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Evaluating Requirements Engineering Tools and Catalogue-Based Reuse of Natural-Language Requirements in Global Software Engineering

Evaluación en Ingeniería Global de Software de Herramientas de Ingeniería de Requisitos y de la Reutilización de Requisitos en Lenguaje Natural Basada en Catálogos

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Evaluating Requirements Engineering Tools and Catalogue-Based Reuse of Natural-Language Requirements in Global Software Engineering

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Resumen

Introducción

La reutilización de software se puede definir como el proceso de usar artefactos software preexistentes en lugar de construirlos desde cero. El principal beneficio de la reutilización de artefactos software es la reducción en el tiempo y el esfuerzo necesarios para *construir* sistemas software. Además, la calidad de los sistemas software es mejor cuando se reutilizan artefactos software de calidad, lo que a su vez reduce el tiempo y el esfuerzo necesarios para *mantener* sistemas software. Los artefactos reutilizables pueden ser recursos tales como fragmentos de código fuente, estructuras de diseño, estructuras de implementación a nivel de módulo, especificaciones, documentación, transformaciones, etc. Sin embargo, el nivel de reutilización determina la efectividad de las mejoras en la productividad, la calidad y el tiempo de desarrollo que se pueden obtener. De este modo, se obtienen mayores beneficios cuando la reutilización se aplica durante los procesos iniciales del ciclo de vida de desarrollo de software.

La Ingeniería Global de Software (IGS) implica un cambio de paradigma hacia equipos de desarrollo distribuidos globalmente. La IGS puede ayudar a disminuir los costes, capitalizar las reservas de recursos globales, situar el desarrollo cerca de los clientes, explotar el desarrollo *follow-the-sun*, y abastecer a los mercados locales. La distancia temporal, geográfica, cultural y lingüística, sin embargo, conlleva la existencia de un mayor riesgo de que aparezcan brechas o lagunas en la comunicación. Esto podría obstaculizar gravemente las actividades de colaboración que requieran que los interesados (*stakeholders*) compartan un modelo mental del problema y los requisitos. Por lo tanto, la Ingeniería de Requisitos (IR) presenta varios retos y dificultades específicas cuando los interesados se encuentran distribuidos, debido a que implica la realización de una serie de actividades que, por su propia naturaleza, requieren de una colaboración intensiva

entre diversas personas.

Por lo general, las especificaciones de requisitos se gestionan en la industria mediante requisitos documentados en lenguaje natural no estructurado (LN), los cuales resultan más fáciles de entender que otras notaciones no textuales, aún en el caso de que los interesados carezcan de cualquier tipo de formación técnica. Sin embargo, el LN es inherentemente ambiguo y puede dar lugar a diferentes interpretaciones en función del contexto. Este inconveniente se ve agravado cuando en el proceso se encuentran involucrados interesados que están distribuidos globalmente, en lo que respecta a la existencia de diferencias lingüísticas, sociales y culturales, y problemas derivados de la falta de conocimiento tácito en relación con los requisitos. Además, algunos autores hacen hincapié en la necesidad de disponer de herramientas apropiadas. Las herramientas representan un área importante de investigación en IGS, y un número considerable de los últimos avances que se han producido tienen relación con el desarrollo de herramientas de apoyo para ciertas prácticas colaborativas. El soporte de herramienta automatizado ayuda en la gestión de requisitos y es un factor clave de éxito para las empresas en IGS.

Hipótesis

A pesar de que la reutilización de requisitos y la globalización son dos cuestiones relevantes, y la utilidad de la reutilización de requisitos ya ha sido confirmada en varios estudios, hasta donde sabemos, no existen en la actualidad propuestas que aborden la reutilización de requisitos y la IGS conjuntamente. Creemos que si se definen mecanismos adecuados basados en reutilización para la especificación de requisitos en lenguaje natural, la eficacia y la productividad de los proyectos de IGS podrían verse enormemente favorecidos. La hipótesis de esta tesis doctoral es, por lo tanto, la siguiente:

Si se definieran técnicas adecuadas de reutilización basada en catálogos y una herramienta de soporte automatizado para la especificación de requisitos en lenguaje natural cuando los interesados están distribuidos globalmente, entonces se obtendrían ganancias relevantes de eficacia y productividad en los proyectos de desarrollo de software.

Objetivos

Con el fin de probar la hipótesis anterior, definimos el siguiente objetivo general para esta tesis doctoral:

> *Proponer técnicas de reutilización basada en catálogos y una herramienta de soporte automatizado para la especificación de requisitos en lenguaje natural en IGS, y validarlas empíricamente.*

Este objetivo general se desglosa en los siguientes objetivos específicos:

- **Objetivo 1**. Proponer técnicas basadas en reutilización para la especificación de requisitos en lenguaje natural en IGS.
- **Objetivo 2**. Proporcionar un soporte automatizado para las técnicas de reutilización de requisitos por medio de un prototipo de herramienta.
- **Objetivo 3**. Validar empíricamente las técnicas y el prototipo en un escenario de IGS.

Metodología

En lo que respecta a la metodología y las técnicas de investigación utilizadas, debemos destacar que los métodos empíricos han convertido en una parte integral de la investigación y la práctica en Ingeniería del Software (IS). Los estudios empíricos se suelen clasificar en tres grupos: encuesta, caso de estudio y experimento. Dos de estas técnicas se han aplicado en esta tesis doctoral, a saber encuesta y experimento. La encuesta permite describir una situación o fenómeno a partir de datos obtenidos a través de entrevistas o cuestionarios administrados a una muestra representativa de la población objeto de estudio. Por otra parte, el experimento proporciona un alto nivel de control, ya que permite la manipulación de variables y la medición de sus efectos.

La Revisión Sistemática de la Literatura (RSL) también se ha utilizado en esta tesis doctoral. Es un medio para sintetizar de forma rigurosa la literatura científica en relación a una pregunta formulada por el investigador. Esta técnica permite caracterizar la evidencia sobre un tema en particular y ayuda a identificar

las brechas en el estado del arte, con el fin de establecer las bases de una nueva actividad de investigación.

Otros métodos de investigación son más específicos y se adaptan muy bien a la investigación llevada a cabo en determinados campos del conocimiento. DESMET es un método diseñado para evaluar los métodos y herramientas de IS. Por esta razón, se ha aplicado también en esta tesis doctoral.

Tareas

A continuación se presenta la visión general de las tareas llevadas a cabo para alcanzar el objetivo trazado para esta tesis doctoral:

- **Tarea 1**. Estudiar el estado del arte sobre IR en IGS y proponer técnicas basadas en reutilización para la especificación de requisitos en lenguaje natural en IGS.
  - **Tarea 1.1**. Estudiar el estado del arte sobre los riesgos y salvaguardas para la IR en IGS utilizando una RSL y un enfoque cuantitativo para medir la asociación entre ellos.
  - **Tarea 1.2**. Proponer técnicas basadas en reutilización para la especificación de requisitos en lenguaje natural en IGS, en el contexto del método PANGEA de IR para IGS.
- **Tarea 2**. Estudiar el estado de la práctica sobre las herramientas de IR, seguido por el diseño y prototipado de una herramienta de soporte automatizado para las técnicas de especificación de requisitos en lenguaje natural en IGS basadas en reutilización, que fueron propuestas durante la **Tarea 1**.
  - **Tarea 2.1**. Estudiar el estado de la práctica sobre las herramientas de IR disponibles en el mercado mediante una encuesta, utilizando el método de análisis DESMET para evaluarlas, y un marco de clasificación inspirado en la norma ISO/IEC TR 24766 para categorizar sus capacidades generales y relacionadas con la IGS.
  - **Tarea 2.2**. Realizar un análisis de necesidades para la herramienta de IR PANTALASA (*PANgea Tool And Lightweight Automated Support Architecture*) y su especificación de requisitos, teniendo en cuenta: (1) el

estado-del-arte sobre IR en IGS estudiado en la **Tarea 1.1** y las técnicas basadas en reutilización para la especificación de requisitos en lenguaje natural en IGS propuestas en la **Tarea 1.2**; y (2) el estado-de-la-práctica sobre las capacidades de las herramientas de IR actuales estudiado en la **Tarea 2.1**.

  - **Tarea 2.3**. Producir el diseño de alto nivel o arquitectónico de la herramienta de IR PANTALASA, incluyendo: (1) la estructura de un repositorio de requisitos reutilizables; y (2) los mecanismos específicos necesarios para trabajar en entornos de IGS.
  - **Tarea 2.4**. Implementar un prototipo de la herramienta de IR PANTALASA que sirva para poner en práctica y validar la propuesta, que incluye las técnicas metodológicas y capacidades de las herramientas de IR que se mencionaron anteriormente.

- **Tarea 3**. Analizar empíricamente la viabilidad práctica de la propuesta mediante dos experimentos sucesivos llevados a cabo con estudiantes distribuidos de acuerdo a un escenario de IGS de tipo nearshore, que incluye participantes ubicados en Rabat (Marruecos) y Murcia (España).

Conclusiones

La gestión del conocimiento en escenarios distribuidos globalmente es una tarea difícil. Esta tesis se centra principalmente en un método de IR basado en reutilización para IGS que especifica el conocimiento en forma de requisitos en lenguaje natural. Se propone el uso de un repositorio para organizar en catálogos conjuntos de requisitos reutilizables interrelacionados, con la finalidad de gestionar el conocimiento de los requisitos. Hasta donde sabemos, no hay otras propuestas que aborden ambas cuestiones, IGS y reutilización de requisitos, de manera conjunta. Nuestra contribución clave en el contexto del método mencionado anteriormente radica en: (1) las técnicas de especificación requisitos; (2) la herramienta prototípica de soporte automatizado; y (3) la validación empírica de la propuesta.

En el curso de esta tesis doctoral, se han analizado herramientas de IR comerciales actuales por medio de una encuesta. Se descubrieron profundas dife-

rencias de funcionalidad entre ellas. Se ha demostrado empíricamente que de ninguna manera todas las soluciones dan el mismo apoyo a las distintas actividades del proceso de IR. Tres grupos de herramientas relacionadas fueron identificadas a través de una estrategia de *clustering*, que podría ser utilizada para considerar diferentes opciones relacionadas cuando debe tomarse una decisión de compra. Esta completa instantánea de las capacidades de las herramientas de IR también ha sido utilizada como entrada para diseñar la herramienta de soporte automatizado para las técnicas de reutilización propuestas.

Las capacidades de las herramientas de IR incluidas en el marco de clasificación fueron refinadas y ampliadas para reducir su ambigüedad, y como resultado de este proceso, se obtuvo una especificación de requisitos para la herramienta de soporte automatizado. A partir de este documento, se examinaron dos alternativas de diseño para construir, de acuerdo con las especificaciones, un prototipo de la herramienta de IR basada en reutilización para IGS. A continuación se aplicó un enfoque de "prueba de concepto" para investigar su idoneidad. Por un lado, se examinaron las wikis y wikis semánticas en un esfuerzo por implementar un repositorio de requisitos reutilizables, con o sin integración de redes sociales para hacer frente a los problemas de comunicación. Por otro lado, se investigaron los sistemas de gestión de contenidos. Se ha confirmado que el uso de gestores de contenidos, en particular Drupal, es apropiado para la construcción de una herramienta de IR basada en reutilización para IGS que cumpla con las condiciones de la propuesta presentada en esta tesis.

