 52. doi:10.1007/s10916-015-0228-0. JCR Science Edition 2014 impact factor: 2.213; Q2 (7/24): *Medical Informatics*; Q2 (31/88): *Health Care Sciences & Services*.

  *Summary*: An analysis and assessment of the characteristics of 169 free blood donation applications as regards features and functionality.

- **Contribution 4**. Sofia Ouhbi, José Luis Fernández-Alemán, Ambrosio Toval, José Rivera Pozo and Ali Idri. "Assessing Sustainability of Connected Health Applications." *Major revision*. In *Journal of Software: Evolution and Process*. JCR Science Edition 2015 impact factor: 0.729; Q3 (69/106): *Computer Science, Software Engineering*.

  *Summary*: Presentation of a checklist, generated from a reusable requirements catalog, to assess sustainability of connected health applications.

### 1.7.6 Communications in international conferences and workshops

- **Contribution 5**. Sofia Ouhbi, José Luis Fernández-Alemán, Ali Idri, Ambrosio Toval, José Rivera Pozo and Manal El Bajta. "A Reusable Requirements Catalog for Internationalized and Sustainable Blood Donation Apps."

In the *12th International Conference on Evaluation of Novel Approaches to Software Engineering (ENASE)*, pp. 285-292. SCITEPRESS, 2017. CORE 2017: B. doi: 10.5220/0006360202850292.

*Summary*: Presentation of a reusable requirements repository for blood donation applications based on the main related software engineering standards, e-health technology standards and literature.

- **Contribution 6**. Sofia Ouhbi, José Luis Fernández-Alemán, Ali Idri, and José Rivera Pozo. "Are mobile blood donation applications green?" In 2015 *10th International Conference on Intelligent Systems: Theories and Applications (SITA)*, pp. 1-6. IEEE, 2015. doi: 10.1109/SITA.2015.7358377.

  *Summary*: Greenability assessment of seventy-two free blood donation applications using individual, social, environmental and technical dimensions of sustainability.

### 1.7.7 Chapters in international books

- **Contribution 7**. Sofia Ouhbi, Ali Idri and José Luis Fernández-Alemán. "Connected Health Services in Smart Cities." *Under review*. To be published in *Smart Cities: Development and Governance Frameworks* by Springer, 2018.

  *Summary*: Presentation of different types, applications and benefits of connected health services in addition to the challenges that affect the large-scale adoption of connected health services in smart cities.

### 1.7.8 Communications in national conferences and workshops

- **Contribution 8**. Sofia Ouhbi, José Luis Fernández-Alemán, Ambrosio Toval, José Rivera Pozo and Ali Idri. "Towards Sustainable Connected Health Applications". In *III Jornadas Doctorales de la Universidad de Murcia*. Murcia, Spain. 30 May - 1 June 2017.

  *Summary*: Presentation of requirements that can be used to develop sustainable connected health applications.

### 1.7.9 Goal coverage

Table 1.2 shows the matching between the goals of this doctoral dissertation and its contributions.

**Table 1.2:** Coverage of the goals with publications

| Goal | Goal 1 | Goal 2 | Goal 3 | Goal 4 |
|---|---|---|---|---|
| **Contr. 1** | | X | X | X |
| **Contr. 2** | X | | | |
| **Contr. 3** | X | | | |
| **Contr. 4** | | X | X | X |
| **Contr. 5** | | X | X | X |
| **Contr. 6** | X | | | X |
| **Contr. 7** | | X | | |
| **Contr. 8** | | X | | |

## 1.8 Conclusions

In spite of the undeniable relevance of i18n and sustainable software in our IT-driven globalized world, no specific standards dealing with software sustainability and e-health i18n were found. The catalog presented in this dissertation is therefore very beneficial for different blood donation application stakeholders. In fact, developers can use all or some requirements of this catalog to develop internationalized and sustainable blood donation applications. Blood donation health organization or development companies which are willing to promote blood donation via applications can elicit and specify their requirements from the ISBD-CAT. Moreover, the i18n and sustainable requirements are adaptable and can be reused for other connected health applications such as applications for cardiology or oncology.

Furthermore, audit organizations or blood donation application stakeholders can use the ISBD-CAT to evaluate and/or audit blood donation applications. A checklist can be generated from the ISBD-CAT. This checklist should include a set of requirements that will constitute the list of items to be checked and can be

adapted to the blood donation application to be evaluated. To that end, a reuse-based approach to generate new requirements documents from the ISBD-CAT should be applied. This step is necessary, since the variation points of the reusable requirements, which are basically parameterized requirements and traceability relationships, must be resolved in reuse time in accordance with the system evaluation and/or audit. The requirements documents will then be mapped onto items of the Checklist in order to carry out the evaluation and/or the audit of blood donation applications.

The catalog can be applied in different scenarios and adapted to fully capture the needs and constraints of blood donation application development. The requirements catalog contents will be subject to continuous improvement through the incorporation of new knowledge originating from additional information sources, such as other recommendations, standards or policies.

At this point, I am able to conclude that the results derived from our study support the hypothesis of this doctoral dissertation, which was posed in Section 1.3. Connected health applications, especially blood donation applications, can be effectively improved through artifacts and methods defined from the field of Requirements Engineering. However, a case study in a blood donation institution is still needed to fully judge the practical contributions of this thesis.

Fig. 1.3 presents the types of contributions shown in Table 1.2. Part of the results of this thesis have been submitted and published in various peer-reviewed forums. At the time of writing, 2 out of 8 contributions are not published yet, but instead *under review*. Fig. 1.4 provides an overview on the status of the contributions.

Further research should be undertaken to improve the method and application of this dissertation.

- The improvement of the sustainability and i18n catalog through harmonizing the multiple e-health sustainability and i18n requirements that are scattered throughout different sources, and incorporate new knowledge originating from other standards, information sources and even directly from the stakeholders involved in the audit method. This harmonization

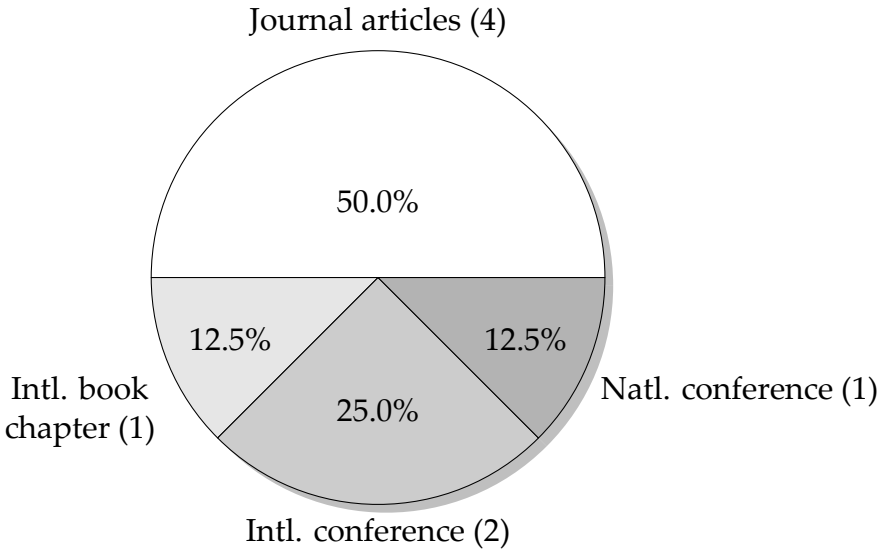


**Figure 1.3:** Types of the contributions

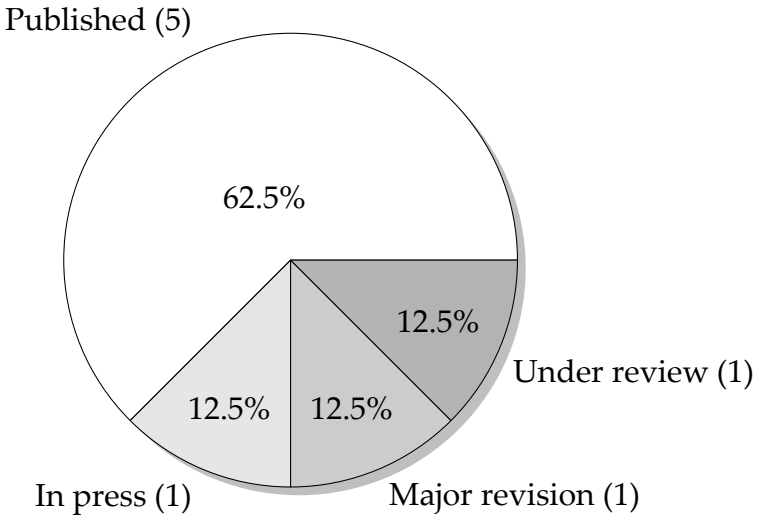


**Figure 1.4:** Status of the contributions

procedure will be based on widely accepted best practices [95, 96].