Con respecto a la validación práctica de nuestros resultados, se llevó a cabo una familia de experimentos educativos con la que se midió el impacto de la reutilización de requisitos en entornos co-localizados y distribuidos, en lo relativo a la eficacia y la productividad del proceso de IR. El aspecto más innovador de los experimentos es la evaluación de un método de IR basado en catálogos frente a un método de IR en el que se especifican los requisitos desde cero en un contexto de IGS de tipo nearshore. Los resultados muestran que el proceso de especificación de requisitos puede ser mejorado mediante el uso de catálogos de requisitos reutilizables. Vale la pena señalar que la preexistencia de una base de conocimiento en forma de catálogos requiere de una creación inicial y de un esfuerzo de mantenimiento continuo, lo que puede ser una actividad que consuma

mucho tiempo. Un catálogo de requisitos reutilizables debe ser constantemente actualizado y enriquecido, si se va a reutilizar una cantidad importante de requisitos.

Podemos concluir diciendo que nuestros resultados confirman la hipótesis de partida de esta tesis doctoral. Se pueden definir técnicas simples basadas en reutilización y un soporte de herramienta automatizado para la especificación de requisitos en lenguaje natural que den soporte a la IR distribuida globalmente y obtener ganancias significativas de eficacia y productividad. Sin embargo, todavía sigue siendo necesaria una evaluación empírica en la industria para juzgar plenamente las contribuciones prácticas de esta tesis. A nivel de publicaciones, entre los resultados de esta tesis se incluyen un total de 19 trabajos: ocho artículos en revistas indexadas en Journal Citation Reports (JCR) —de los cuales cuatro están actualmente *en revisión* y uno está *aceptado con cambios menores*—, un capítulo de libro internacional, un capítulo de libro nacional, cuatro comunicaciones a congresos o workshops internacionales, una comunicación a un congreso o workshop nacional, y cuatro registros de la propiedad intelectual.

El trabajo futuro incluye la investigación sobre cómo apoyar la gestión de proyectos a partir de la IR, de forma que la gestión de proyectos y los procesos de toma de decisiones dentro de la organización se puedan aprovechar del conocimiento explícito o derivado de los requisitos. La idea principal es posibilitar la gestión dirigida por los requisitos de las fábricas de software en entornos globales. La IR sería la columna vertebral para definir, gestionar y desarrollar líneas de producto y productos software dentro de la organización, integrando estándares de IS y dando soporte a la gestión, seguimiento y control de los proyectos a partir de los requisitos de manera efectiva. Con respecto a la evaluación de las herramientas de IR comerciales, hay tres cuestiones principales en las que se podría centrar nuestro trabajo futuro: (1) proporcionar un *ranking* de criterios para la clasificación de las capacidades o características de las herramientas de IR, dado que se ha definido un marco clasificación general e integral para las capacidades de las herramientas de IR, pero estas capacidades podrían tener más o menos relevancia y valor en función de las circunstancias; (2) nuestro marco de clasificación podría ser mejorado con nuevas capacidades para reflejar las tendencias más recientes y nuevos temas que pueden resultar interesantes, y

podríamos entonces lanzar el cuestionario de nuevo a los proveedores de herramientas de IR y actualizar nuestros datos; y (3) nuestros amplios datos sobre las capacidades de las herramientas de IR podrían utilizarse en forma de un sistema de recomendación para proporcionar a los profesionales un proceso de decisión asistido cuando se enfrentan a la responsabilidad de escoger una herramienta de IR para su organización.

Evaluating Requirements Engineering Tools and Catalogue-Based Reuse of Natural-Language Requirements in Global Software Engineering

Abstract

Software reuse can be defined as the process of using preexisting software artifacts rather than building them from scratch. The major benefit of reusing software artifacts is to reduce the time and effort required to *build* software systems. In addition, the quality of software systems is better when quality software artifacts are reused, which in turn reduces the time and effort required to *maintain* software systems. The reusable artifacts can be assets such as source code fragments, design structures, module-level implementation structures, specifications, documentation, transformations, etc. The reusability level determines the effectiveness of improvements in productivity, quality and development time. Greater benefits are thus obtained when reusability is applied during the initial processes of the software development life cycle.

Global Software Engineering (GSE) implies a paradigm shift towards globally-distributed development teams. GSE can assist to decrease costs, capitalise on global resource pools, locate development closer to customers, exploit follow-the-sun development, and cater to local markets. Temporal, geographic, cultural and linguistic distance result, however, in an increased risk of communication gaps. This might hinder collaborative activities that require stakeholders to share a mental model of the problem and requirements. Therefore, Requirements Engineering (RE) presents several specific challenges and difficulties when the stakeholders are distributed, owing to its collaboration-intensive nature.

Requirements specifications are generally managed in industry by means of unstructured natural language (NL) requirements, which are easier to understand than other non-textual notations, especially when the stakeholders lack any kind of technical training. However, NL is inherently ambiguous and can lead to different interpretations depending on the context. This drawback will be therefore exacerbated when globally distributed stakeholders are involved in

the process, as regards language, social and cultural differences, and problems resulting from a lack of tacit knowledge related to requirements. In addition, some authors emphasise the need for appropriate tools since they help in managing requirements and are key success factors in GSE. Tools represent an important area of research, and a considerable number of recent advances are related to the development of supporting tools for certain collaborative practices.

Even though requirements reuse and globalisation are two relevant issues, and the usefulness of requirements reuse has already been confirmed in several studies, to the best of my knowledge, there are no proposals addressing both NL requirements reuse and GSE together. I believe that if adequate reuse-based mechanisms for natural-language requirements specification are defined, effectiveness and productivity of GSE projects could be greatly favoured. The hypothesis of this doctoral dissertation is thus as follows:

If adequate catalogue-based reuse techniques and an automated tool support were defined for natural-language requirements specification when stakeholders are globally distributed, then relevant gains of effectiveness and productivity in software development projects would be obtained.

Knowledge management in globally distributed settings is a challenging task. This thesis primarily focuses on a reuse-based RE method for GSE that specifies knowledge in the form of natural language requirements. The use of a repository is proposed to arrange into catalogues sets of interrelated reusable requirements, with the purpose of managing requirements knowledge. To the best of my knowledge, there are no other proposals which tackle both issues, GSE and NL requirements reuse, jointly. My key contribution in the context of the previously mentioned method lies in: (1) devising the requirements specification techniques; (2) developing the prototypical automated tool support, based on an extensive study of the RE tools market; and (3) performing the empirical validation of the proposal.

In the course of this doctoral thesis, current, commercial RE tools have been analysed by means of a survey. Profound differences in functionality between them were uncovered. It has been empirically demonstrated that in no way does every solution give the same support to the various activities of the RE process.

This comprehensive snapshot of the RE tool capabilities was also used as an input to design the automated tool support. The RE tool capabilities, which were included in a classification framework, were refined and expanded, and as a result of this process, a requirements specification for the automated tool support was obtained. Starting from this specification, two design alternatives were examined to build a prototype of the reuse-based RE tool for GSE. Then, a "proof of concept" approach was applied to investigate their suitability.

A family of educational experiments was carried out with which the impact of requirements reuse in co-located and distributed environments was measured, as regards effectiveness and productivity of the RE process. The most innovative aspect of the experiments is the evaluation of a catalogue-based RE method versus an RE method in which requirements are specified from scratch in a near-shore GSE setting (Murcia-Rabat). The results show that the requirements specification process can be improved by using reusable requirements catalogues. On the other hand, the preexistence of a knowledge base in the form of catalogues requires an initial creation and continuous maintenance effort, which can be a time-consuming activity. A reusable requirements catalogue must be constantly updated and enriched, if it is to be truly incorporated in a company's work practices.

Further work includes research on how to support project management issues by relying on RE, so that project management and decision making processes within the organisation can take advantage of explicit or derived requirements knowledge. The main idea is to enable requirements driven management of software factories in global environments. RE would be the backbone for defining, managing and developing software product lines and products within the organisation, effectively integrating SE standards and supporting management, monitoring and control of projects starting from the requirements. With regard to the evaluation of commercial RE tools, there are three main issues in which my future work could be focused: (1) provide criteria ranking for RE tools capabilities or features, given that a general, comprehensive classification framework for RE tool capabilities has been defined, but these capabilities could have more or less relevance and value depending on the circumstances; (2) my classification framework could be improved with new capabilities to reflect recent trends and

new topics that are interesting for us (specifically reuse), and I could then launch the questionnaire again to the RE tool vendors and update my dataset; and (3) my extensive data on RE tool capabilities could be used in the form of a recommendation system to provide practitioners with an assisted decision process when they face the responsibility of picking out an RE tool for their organisation.

Preface

This doctoral dissertation has been presented in the form of *thesis by publication*. It comprises four already-published or accepted journal articles and one book chapter. 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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thankful to Dr. Aurora Vizcaíno, who helped me a lot when I was at the beginning of this endeavour and followed my progress until its conclusion. Concerning my short-term research stays at foreign institutions, when I was in Germany, I worked under the supervision of Dr. Christof Ebert. On the other hand, my supervisor in Morocco was Dr. Ali Idri. I am grateful to have had these opportunities; it was an honour for me to work with them. I greatly appreciate their advice and interesting ideas during our meetings. What is more, they made me and my family feel fine, despite being far from home.

My laboratory colleagues have also been really important to me during this large period of time. This is true to the point that I felt encouraged to wake up early many, many days thinking of the morning coffee that I used to have in their company. Nowadays they, for the most part, have left the Software Engineering Laboratory, but I still miss them a lot and I like to remember the good old times. I want to express my deepest esteem and affection to Javier Bermúdez, Óscar Sánchez, Javier Espinazo, Jesús Perera, Javier Cánovas, Sofia Ouhbi, Saad Chadli, Manal El Bajta, Lamyae Sardi, Jesús Sánchez, Fernando Molina, Joaquín Lasheras, Francisco Frutos, Bernabé Nicolás, Inmaculada Carrión, Pedro Ángel Oliver and Youssef Oufaska.

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Juan Manuel Carrillo de Gea
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I lovingly dedicate this dissertation to my three sons, who always bring light into the end of each working day and inspiration to welcome every morning enthusiastically, and to my wife, who bravely fights what many will never experience or understand.

"C'mon" Caramon grinned wearily "save it to tell Flint."
He drew his sword. "Ready?"
"Ready," answered Tas stoutly. "'Always save the best for last', my father used to say. Although" the kender paused "I think he meant that in reference to dinner, not to dying. But perhaps it has the same significance."
Drawing his own small knife, Tas followed Caramon into the enchanted Forest of Wayreth.