- As mentioned above, this research has identified the lack of a standard focused on the i18n of software, not only in the e-health realm, but, even worse, in the ICT industry. For this reason, and as a possible solution, it is our intention to make a proposal to some standardization international organization, such as IEEE, ITU or ISO, contacting the related committees or subcommittees that can be more related to this i18n topic. For example, we have identified the ISO/IEC JTC 1 Information Technology (Joint Committee), in particular through the following subcommittee and group: ISO/IEC JTC 1/SC 36/WG7 ITLET - Culture, language and individual needs, for this aim. The outcome of the harmonization step could be a starting point for carrying out such a standardization.

- A web-based tool is currently under construction, since the use of an automated tool is highly advisable as regards carrying out the audit method, given that the audit process can be tedious and error prone [52, 97].

- A case study to implement and evaluate a mobile application in a blood donation center in Murcia, Spain will be performed to improve the requirements catalog and the audit method and to complete the evaluation of their applicability.

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*"It seems right now that all I've ever done in my life is making my way here to you."*

Graeme Simsion, *The Rosie Project*

# A Publications

This doctoral dissertation has been presented in the form of *thesis by publication*. As stated in the applicable regulations, doctoral candidates may opt to submit their thesis in this modality provided they have **a minimum of three papers** published or accepted in **journals indexed in international databases** of recognized prestige, or in **scientific journals** or **edited books** of justified importance, according to the quality indications established in Spain by the National Agency of Quality Assessment and Accreditation (ANECA). It is necessary to provide full copies of the articles, their references, the personal details of all of the authors and the venues in which they have been published. In addition, the doctoral candidate is expected to specify her contribution to the included papers. All these requirements are fulfilled in this appendix.

The doctoral candidate has submitted three journal articles [9, 82, 92] and two conference papers [66, 94], whose full copies are included in the following sections. The references of these works are as follows:

- Sofia Ouhbi, José Luis Fernández-Alemán, Juan Manuel Carrillo-de-Gea,

Ambrosio Toval, and Ali Idri. "E-health internationalization requirements for audit purposes." In *Computer Methods and Programs in Biomedicine* 144 (2017): 49-60. doi: 10.1016/j.cmpb.2017.03.014.

- Sofia Ouhbi, José Luis Fernández-Alemán, José Rivera Pozo, Manal El Bajta, Ambrosio Toval, and Ali Idri. "Compliance of blood donation apps with mobile OS usability guidelines." In *Journal of Medical Systems* 39, no. 6 (2015): 63. doi:10.1007/s10916-015-0243-1

- Sofia Ouhbi, José Luis Fernández-Alemán, Ambrosio Toval, Ali Idri, and José Rivera Pozo. "Free blood donation mobile applications." In *Journal of Medical Systems* 39, no. 5 (2015): 52. doi:10.1007/s10916-015-0228-0

- Sofia Ouhbi, José Luis Fernández-Alemán, Ali Idri, Ambrosio Toval, José Rivera Pozo and Manal El Bajta. "A Reusable Requirements Catalog for Internationalized and Sustainable Blood Donation Apps." In the *12th International Conference on Evaluation of Novel Approaches to Software Engineering (ENASE)*, pp. 285-292. SCITEPRESS, 2017. doi: 10.5220/0006360202850292.

- Sofia Ouhbi, José Luis Fernández-Alemán, Ali Idri, and José Rivera Pozo. "Are mobile blood donation applications green?" In 2015 *10th International Conference on Intelligent Systems: Theories and Applications (SITA)*, pp. 1-6. IEEE, 2015. doi: 10.1109/SITA.2015.7358377

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- Mrs. Manal El Bajta (manal.elbajta@gmail.com). PhD student, University of Mohammed V in Rabat, Ecole Nationale Supérieure d'Informatique et d'Analyse des Systèmes, Avenue Mohammed Ben Abdallah Regragui, BP 713 Rabat, Morocco.