Margaret Weis and Tracy Hickman, *Test of the Twins*

1 Introduction

1.1 Introduction

Mili et al. [1] affirmed that software reuse is "the (only) realistic approach to bring about the gains of productivity and quality that the software industry needs". Software reuse can be defined as the process of using preexisting software artifacts rather than building them from scratch [2]. According to Meyer [3], the main benefits of reusability are: (1) improved timeliness, decreased time to market; (2) reduced software maintenance efforts; (3) improved reliability, efficiency and consistency of the developed software; and (4) enhanced investment, preservation of the know-how. The types of reusable artifacts are not limited to source code fragments, but rather may include other assets such as design structures, module-level implementation structures, specifications, documentation, transformations, and so on [4].

The higher the abstraction level, and the more not only source code but also design and specifications are reused, the greater the reusability benefits are [5,

6]. To the best of my knowledge, Rine and Nada [7] are the first authors who demonstrated empirically that the reusability level determines the effectiveness of improvements in productivity, quality and development time, concluding that greater benefits are obtained when reusability is applied during the initial processes of the software development life cycle. In this respect, Favaro [8] affirmed that "a well-formulated, measurable, reusable requirement [...] is every bit as valuable as a reusable software module". Robertson and Robertson [9] claimed that if the development starts with a set of requirements that were specified for other projects or domains, the accuracy of the requirements specification is improved and the time to develop this specification is reduced.

Cheng and Atlee [10] highlighted *globalisation* and *requirements reuse* as two of the more urgent needs and grand challenges in Requirements Engineering (RE) research. Global Software Engineering (GSE) implies a paradigm shift towards globally-distributed development teams [11]. Implementation of GSE can assist to decrease costs, capitalise on global resource pools, locate development closer to customers, exploit follow-the-sun development, and cater to local markets [12]. Besides, GSE implies an increased risk of communication gaps given the temporal, geographic, cultural and linguistic nature of the distance imposed by GSE [13]. This might hinder collaborative activities that require stakeholders to share a mental model of the problem and requirements [10]. Therefore, RE presents several specific challenges and difficulties when the stakeholders are distributed, owing to its collaboration-intensive nature [11, 14, 15].

Herbsleb [11] stated that *environments and tools* is an important area of research in GSE, specifically collaborative capabilities should be integrated into the development environment, and there is also the need for interoperable tools that should support standard data formats and interaction protocols. Mistrík et al. [16] pointed out that a considerable number of recent advances are related to the development of supporting tools for certain collaborative practices. Besides, Heindl et al. [17] detected a lack of traceability and RE tools for GSE. Traceability facilitates change management and must include horizontal and vertical dependencies, between artefacts in the same and in different abstraction levels, respectively. Ebert [18] emphasised that change management is unmanageable without automated tools in a GSE environment. The reduced communication band-

width in GSE makes it much more difficult to face the problem of understanding what other project members are doing at each moment, and thus coordinate effectively with them [19–21]. Awareness and communication are relevant and interrelated issues in GSE [11]. Synchronous and asynchronous communication features should be integrated into RE tools to mitigate this problem, while the use of e-mail instead of web-based tools or shared repositories to manage requirements should be avoided [22].

The rest of this chapter is organised as follows: Section 1.2 presents related work. Section 1.3 shows my hypothesis. Section 1.4 outlines my goals. Section 1.5 summarises the methodology used in this work. Section 1.6 describes the context of the thesis. Section 1.7 provides a detailed explanation of the tasks carried out to accomplish my goals. Section 1.8 presents the contributions of this dissertation. Finally, Section 1.9 highlights my conclusions.

1.2 Related work

Requirements reuse can be tackled by using different strategies, according to the systematic mapping study carried out by Vavassori and da Silva [23]. Most of these approaches are usually focused on large companies, since they involve systematic exploration across applications to find commonalities and differences in requirements, which is more complex and difficult than requirements modelling for individual applications [24]. However, the software requirements catalogue approach uses a requirements catalogue as a source for requirements, so that requirements can be searched, identified, examined, evaluated and selected according to their relevance for the new project. Each reusable requirement in the catalogue is individually described and classified according to its priority, functionality and importance —among other criteria— by means of attributes or meta-information [25]. The requirements catalogues contain sets of related requirements that belong to the same domain and not to a product line. In this regard, the requirements catalogue approach matches with the needs of a small-sized software company that develops software with different characteristics and not packaged software products [24].

Even though *requirements reuse* and *globalisation* are two relevant issues [10],

and the usefulness of requirements reuse has already been confirmed in several studies [1, 7, 9, 23–27], to the best of my knowledge, there are no proposals addressing both requirements reuse and GSE together following a software requirements catalogue approach. Exemplifying, Vavassori and da Silva [23] studied the reuse of requirements specifications, concluding that it leads to greater reuse of other artefacts, but their experience was not conducted in a GSD environment. Pacheco et al. [24] carried out a case study in a small-sized software organisation to evaluate a requirements reuse model for software requirements catalogues, but again this research was conducted in a co-located context.

Only a few proposals deal with requirements reuse for distributed software development scenarios using a Software Product Line (SPL) approach. Cho [28] stated that it is not easy to develop an SPL to leverage requirements reuse and to serve design inputs while expressing variations of every product requirements in a simple and flexible way. This author shows the types of requirement variations, the scheme of SPL requirement specification and the relationships of SPL requirements and other requirements. Ebling et al. [29] presented a requirements reuse method that integrates software reuse in the context of SPLs, to improve RE in a GSE environment. However, practical evaluation of the proposal is not provided. Martini et al. [30] emphasised that software reuse in the context of large scale agile practices for software development is currently an open issue in industry. They investigated, through a survey, communication factors affecting both speed and reuse in three large companies employing agile software development and SPLs. Thurimella and Wolf [31] proposed that the issue model (a rationale model) can be used to model product line variability supporting informal collaboration for variability management. Further issue-based variability modeling addresses the capture of rationale, and supports the instantiation and evolution of the variation points. The approach is illustrated using an industrial case study from the domain of infotainment systems and is evaluated empirically. Other related work by Thurimella and Brügge [32, 33] also focused on managing rationale information during the decision-making activities that arise during variability management, and reported a quasi-experiment for evaluating this rationale-enriched collaborative variability management methodology called issue-based variability modeling.

1.3 Hypothesis

Requirements specifications are usually managed in industry by means of unstructured natural language (NL) requirements [34, 35], which are easier to understand than other non-textual notations, especially when the stakeholders lack any kind of technical training [36]. However, NL is inherently ambiguous and can lead to different interpretations depending on the context [36–38]. This drawback will be therefore exacerbated when globally distributed stakeholders are involved in the process, as regards language, social and cultural differences, and problems resulting from a lack of tacit knowledge related to requirements [13]. In addition, some authors emphasise the need for appropriate tools since they help in managing requirements and are key success factors in GSE [11, 17, 18, 22, 39].

The hypothesis of this doctoral dissertation is as follows:

> *If adequate catalogue-based reuse techniques and an automated tool support were defined for natural-language requirements specification when stakeholders are globally distributed, then relevant gains of effectiveness and productivity in software development projects would be obtained.*

1.4 Goals

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

> *Propose catalogue-based reuse techniques and an automated tool support for natural-language requirements specification in GSE, and validate them empirically.*

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

- **Goal 1**. Devise reuse-based techniques for natural-language requirements specification in GSE.
- **Goal 2**. Provide automated support for the requirements reuse techniques by using a prototypical tool.

- **Goal 3**. Validate the techniques and the prototype empirically in a GSE scenario.

1.5 Methodology

Empirical methods have become an integral part of research and practice in Software Engineering (SE) [40]. According to Wohlin et al. [41], empirical studies are usually classified into three groups: survey, case study and experiment. Two of these techniques have been applied in this doctoral thesis, namely survey and experiment. The survey allows to describe a situation or phenomenon using data obtained through interviews or questionnaires administered to a representative sample of the population under study. On the other hand, the experiment provides a high level of control, as it enables manipulation of variables and measurement of their effects.

The Systematic Literature Review (SLR) [42] has also been used in this dissertation. It is a means to rigorously synthesise the scientific literature in relation to a question asked by the researcher. This technique allows to characterise the evidence on a particular issue and helps identify gaps in the state-of-the-art, in order to establish the basis of a new research activity.

Other research methods are more specific and fit very well to the research carried out in certain fields of knowledge. DESMET [43] is a method designed for evaluating SE methods and tools. For this reason, it has been also applied in this doctoral thesis so as to evaluate RE tools.

1.6 Context of the thesis

Several researchers and research groups are making contributions in the same scientific field in which this doctoral thesis falls. Just as a brief summary, some of the most important will be mentioned below.

The intensive work of Dr. Daniela Damian, who leads the SEGAL (*Software Engineering Global interAaction Lab*) group at the University of Victoria (Victoria, Canada), must be acknowledged. They have studied many issues related to RE in GSE, including negotiation, social networking, coordination, communication,

collaboration, risk management, etc. I can also highlight Dr. Filippo Lanubile, head of the CDG (*Collaborative Development Group*) at the University of Bari (Bari, Italy). They work on collaboration and GSE, including distributed agile development, collaborative development environments, communication in RE and computer-mediated communication, among other issues. Dr. Ita Richardson and Dr. Sarah Beecham, both from Lero —the Irish Software Engineering Research Centre—, work in GSE and agile processes among other topics. They work closely with industry, implementing a Model of Global Teaming, and validating a Decision Support System that aims to tailor Global Software Development (GSD) processes to meet individual organisation needs. The MuNDDoS group at the PUCRS (Porto Alegre, Brazil) is coordinated by Dr. Jorge Luis Nicolas Audy and Dr. Rafael Prikladnicki. They work on aspects related to management of distributed projects, process models, process improvement, estimation, and service-oriented architectures. Dr. Christof Ebert is managing director at Vector Consulting Services GmbH and professor at the University of Stuttgart (Stuttgart, Germany). He is a world-renowned researcher and practitioner specialising in GSE, RE, product and project management, software measurement and estimation.

At the national level, I must emphasise the extensive experience in the study of GSE of the Alarcos research group at the University of Castilla-La Mancha (Ciudad Real, Spain), headed by Dr. Mario Piattini. Dr. Aurora Vizcaíno is a leading author in the field of communication and collaboration tools, recommendation systems, skill training simulators, and GSE education in general. The KR (*Knowledge Reuse*) group at the University Carlos III (Madrid, Spain) is led by Dr. Juan Llorens. The group's interests are centered around reuse, knowledge representation, and knowledge retrieval in SE. It is worth noting the academic origin of The Reuse Company as a university spin-off of the research group that operates mainly in the financial and systems/software development sectors. The GIRO (*Grupo de Investigación en Reutilización y Orientación a objetos*) group at the University of Valladolid (Valladolid, Spain) has also a long research history in the area of reuse, specifically in software product lines and refactoring. These research lines are led by Dr. Miguel Ángel Laguna and Dr. Yania Crespo, respectively.

There are some conferences and journals that are close to the topics of this dissertation. Specifically, the ICGSE (*International Conference on Global Software Engineering*) brings together researchers and practitioners interested in solving the challenges of continentally distributed SE. The SEAFOOD (*Software Engineering Approaches For Offshore and Outsourced Development*) conferences examine distributed software development from a SE perspective. The International Global Requirements Engineering Workshop (GREW) was held in conjunction with the ICGSE. The goals of this workshop were to identify, report, discuss, and address the challenges associated with RE and product management. The International Requirements Engineering Conference (RE), which is the most influential conference in the field of RE, held its 15th edition in 2007 with the following main target: "Understanding Requirements in the Global Economy". Moreover, a number of special issues have been published in relevant journals on the topic of GSE, which is the case of *IEEE Software* (special issue on Global Software Development, Mar./Apr. 2001 and Sep./Oct. 2006, and special issue on Virtual Teams, Nov./Dec. 2014), *Software Process: Improvement and Practice* (special issue on SPI Experiences and Innovation for Global Software Development, Sep./Oct. 2009 and Nov./Dec. 2009), and *Journal of Software: Evolution and Process* (special issue on Global Software Engineering, Oct. 2012), just to mention a few. In addition, some journals and conferences explicitly refer to GSE in their aims and scope, for example *Journal of Systems and Software*.

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:

PEGASO/PANGEA

PEGASO (*Procesos para la mEjora del desarrollo GlobAl del SOftware*, in English *Processes for the Improvement of Global Software Development*) is a national research project funded by the Spanish Interministerial Commission on Science and Technology (CICYT) and coordinated between the Alarcos group of the University of Castilla-La Mancha and the University of Murcia. In particular, the University

of Murcia is in charge of the PANGEA (*Process for globAl requiremeNts enGinEering and quAlity*) subproject.

In the PEGASO project, research is focused on the application of different software process engineering techniques to improve the quality of software developed in global environments. In the PANGEA subproject, the main focus is on conceiving and validating a reuse-based RE method —the PANGEA method— for GSE. The principal investigator (PI) of the PEGASO project is Dr. Mario Piattini from the University of Castilla-La Mancha, while the PI of the PANGEA subproject is Dr. Ambrosio Toval from the University of Murcia. The project has a duration of three years (from January 2010 to December 2012).

Through this project, the doctoral candidate was able to be in direct contact and collaborate with both national and international researchers and research groups, such as Dr. Aurora Vizcaíno from the Alarcos group at the University of Castilla-La Mancha (Ciudad Real, Spain) and Dr. Christof Ebert from the University of Stuttgart and the consulting company Vector Consulting Services GmbH (Stuttgart, Germany).

ORIGIN

ORIGIN (*ORganizaciones Inteligentes Globales INnovadoras*, in English *Innovative Global Intelligent Organisations*) is a national research project funded by the Spanish Centre for the Development of Industrial Technology (CDTI). Indra Software Labs is the project coordinator, and the University of Castilla-La Mancha is one of the participating entities. In the ORIGIN project, the goal is to increase productivity of software development activities in global scenarios, improving the quality of the products developed, thereby increasing the international competitive level of enterprises. Concerning this thesis, a technology transfer contract funded by the University of Castilla-La Mancha and Indra took part in the context of the ORIGIN project. The University of Murcia was the recipient of this contract, which was focused on providing advice to Indra on the development of a corporate reuse-based RE tool oriented towards supporting global RE, starting from the evaluation of the characteristics of their current RE tool. The contract has a duration of eight months (from March 2012 to October 2012).

Through this contract, the doctoral candidate was able to put into practice research findings related to RE tools, requirements reuse and GSE, of both methodological and instrumental nature, directly derived from his dissertation.

GEODAS/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 optimise 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 has a duration of three years (from January 2013 to December 2015).

Through this project, the doctoral candidate was able to maintain and extend its established collaborations with Dr. Aurora Vizcaíno and Dr. Christof Ebert.

1.6.2 Doctoral programme

The doctoral candidate has been working on his thesis within the framework of a doctoral programme that was assigned an Excellence mention awarded by the Secretariat General for Universities of the Spanish Ministry of Education, Culture and Sport, and an Excellence label awarded by the Mediterranean Office for Youth (MOY).

1.6.3 Scholarships and research stays

During the execution of this dissertation, the doctoral candidate has benefited from two research grants offered by funding organisations, which followed a

scheme of subsidies awarded on an open and competitive basis. These grants allowed the doctoral candidate to complete two research stays in locations outside Spain, which were useful to intensify collaboration with international researchers and research groups.

Mediterranean Office for Youth

The MOY awarded the doctoral candidate an international mobility scholarship that enabled the doctoral candidate to work 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 (Rabat, Morocco).

During his stay in the ENSIAS of the Mohammed V University, the doctoral candidate carried out a first experiment with students whereby his approach for RE in GSE was empirically validated in a nearshore scenario (Spain-Morocco). This research stay was specially important because it paved the way for a second experiment with students that took place one year and a half after the first experiment, in the same scenario, with the purpose of replicating his previous study.

Duration: months 25–29, five months.

German Academic Exchange Service

The German Academic Exchange Service (DAAD) awarded the doctoral candidate a three-month international mobility scholarship to carry out a short-term research stay at a public institution of higher education or non-university research institution in Germany. The chosen organisation was the IAS (*Institut für Automatisierungs- und Softwaretechnik*, in English *Institute of Industrial Automation and Software Engineering*) at the University of Stuttgart, where the doctoral candidate worked under the supervision of Dr. Christof Ebert.

During his stay in the IAS of the University of Stuttgart, the doctoral candidate conducted a joint research project whereby mechanisms for reusing requirements in GSE environments, specified in natural language, were investigated. Other topics investigated in the course of the research stay were evaluation of

RE tool capabilities and gamification of the teaching-learning process in project and product management, software engineering and requirements engineering.

Duration: months 32–34, three months.

1.7 Tasks

Below, an overview of the tasks performed for accomplishing the goal of this doctoral thesis is presented. The tasks have taken place so that the work has spanned 48 months:

- **Task 1**. Study the state-of-the-art on RE in GSE and propose reuse-based techniques for natural-language requirements specification in GSE.

  Traces from: **Goal 1**; *Duration*: months 1–12 and months 31–36, 18 months.

  - **Task 1.1**. Study the state-of-the-art on the risks and safeguards for RE in GSE using an SLR and a quantitative approach to measure the association between them.
  - **Task 1.2**. Propose reuse-based techniques for natural-language requirements specification in the context of the PANGEA method for GSE.

- **Task 2**. Study the state-of-the-practice on RE tools, followed by the analysis, design and prototyping of an automated tool support for the reuse-based techniques for natural-language requirements specification in GSE, which were proposed during **Task 1**.

  Traces from: **Goal 2**; *Duration*: months 7–24 and months 34–42, 27 months.

  - **Task 2.1**. Study the state-of-the-practice on commercially available RE tools by a survey, using the DESMET analysis method to evaluate them, and a classification framework inspired on the ISO/IEC TR 24766 to categorise their general and GSE-related capabilities.
  - **Task 2.2**. Perform a needs analysis for the PANTALASA (*PANgea Tool And Lightweight Automated Support Architecture*) RE tool and its requirements specification, considering: (1) the state-of-the-art on RE

in GSE studied in **Task 1.1** and the reuse-based techniques for natural-language requirements specification in GSE proposed in **Task 1.2**; and (2) the state-of-the-practice on the capabilities of current RE tools studied in **Task 2.1**.

- **Task 2.3**. Produce the high-level design of the PANTALASA RE tool, including: (1) the structure of a repository of reusable requirements; and (2) the specific mechanisms required to work in GSE environments.
- **Task 2.4**. Implement a prototype of the PANTALASA RE tool by means of the wiki, semantic wiki and Content Management System (CMS) technologies that serves to put into practice and validate the proposal, which includes the methodological techniques and RE tool capabilities that were previously mentioned.

- **Task 3**. Analyse the practical feasibility of the proposal empirically by two successive experiments carried out with students distributed according to a nearshore GSE scenario, which includes participants located at Rabat (Morocco) and Murcia (Spain).

  Traces from: **Goal 3**; *Duration*: months 19–30 and months 40–48, 21 months.

Fig. 1.1 shows a Gantt chart that plots the distribution in time of the previously defined tasks. As illustrated in the diagram, this dissertation was structured in two iterations. The fist iteration was longer than the second one, given that I could not build on previous work at the beginning.

1.8 Contributions

The contributions of this doctoral dissertation are presented in the following paragraphs. Section 1.8.1, Section 1.8.2 and Section 1.8.3 include the contributions related to **Goal 1**, **Goal 2** and **Goal 3** respectively. The contributions in which the doctoral candidate has been involved are listed in Sections 1.8.4-1.8.9. Finally, Section 1.8.10 elaborates on the matching between the tasks of this doctoral dissertation and its contributions.