A brief explanation of the relevance of the venues in which the papers have been published is as follows:

- *Computer Methods and Programs in Biomedicine* is a peer-reviewed scientific journal published by ELSEVIER (Ireland) since 1985. It covers computing methodology and software systems derived from computing science for implementation in all aspects of biomedical research and medical practice. It is designed to serve: biochemists; biologists; geneticists; immunologists; neuroscientists; pharmacologists; toxicologists; clinicians; epidemiologists; psychiatrists; psychologists; cardiologists; chemists; (radio)physicists; computer scientists; programmers and systems analysts; biomedical, clinical, electrical and other engineers; teachers of medical informatics and users of educational software. It was included in the top quartile of the JCR list at the moment of publishing the article. JCR Science Edition 2015 impact factor: 1.862; Q1 (16/105): *Computer Science, Theory & Methods*. SJR 2015 impact factor: 0.985; Q1: *Computer Science Applications*; Q1: *Health Informatics*; Q1: *Software*.
- *Journal of Medical Systems* is a peer-reviewed scientific journal published by SPRINGER (United States) since 1977. Journal of Medical Systems provides a forum for the presentation and discussion of the increasingly extensive applications of new systems techniques and methods in hospital

clinic and physician's office administration; pathology radiology and pharmaceutical delivery systems; medical records storage and retrieval; and ancillary patient-support systems. It publishes informative original articles, reviews, and studies across the entire scale of medical systems, from large hospital programs to novel small-scale medical services. It was included in the second quartile of the JCR list at the moment of publishing the article. JCR Science Edition 2014 impact factor: 2.213; Q2 (7/24): *Medical Informatics*; Q2 (31/88): *Health Care Sciences & Services*. SJR 2015 impact factor: 0.717; Q1: *Health Information Management*; Q2: *Health Informatics*.

- *The International Conference on Evaluation of Novel Approaches to Software Engineering (ENASE)* is an international conference to advance knowledge and research in software engineering, including and emphasizing service-oriented, business-process driven, and ubiquitous mobile computing. The conference ENASE aims at identifying most hopeful trends and proposing new directions for consideration by researchers and practitioners involved in large-scale systems and software development, integration, deployment, delivery, maintenance and evolution. All papers presented at the conference venue are available at the SCITEPRESS Digital Library. The international conference ENASE is a CORE 2017: B and it is indexed in DBLP and Scopus.

- *The International Conference on Intelligent Systems: Theories and Applications (SITA)* is a major international scientific event, technically co-sponsored by IEEE, organized with the objective of bringing together researchers and industry professionals sharing the Intelligent Systems passion. SITA aims at presenting the latest research works dealing with emerging Theories and Applications of Intelligent Systems. The proceeding of this conference is published in IEEE Xplore (IEEE Digital Library). SITA is indexed in Scopus.

The doctoral candidate is the lead author of all of the mentioned articles. She worked both independently and also as part of a team with her generally more experienced colleagues. The doctoral candidate carried out the bulk of the work,

she wrote the first version of the papers, she handled the manuscript revisions and finally she saw the manuscripts through to publication. The doctoral candidate counted on the timely advice of the rest of co-authors. The role of the rest of co-authors was thus mostly focused on guidance and supervision.

## A.1 Article in *Computer Methods and Programs in Biomedicine*

**E-health Internationalization Requirements for Audit Purposes**

**Abstract**

*Background and objective*: In the 21st century, e-health is proving to be one of the strongest drivers for the global transformation of the health care industry. Health information is currently truly ubiquitous and widespread, but in order to guarantee that everyone can appropriately access and understand this information, regardless of their origin, it is essential to bridge the international gap. The diversity of health information seekers languages and cultures signifies that e-health applications must be adapted to satisfy their needs.

*Methods*: In order to achieve this objective, current and future e-health programs should take into account the internationalization aspects. This paper presents an internationalization requirements specification in the form of a reusable requirements catalog, obtained from the principal related standards, and describes the key methodological elements needed to perform an e-health software audit by using the internationalization knowledge previously gathered.

*Results*: S Health, a relevant, well-known Android application that has more than 150 million users in over 130 countries, was selected as a target for the e-health internationalization audit method and requirements specification presented above. This application example helped us to put into practice the proposal and show that the procedure is realistic and effective.

*Conclusions*: The approach presented in this study is subject to continuous improvement through the incorporation of new knowledge originating from additional information sources, such as other standards or stakeholders. The application example is useful for early evaluation and serves to assess the applicability of the internationalization catalog and audit methodology, and to improve them. It would be advisable to develop of an automated tool with which to carry out the audit method.