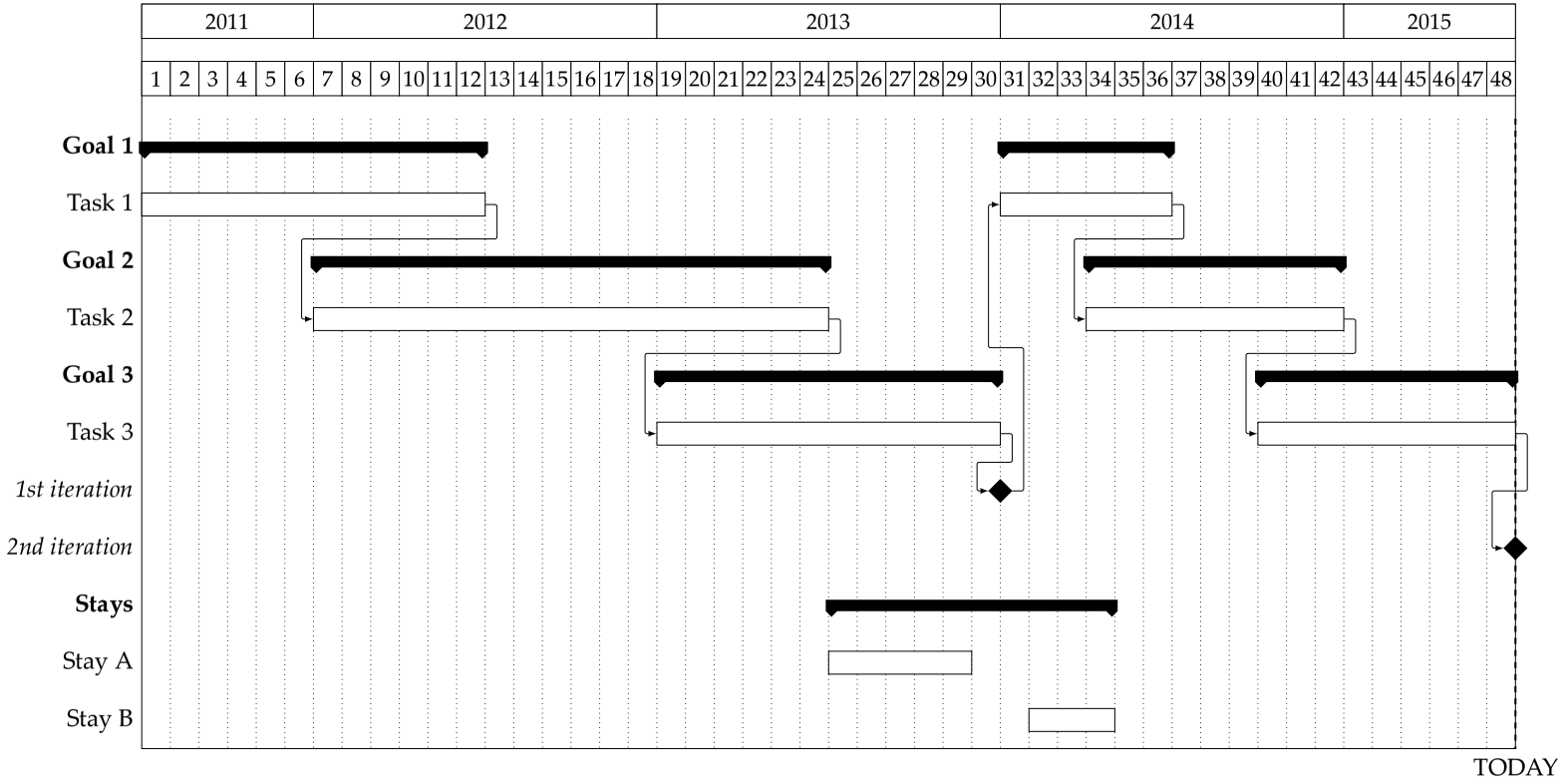

Figure 1.1: Task schedule

1.8.1 Goal 1: Reuse-based techniques for requirements specification in GSE

My first step was to study the state-of-the-art on RE in GSE. Specifically, the state-of-the-art on the risks and safeguards for RE in GSE was analysed using a SLR and a quantitative approach to measure the association between them [44]. A great variety of risks to RE in GSE (148), along with a large number of safeguards (90 in total), were identified; starting from these results, a risks and safeguards repository encompassing the state-of-the-art on RE in GSE was made publicly available [45]. This repository can be used as a growing knowledge base by any organization interested in carrying out RE in GSE. The objective is to assist those organizations that are inexperienced in GSE to handle the problems that may arise when involved in a de-localised development. The most common risks identified in literature are related to: (1) client and vendor relationships; (2) communication problems caused by a lack of face to face meetings and informal communication; and (3) problems in common process models. It was also found that the risks related to: (1) knowledge management and awareness; and (2) customer-supplier distance have the greatest lack in terms of the safeguards proposed in the literature, and these are therefore concerns to which more attention should be paid.

Once enough knowledge was acquired, reuse-based techniques for natural-language requirements specification in GSE were proposed, based on existing scientific literature and previous work of the research group on RE and reuse. Many of the contributions of this thesis discuss this subject in one way or another. My proposal rest on well-known RE techniques such as natural-language requirements, parameterised requirements and simple traceability relationships [46–53], with extensions to these base techniques in the form of requirements templates and collaborative tagging [54].

1.8.2 Goal 2: Automated support for the requirements reuse techniques

The most important outcome of this dissertation, in terms of articles published in journals indexed in international databases, comes from the study of the state-of-the-practice on commercially available RE tools [55] by means of a survey mainly based on the ISO/IEC TR 24766 [56]. Their support to general RE capa-

bilities [57–59] and both general and GSE-related capabilities [46, 60] were analysed. Profound differences in functionality between them were uncovered. It has been empirically demonstrated that in no way does every solution give the same support to the various activities of the RE process. A clustering approach was used to identify groups of related tools, which could be used to consider different, alternative options when a purchase decision is to be taken. Additionally, other feature domains for RE tools were studied. In particular, accessibility and internationalisation capabilities according to the ISO/IEC 9241-171 [61] have been addressed in [62]. My work on evaluation of RE tools can be summarised in the following milestones: (1) define a meaningful classification framework for RE tool capabilities; (2) collect information about current RE tools; (3) describe the state-of-the-art on RE tools; and (4) define a statistical approach to assess RE tools and categorise them systematically according to the classification framework previously proposed. Items (1), (2) and partially (3) were addressed in [46, 57–59]. Carrillo de Gea et al. [60] deals with (3) and (4).

The next step is concerned with the analysis, design and prototyping of an automated tool support (PANTALASA) for reuse-based techniques for natural-language requirements specification in GSE. My comprehensive snapshot of the RE tool capabilities was used as an input to conceive PANTALASA. The RE tool capabilities included in the classification framework were refined and expanded, and as a result of this process, a requirements specification for PANTALASA was obtained. Some of the artefacts of the IBM Rational Unified Process (RUP) methodology were used to collect the system features and the specific requirements derived from them [46]. Specifically, the Feature (FEAT), Use Case (UC) and Supplemental Requirement (SUPL) requirement types, and the Vision[1] (VIS), Use Case Specification[2] (UCS) and Supplementary Requirements Specification[3] (SUP) document types were utilised. There are 38 features, 16 use cases and 195 requirements in the specification. Fig. 1.2 depicts the general structure of the specification and illustrates with an example the kind of included arte-

[1] http://www.um.es/giisw/juanma/CARE-tool/VIS.pdf

[2] http://www.um.es/giisw/juanma/CARE-tool/UCS.zip

[3] http://www.um.es/giisw/juanma/CARE-tool/SUP.pdf

facts. The high-level design and implementation of PANTALASA are heavily addressed in [46, 63, 64], whereas they are also tackled in [49–52].

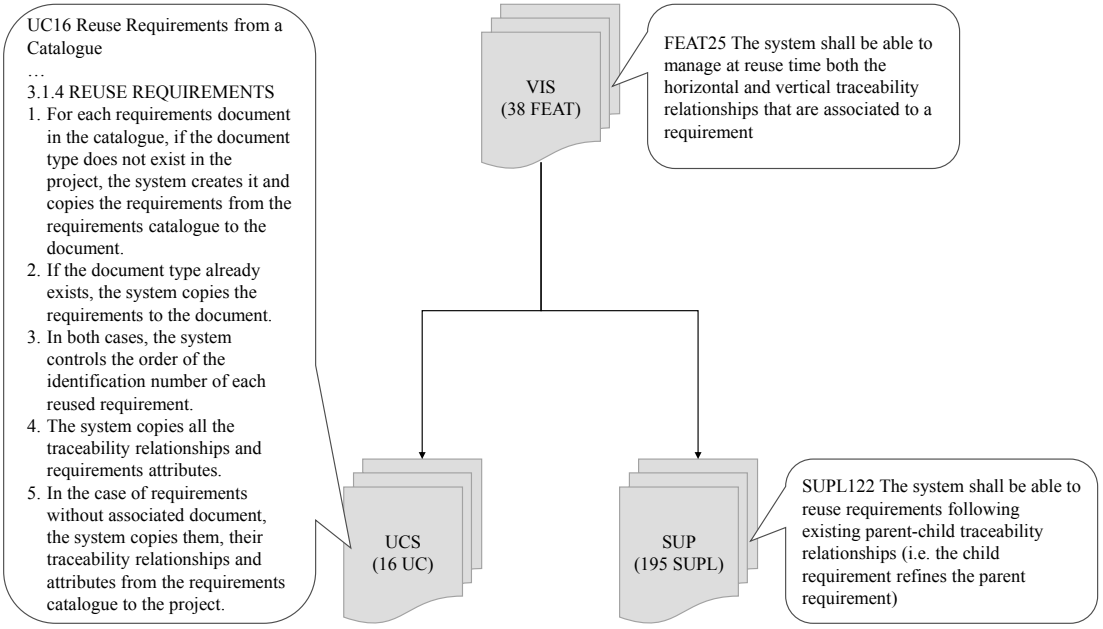

Figure 1.2: Structure of the specification

The knowledge gathered in these documents was yielded to two software development companies —ATICA and Indra—, a measure aimed at improving their corporate RE tools. This action, in turn, was useful for us to validate the specifications. ATICA[4] is the center responsible for developing, maintaining and managing general applications and computing resources from other units and departments of the University of Murcia. In addition, ATICA collaborates with public and business organisations of its national and international environment, as illustrated by more than 30 external projects in the past three years. More than 100 people currently work in ATICA. Indra[5] is the leading consulting and technology multinational in Spain and Latin America. It provides solutions and services for a variety of economic sectors: transport and traffic, energy and industry, public administration and healthcare, financial services, security and

[4] `http://www.um.es/atica/index.php` (in Spanish)

[5] `http://www.indracompany.com/en`

defence, and telecom and media. The main figures deriving from Indra operations include €3 billion in sales, presence in 149 countries and 43,000 professionals. My collaboration with the two software development companies mentioned above took part in the form of internal cooperation within the University in the case of ATICA, and a technology transfer contract in the case of Indra (see Section 1.6.1).

In a subsequent stage, two main alternatives were examined to build, according to the specifications, a prototype of the reuse-based RE tool for GSE. Then a "proof of concept" approach was applied to investigate their suitability. In other words, PANTALASA was implemented by using the following technological frameworks: (1) wikis and semantic wikis with or without social network integration with Facebook [46, 50, 51, 63]; and (2) CMSs [46, 49, 52, 64]. The first alternative builds on widespread platforms that offer many relevant features. A block diagram of the prototype is shown in Fig. 1.3. Wikis were originally conceived for distributed collaborative content creation, but it is possible to use them to support collaboration among stakeholders [65], capture requirements [66] and domain knowledge [67]. Networking and social networks improve formal and informal communication [68] and have many potential applications in the context of an RE process, such as stakeholder analysis [69] or identification and prioritisation of software requirements [70]. However, these systems have demonstrated lack of flexibility, which makes it hard to adapt them to the specific needs of PANTALASA.

From the point of view of implementation, it is much easier to work with common programming languages (e.g. Java, C, PHP) than to make use of the *wikitext* language syntax. Throughout the development of the tool with SMW+, several problems, limitations and disadvantages have arisen. One of them is related to the management of user requests that SMW+ makes. Each user has a request queue that is served sequentially. Thus, each user can only perform one action at a time, having to wait to complete this action to make another request. In addition, SMW+ does not allow to perform certain actions transparently; any action of creation or modification on a page must be preceded by user interaction. All this prevents achieving full automation of the processes and generates significant slowdowns in the use of the tool. Another problem is that some-

times pages fall into an inconsistent state that must necessarily be resolved by the user. Coupled with the above problems is the fact that the company behind the development of SMW+ has undergone critical changes that have led to a poor platform support.

The second alternative, in particular Drupal, must be set up according to the technical specifications to add the functionality that is absent *out of the box*, but there are many modules available implementing different features that make the development process of the initial project stages much faster and less time-consuming if comparing to a manual coding process. A high-level architecture diagram of the prototype is shown in Fig. 1.4. Summarising, it has been confirmed that the use of CMSs strike a balance between the development of purpose-built applications and the adaptation of pre-built, off-the-shelf products. My conclusion supports the idea that CMSs are thus appropriate for building a reuse-based RE tool for GSE that meets the conditions of the proposal presented in this dissertation.

1.8.3 Goal 3: Empirical validation of the techniques and the prototype

The version of PANTALASA that was implemented with Drupal is being used by around 100 students enrolled in *Requirements Engineering and Project Management*, a 3rd course subject of the undergraduate programme in Computer Science and Engineering of the University of Murcia. Furthermore, this prototypical tool has also been used during the practical validation of the results of this thesis. Two educational experiments were carried out with which the impact of requirements reuse in co-located and distributed environments was measured [46–49, 53, 54]. The most innovative aspect of the experiments is the evaluation of a catalogue-based RE method versus an RE method in which requirements are specified from scratch in a nearshore GSE setting (Murcia-Rabat). In addition, I am involved in an European-funded research project that includes 14 leading institutions as full partners and 9 other organisations as associated partners in

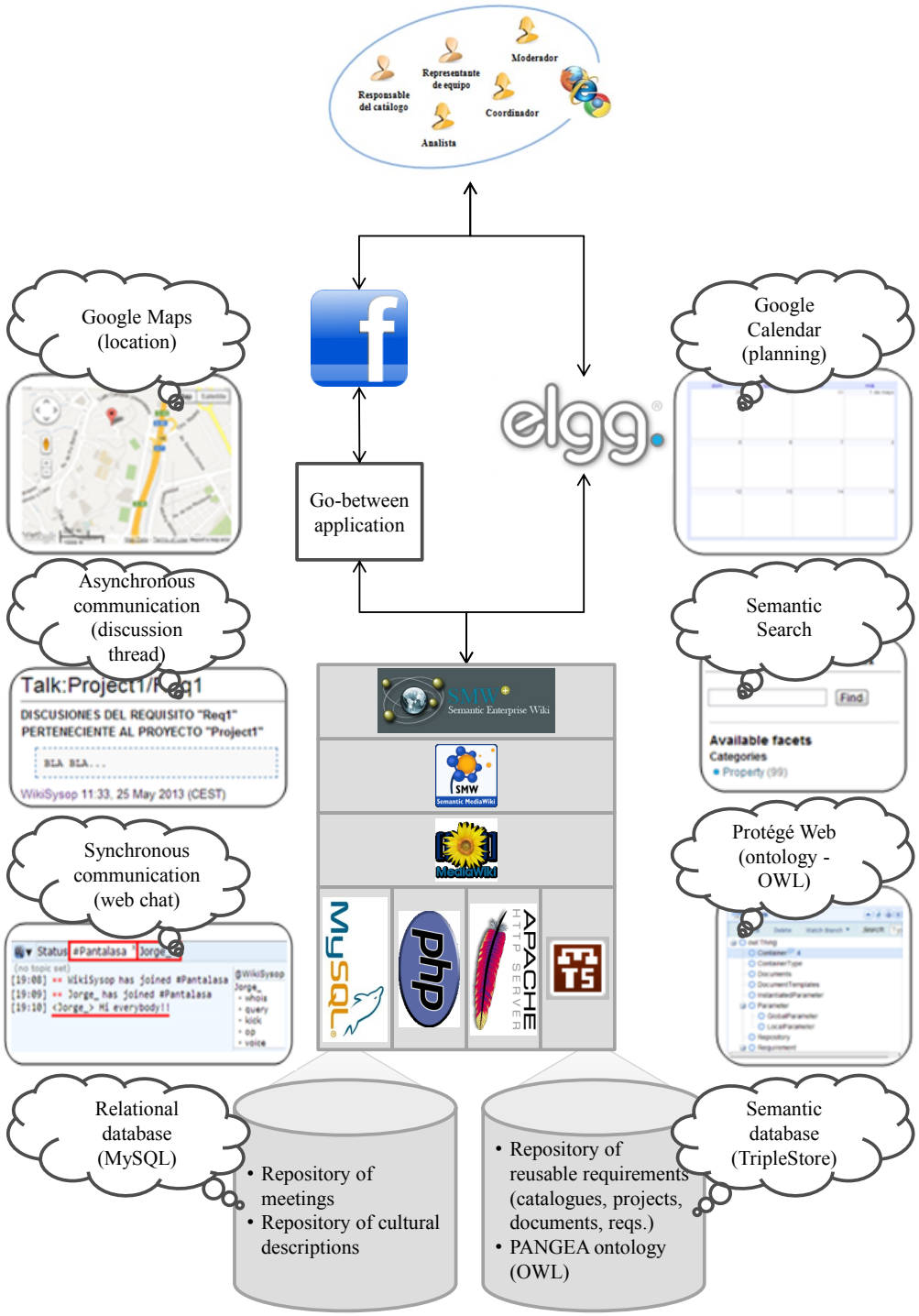

Figure 1.3: Free-form architecture diagram of the PANTALASA prototype using social networks and semantic wikis

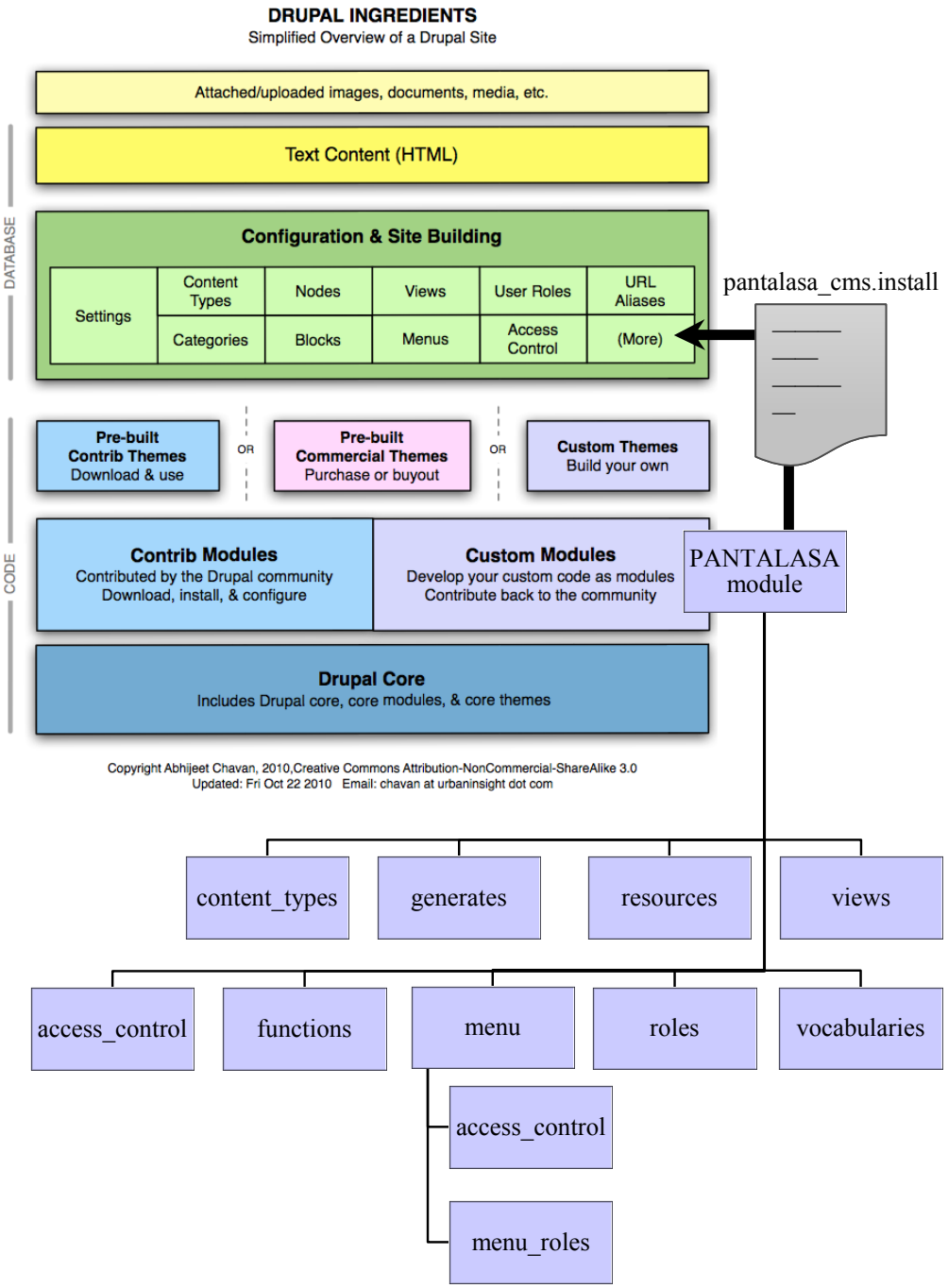

Figure 1.4: Free-form architecture diagram of the PANTALASA prototype using a CMS

a transnational network[6]. This represents an opportunity to carry out a case study that puts into practice both PANGEA and PANTALASA in an internationally distributed scenario [52]. Given that reusing software artifacts, and in particular requirements and specifications, is beneficial in traditional, co-located development [7–9], the same benefits can be expected in (globally) distributed development scenarios. Indeed, my results show that the requirements specification process can be improved by using reusable requirements catalogues.

Concerning my experiments, a total of 76 students enrolled on three courses related to project management for software development at the University of Murcia and the Mohammed V University of Rabat were involved [49]. The results of a fixed effects meta-analysis (Hedges' g) obtained a medium effect (-0.495; $p = 0.034$) for *productivity*, and a large effect (-1.077; $p < 0.001$) for *effectiveness*, in favor of using a catalogue-based reuse process rather than a conventional specification process. There was no statistically significant interaction between the process used (catalogue-based reuse or conventional specification) and the co-factor *distribution* (global or co-located) as regards effectiveness and productivity. The experiments were set in the domain of software internationalisation (i18n). The existing knowledge on i18n was collected in the form of a reusable requirements catalogue [71, 72] and then such a catalogue was used as an input for the reuse-based method in the experiments. It is worth to note that the preexistence of a knowledge base in the form of catalogues requires an initial creation and continuous maintenance effort, which can be a time-consuming activity [73]. A reusable requirements catalogue must be constantly updated and enriched, if it is to be truly incorporated in a company's work practices.

My automated tool support for reuse-based RE in GSE, built using the Drupal open source CMS, was evaluated. It includes: (1) the validation of the analysis artefacts by two software development companies (see Section 1.8.2); and (2) the validation of my prototypical tool by an experiment with distributed (Murcia-Rabat) university students ($n = 57$) [46]. A *post-mortem* questionnaire was administered to obtain feedback about the students' perceptions as regards the tasks assigned to them, and particularly their experience with the RE techniques

[6] http://www.itn-dch.org/

and the RE tool used. Furthermore, the questionnaire was designed bearing in mind the Technology Acceptance Model (TAM), which can help us to put my results into a perspective of technology adoption [74]. A total of 27 questions were answered by the participants using a five-point Likert-type scale. The null hypothesis that the median of the responses equals the mid-value (3) was checked by using the one-sample Wilcoxon Signed Rank test. According to my findings, the participants agree with the idea that the tool can be used in a real project, offers better functionality than a word processing application, helps in reusing requirements and managing traceability relationships, is easy to use, useful, and easy to learn, in general they would use the tool if they needed to, and they would recommend the tool. In contrast, the participants considered that the tool is not particularly suitable for managing users and user roles ($p = .064$).