**DOI**

`https://doi.org/10.1016/j.cmpb.2017.03.014`

## A.2 Articles in *Journal of Medical Systems*

**Compliance of Blood Donation Apps with Mobile OS Usability Guidelines**

**Abstract**

The aim of this paper is to employ the guidelines of Android, iOS, Blackberry and Windows Phone to analyze the usability compliance of free blood donation (BD) apps. An analysis process based on a systematic review protocol is used to select free BD apps. An assessment is conducted using a questionnaire composed of 13 questions concerning the compliance of free BD apps with Android, Blackberry, iOS and Windows Phone usability guidelines. A total of 133 free BD apps have been selected from the 188 BD apps identified. Around 63 % of the free BD apps selected have a good compliance with mobile OS usability recommendations. Around 72 % of Android, 57 % of Windows Phone, 33 % of iOS and 33 % of Blackberry BD apps have a high usability score. The aspect of BD app behavior should be improved along with some style components: the use of pictures to explain ideas and the adaptation of the app to both horizontal and vertical orientations. Structure patterns should also be used to improve the structure aspect of a BD app. Usability is a quality aspect that should be improved in current BD apps. Our study provides smartphone users with a list of usable free BD apps and BD app developers with recommendations.

**DOI**

`https://doi.org/10.1007/s10916-015-0243-1`

**Free Blood Donation Mobile Applications**

**Abstract**

Blood donation (BD) is a noble act and mobile applications (apps) can help increase awareness about it. This paper analyzes and assesses the characteristics of free apps for BD as regards features and functionality. A search in Google Play, Apple Apps store, Blackberry App World and Windows Mobile App store was carried out to select 169 free BD apps from the 188 apps identified. The results presented in this paper show that the majority of the apps selected have been developed for the Android operating system. Moreover, most of the apps selected are available to help users search for donors. Few of the apps could not be installed and/or accessed. Of those that could be installed: half of them do not require any kind of authentication; a few of them are available in more than one language; half of them have a geographical restriction; around 60 % of them do not notify the user of BD events and requests; one, which is available for Android and iOS, can connect with a laboratory; around 45 % of them allow users to share information via social networks, and the majority of them do not provide BD recommendations. These results are used as a basis to provide app developers with certain recommendations. There is a need for better BD apps with more features in order to increase the number of volunteer donors.

**DOI**

`https://doi.org/10.1007/s10916-015-0228-0`

## A.3 Article in the *International Conference on Evaluation of Novel Approaches to Software Engineering (ENASE)*

**A Reusable Requirements Catalog for Internationalized and Sustainable Blood Donation Apps**

**Abstract**

Blood donation mobile applications are efficient tools to increase awareness about the importance of blood donation acts and to attract blood donors. The aim of this paper is to define a reusable requirements repository (catalog) for blood donation applications based on the main related software engineering standards, e-health technology standards and literature. The catalog contains requirements regarding internationalization to bridge the cultural and language barriers among blood donors. It includes also requirements for sustainable blood donation applications which cover the individual, social, environmental, and technical dimensions of sustainability. This catalog can be very useful to develop, evaluate and audit blood donation applications and it can be adapted to other m-health applications..

**DOI**

`https://doi.org/10.5220/0006360202850292`

## A.4 Article in the *International Conference on Intelligent Systems: Theories and Applications (SITA)*

**Are Mobile Blood Donation Applications Green?**

**Abstract**

On a global scale, software sustainability is attracting more and more attention. The term green software often refers to environmental sustainability applied to software systems, however, it is impacted by the different dimensions of sustainability. Green software can be divided into green by software and green in software. Blood donation mobile applications are more and more used by smartphone users. They represent an alternative way to attract volunteers and increase awareness about the importance of blood donation acts. The aim of this paper is to assess the greenability of seventy-two free blood donation applications using individual, social, environmental and technical dimensions of sustainability. The type, functionality and energy consumption of each app are identified and analyzed. Results have shown that the type of the BD app has a great impact on its level of greenability.

**DOI**

`https://doi.org/10.1109/SITA.2015.7358377`

# Colophon

This thesis was typeset using LaTeX, originally developed by Leslie Lamport and based on Donald Knuth's TeX. The body text is set in 12 point Palatino Linotype. Palatino is the name of a large typeface family designed by Hermann Zapf, initially released in 1948 and named after 16th century Italian master of calligraphy Giambattista Palatino. It is based on the humanist fonts of the Italian Renaissance. In 1999, Zapf revised Palatino for Linotype and Microsoft, called Palatino Linotype. A template, released under the permissive MIT (x11) license, has undergone some adaptations and modifications to end in the current layout of this doctoral dissertation. The original template can be found online at github.com/suchow/ or from the author at suchow@post.harvard.edu.