1.8.4 Journals indexed in Journal Citation Reports (JCR)

- **Contribution 1**. Joaquín Nicolás, Bernabé Nicolás, Juan Manuel Carrillo de Gea, José Luis Fernández Alemán and Ambrosio Toval. On the Risks and Safeguards for Requirements Engineering in Global Software Development: Systematic Literature Review and Quantitative Assessment. *J. Assoc. Inf. Syst.* (*in review*). JCR Science Edition 2013 impact factor: 1.250; Q2 (57/135): *Computer Science, Information Systems*.

  Summary: SLR that addresses the risks and safeguards for RE in GSE with a quantitative approach to measure the association between them.

- **Contribution 2**. Juan Manuel Carrillo de Gea, Joaquín Nicolás, José Luis Fernández Alemán, Ambrosio Toval, Christof Ebert and Aurora Vizcaíno. Requirements engineering tools. *IEEE Softw.*, 28(4):86–91, July/Aug. 2011. JCR Science Edition 2011 impact factor: 1.508; Q1 (18/103): *Computer Science, Software Engineering*.

  Summary: Support of commercial RE tools to general RE capabilities according to the ISO/IEC TR 24766, with a practical perspective for the practitioner.

- **Contribution 3**. Juan Manuel Carrillo de Gea, Joaquín Nicolás, José Luis

Fernández Alemán, Ambrosio Toval, Christof Ebert and Aurora Vizcaíno. Requirements engineering tools: capabilities, survey and assessment. *Inf. Softw. Technol.*, 54(10):1142–1157, Oct. 2012. JCR Science Edition 2012 impact factor: 1.522; Q1 (33/132): *Computer Science, Information Systems*; Q1 (23/105): *Computer Science, Software Engineering*.

Summary: Support of commercial RE tools to general RE capabilities according to the ISO/IEC TR 24766, with emphasis on the classification framework for RE tool capabilities.

- **Contribution 4**. Juan Manuel Carrillo de Gea, Joaquín Nicolás, José Luis Fernández Alemán, Ambrosio Toval, Christof Ebert and Aurora Vizcaíno. Commonalities and differences between requirements engineering tools: a quantitative approach. *Comp. Sci. Inf. Syst.*, 12(1):257–288, Jan. 2015. JCR Science Edition 2013 impact factor: 0.575; Q3 (101/135): *Computer Science, Information Systems*; Q4 (84/105): *Computer Science, Software Engineering*.

  Summary: Support of commercial RE tools to the full classification framework (general RE capabilities and GSE-related capabilities). During the process of empirical assessment and comparison, descriptive statistics, hierarchical cluster analysis and statistical hypothesis testing were applied.

- **Contribution 5**. Juan Manuel Carrillo de Gea, Joaquín Nicolás, José Luis Fernández Alemán, Ambrosio Toval. Automated Support for Reuse-Based Requirements Engineering in Global Software Engineering. *Inf. Softw. Technol.* (*in review*). JCR Science Edition 2013 impact factor: 1.328; Q2 (51/135): *Computer Science, Information Systems*; Q2 (31/105): *Computer Science, Software Engineering*.

  Summary: Reuse-based RE tool for GSE (PANTALASA), defined according to: (1) the methodological proposal (PANGEA); and (2) the study of commercial RE tools (the classification framework and the survey), implemented with Drupal and validated through an experiment in a nearshore scenario (2nd experiment Murcia-Rabat).

- **Contribution 6**. Juan Manuel Carrillo, Joaquín Nicolás, José Luis Fernández Alemán, Ambrosio Toval, Sofia Ouhbi and Ali Idri. Are the Expected

Benefits of Requirements Reuse Hampered by Distance? An Experiment. *Sci. Comput. Program.* (*in review*). JCR Science Edition 2013 impact factor: 0.548; Q4 (86/105): *Computer Science, Software Engineering*.

Summary: Experiment to study requirements reuse in a nearshore scenario (1st experiment Murcia-Rabat), comparing co-located with distributed, including the basic PANGEA techniques.

- **Contribution 7**. Juan Manuel Carrillo de Gea, Joaquín Nicolás, José Luis Fernández Alemán, Ambrosio Toval, Sofia Ouhbi and Ali Idri. Collaborative Learning of Systems and Software Requirements Specification: An Empirical Study. *J. Softw. Evol. Proc.* (*accepted with major revision*). JCR Science Edition 2013 impact factor: 0.442; Q4 (96/105): *Computer Science, Software Engineering*.

  Summary: Experiment to study the inclusion of requirements reuse in an RE course in a nearshore scenario (1st experiment Murcia-Rabat), comparing non-reuse with the basic PANGEA techniques.

- **Contribution 8**. José Luis Fernández Alemán, Juan Manuel Carrillo de Gea, Joaquín Vidal, Joaquín Nicolás, Ambrosio Toval and Ali Idri. Effects of Using Requirements Catalogs on Effectiveness and Productivity of Requirements Specification in a Software Project Management Course. *IEEE Trans. Educ.* (*in press*). JCR Science Edition 2013 impact factor: 1.221; Q2 (123/248): *Engineering, Electrical & Electronic*; Q3 (18/36): *Education, Scientific Disciplines*.

  Summary: Family of experiments to study requirements reuse in a nearshore scenario (1st and 2nd experiments Murcia-Rabat), comparing non-reuse with the basic PANGEA techniques, with emphasis on empirical evaluation and education.

1.8.5 Chapters in international books

- **Contribution 9**. Juan Manuel Carrillo de Gea, Joaquín Nicolás, José Luis Fernández Alemán, Ambrosio Toval, Aurora Vizcaíno and Christof Ebert.

Reusing Requirements in Global Software Engineering. In *Managing Requirements Knowledge* (W. Maalej and A. K. Thurimella, eds.), pp. 171–197, Springer, 2013.

Summary: Reuse-based RE for GSE method (PANGEA) from the point of view of knowledge management, including an initial prototype of the tool support (PANTALASA), implemented with Facebook and Semantic MediaWiki Plus.

1.8.6 Chapters in Spanish books

- **Contribution 10**. Alejandro López, Ambrosio Toval, José Luis Fernández Alemán, Juan Manuel Carrillo de Gea and Joaquín Nicolás. Ingeniería de Requisitos para DGS. In *Desarrollo Global de Software* (M. Piattini, A. Vizcaíno, and F. García, eds.), pp. 119–147, RA-MA, 2014.

  Summary: Reuse-based RE for GSE method (PANGEA), including an initial prototype of the tool support (PANTALASA), implemented with Facebook and Semantic MediaWiki Plus (in Spanish, extended version).

1.8.7 Communications in international conferences and workshops

- **Contribution 11**. Juan Manuel Carrillo de Gea. Survey on Requirements Engineering Tools. In Industry Track, REFSQ '11: 17th International Working Conference on Requirements Engineering: Foundation for Software Quality (invited talk). Essen, Germany. March 28-30, 2011. Ranking = B (ERA 2010); ANZ Field of Research: 0803 *Computer Software*.

  Summary: Support of commercial RE tools to general RE capabilities according to the ISO/IEC TR 24766 (initial findings).

- **Contribution 12**. Juan Manuel Carrillo de Gea, Joaquín Nicolás, Sofia Ouhbi, José Luis Fernández Alemán, Ambrosio Toval, Ali Idri. Reusing Internationalisation Requirements in a Morocco-Spain Distributed Software Development Scenario. In MED-SOUK: I Campus Mare Nostrum International Conference for Young Researchers in the Mediterranean. Murcia, Spain. October 23-25, 2013.

Summary: Experiment to study requirements reuse in a nearshore scenario (1st experiment Murcia-Rabat), including the basic PANGEA techniques, requirements templates and keywords.

- **Contribution 13**. Juan Manuel Carrillo de Gea. A Proposal for Collaborative and Distributed Specification of Requirements in ITN-DCH. In Workshop on Datasets and Semantics (invited talk). Heraklion, Greece. February 3-4, 2014.

  Summary: Reuse-based RE tool for GSE (PANTALASA) and its possible use for distributed requirements management in the context of the European project FP7-PEOPLE ITN-DCH.

- **Contribution 14**. Juan Manuel Carrillo de Gea, Joaquín Nicolás, José Luis Fernández Alemán, Ambrosio Toval, Sofia Ouhbi and Ali Idri. Cooperative Learning of Requirements Engineering through an International Educational Scenario Enabled by the MOY Programme. In II Congreso Internacional de Innovación Docente. Murcia, Spain. February 20-21, 2014.

  Summary: Experiment to study requirements reuse in a nearshore scenario (1st experiment Murcia-Rabat), comparing non-reuse with the basic PANGEA techniques, with emphasis on education.

1.8.8 Communications in national conferences and workshops

- **Contribution 15**. José Luis Fernández Alemán, Juan Manuel Carrillo de Gea, Joaquín Nicolás, Ambrosio Toval, Diego Alcón and Sofia Ouhbi. Accessibility and Internationalization in Requirements Engineering Tools. In JISBD '12: XVII Jornadas de Ingeniería del Software y Bases de Datos. Almería, España. September 17-19, 2012.

  Summary: Support of commercial RE tools to accessibility and internationalisation capabilities according to the ISO/IEC 9241-171.

1.8.9 Intellectual property registries

- **Contribution 16**. Juan Manuel Carrillo de Gea, Bernabé Nicolás, Joaquín Nicolás and Ambrosio Toval. Repositorio de Amenazas y Salvaguardas

para el DGS. Appl. no. MU-815-2011. Registration record no. 08/2011/827. September 29, 2011.

Summary: Repository of risks and safeguards for the RE process in a GSE environment[7]. Based on an SLR, a taxonomy composed by seven types of concerns or areas of interest was compiled. Each of these classes of concerns contains a set of risks and their corresponding safeguards regarding the specific aspect of GSE that motivates the concern.

- **Contribution 17**. Ambrosio Toval, José Luis Fernández Alemán, Joaquín Nicolás and Juan Manuel Carrillo de Gea. Survey on Requirements Engineering Tools (Estudio de Herramientas de Ingeniería de Requisitos). Appl. no. MU-817-2011. Registration record no. 08/2011/829. September 29, 2011.

  Summary: Results of a study on commercial RE tools[8]. It includes a discussion on the methodology followed during the study.

- **Contribution 18**. Juan Manuel Carrillo de Gea, Antonio Muñoz Gallego, Jorge Rodríguez Lavado, Joaquín Nicolás, José Luis Fernández Alemán and Ambrosio Toval. PANTALASA-WIKI SEMÁNTICA. Appl. no. *ongoing*. Registration record no. *ongoing*.

  Summary: PANTALASA-WIKI SEMÁNTICA is an automated tool support for the RE method PANGEA that has been implemented by means of SMW+, an open source corporate semantic wiki built on Semantic MediaWiki.

- **Contribution 19**. Juan Manuel Carrillo de Gea, Juan Carlos Martínez Expósito, Joaquín Nicolás, José Luis Fernández Alemán and Ambrosio Toval. PANTALASA-CMS. Appl. no. *ongoing*. Registration record no. *ongoing*.

  Summary: PANTALASA-CMS is an automated tool support for a repository of reusable requirements based on the PANGEA methodology, which has been implemented with Drupal, an open source web CMS.

[7] `http://www.um.es/giisw/GSD/wiki`

[8] `http://www.um.es/giisw/EN/re-tools-survey/`

1.8.10 Task coverage

Table 1.1 shows the matching between the tasks of this doctoral dissertation and its contributions.

Table 1.1: Coverage of the tasks with publications

Goal	**Goal 1**		**Goal 2**				**Goal 3**
Task	**Task 1.1**	**Task 1.2**	**Task 2.1**	**Task 2.2**	**Task 2.3**	**Task 2.4**	**Task 3**
Contr. 1	X						
Contr. 2			X				
Contr. 3			X				
Contr. 4			X				
Contr. 5		X	X	X	X	X	X
Contr. 6		X					X
Contr. 7		X					X
Contr. 8		X				X	X
Contr. 9		X			X	X	
Contr. 10		X			X	X	
Contr. 11			X				
Contr. 12		X					X
Contr. 13		X			X	X	X
Contr. 14		X					X
Contr. 15			X				
Contr. 16	X						
Contr. 17			X				
Contr. 18					X	X	
Contr. 19					X	X	

1.9 Conclusions

Ebert and De Man [75] state that a software company or department is confronted with many challenges that must be mastered through continuous improvement, along the following axes: (1) *consolidating*: focusing on a few essential products and maximising their business value; (2) *industrialising*: mastering

projects, processes and knowledge by intelligent collaboration to improve predictability, repeatability and affordability; and (3) *globalising*: depending on the needs of the target market and the size of the company, but its success relies on the other two axes. An approach has been presented in this thesis that leverages this continuous improvement strategy by means of proper management of requirements knowledge. Firstly, an organisation that usually develops products in a domain eventually has enough expertise to generate high-quality requirements catalogues dealing with common issues in that domain (consolidating). Secondly, once such an organization manages domain knowledge appropriately by means of requirements catalogues, the entire software development process benefits and is greatly improved in terms of cost, time and effort (industrialising). Finally, the particularities of globalisation are taken into account and its demands materialised in the RE process in order to be successful in a global environment (globalising).

According to Krueger [2], the major benefit of reusing software artifacts is to reduce the time and effort required to *build* software systems. In addition, this author emphasises that the quality of software systems is better when quality software artifacts are reused, which in turn reduces the time and effort required to *maintain* software systems. This doctoral thesis primarily focuses on a reuse-based RE method for GSE that specifies knowledge in the form of natural language requirements. Cheng and Atlee [10] consider the identification of sets of reusable requirements for particular domains or types of applications to be of interest. In this sense, PANGEA uses a repository to arrange into catalogues these sets of interrelated reusable requirements, with the purpose of managing requirements knowledge. Moreover, PANGEA is based on well-known RE techniques such as natural-language requirements, parameterised requirements and simple traceability relationships, which result in a practical RE method that many organisations can apply. My key contribution in the context of the previously mentioned method lies in: (1) devising the requirements specification techniques; (2) developing the prototypical automated tool support; and (3) performing the empirical validation of the proposal. It is worth to note that the most important outcome of this doctoral dissertation, in terms of articles published in journals indexed in international databases, comes from (2). Specifically, these

results originate in the study of the state-of-the-practice on commercially available RE tools.

With regard to the processes, activities and tasks to be applied to enable systems and software to be constructed from reusable assets, the IEEE Std 1517 [76] provides a common framework for the systematic practice of reuse. Nevertheless, even though the reuse topic has attracted the interest of standardisation bodies, researchers and practitioners, to the best of my knowledge, there are no other software requirements catalogue proposals apart from the one presented here that tackle both issues, GSE and requirements reuse, jointly. Vavassori and da Silva [23] presented an approach for requirements reuse, supported by a tool, that was evaluated in a traditional, co-located setting using a quasi-experiment with university students. Pacheco et al. [24] reported a case study in a small-sized software company in which a requirements reuse model for software requirements catalogues was assessed, but this experience took part in a non-distributed environment. Only a few proposals deal with requirements reuse for distributed software development scenarios, but making use of techniques different from ours, in particular in the context of SPLs. In this regard, Thurimella and Wolf [31] and Thurimella and Brügge [32, 33] must be emphasised, as they present a proposal that is strongly validated through empirical studies.

At this point, I am able to conclude that my results support the hypothesis of this doctoral dissertation, which was posed in Section 1.3. Simple reuse-based techniques and automated tool support for natural-language requirements specification can be defined to support globally distributed RE and obtain significant gains of effectiveness and productivity. However, empirical evaluation in industry is still needed to fully judge the practical contributions of this thesis.

Table 1.2 shows the contributions derived from this thesis classified into categories of publications. In addition, the contributions are linked to the goals of the dissertation, so that it is possible to assess the quality of the contributions associated with each objective. The types of contributions are also illustrated by means of a pie chart (see Fig. 1.5). Part of the results of this thesis have been submitted and published in various peer-reviewed forums. At the time of writing, 5 out of 19 contributions are not published yet, but instead *under review* or *in*

press. All of these still unpublished results are journal articles. Fig. 1.6 provides an overview on the status of the contributions.

Table 1.2: Types of contributions and goals of the dissertation

	Type	Goal 1	Goal 2	Goal 3
Contr. 1	journal article* (JCR Q2)	X		
Contr. 2	journal article (JCR Q1)		X	
Contr. 3	journal article (JCR Q1)		X	
Contr. 4	journal article (JCR Q3)		X	
Contr. 5	journal article* (JCR Q2)	X	X	X
Contr. 6	journal article* (JCR Q4)	X		X
Contr. 7	journal article† (JCR Q4)	X		X
Contr. 8	journal article‡ (JCR Q2)	X	X	X
Contr. 9	intl. book chapter	X	X	
Contr. 10	natl. book chapter	X	X	
Contr. 11	intl. conf. or workshop		X	
Contr. 12	intl. conf. or workshop	X		X
Contr. 13	intl. conf. or workshop	X	X	X
Contr. 14	intl. conf. or workshop	X		X
Contr. 15	natl. conf. or workshop		X	
Contr. 16	intellect. prop. regist.	X		
Contr. 17	intellect. prop. regist.		X	
Contr. 18	intellect. prop. regist.		X	
Contr. 19	intellect. prop. regist.		X	

**Under review*
†*Accepted with major revision*
‡*In press*

Further work includes research on how to support project management issues by relying on RE, so that project management and decision making processes within the organisation can take advantage of explicit or derived requirements knowledge. The main idea is to enable requirements driven management of software factories in global environments. RE would be the backbone for defining, managing and developing software product lines and products within the organisation, effectively integrating SE standards and supporting management,

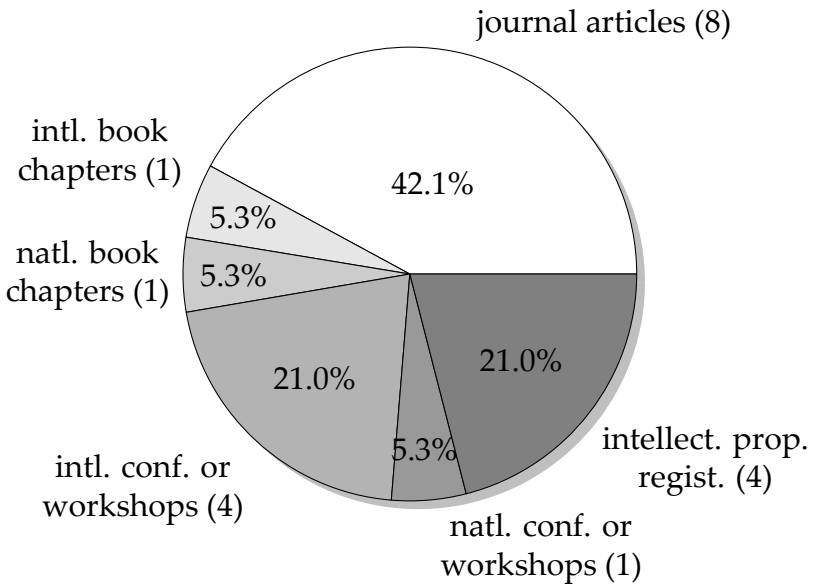

Figure 1.5: Types of contributions

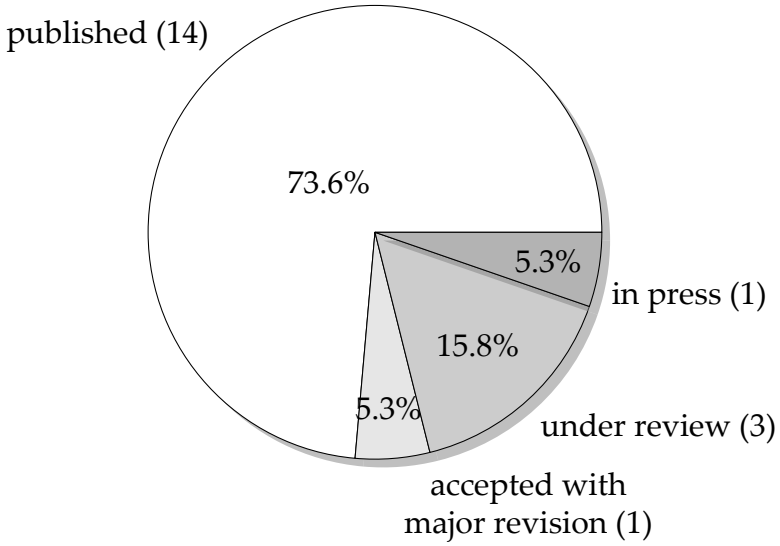

Figure 1.6: Status of the contributions

monitoring and control of projects starting from the requirements. Models have been proposed based on graphs and hypergraphs [77, 78] to store and represent semantic relationships between software artifacts, including related decisions and restrictions, so that software can be understood as a repository of knowledge that can be accessed through querying and application of data mining techniques. The social and organizational context that is especially important for requirements in GSD [79–81], can be managed by hyper-requirements [82], with which the social context of decisions and traceability is supported. Software visualisation makes easier to reach shared understanding of the system to be built [83]; for this reason, it would be interesting to relate models based on graph theory with software visualisation, and more specifically, the visualisation requirements and traceability from the requirements to the other development artefacts and stakeholders. Important aspects to model are the dependencies between requirements. Requirements Interaction Management (RIM) —the analysis and management of dependencies between requirements— aims to the discovery, management and disposition of critical relationships between sets of requirements [84, 85]. The selection of an optimal set of requirements to be implemented in the next version of a software system, *the next release problem* [86], needs to know the information about the dependencies between requirements [87]. RIM also affects traceability management, reuse and the evolution process of requirements [88, 89].

With regard to the evaluation of commercial RE tools, there are three main issues in which my future work could be focused. Firstly, in my previous work I have focused mainly on general RE capabilities. However, I have also studied other more specific subjects, namely collaboration and GSE. More recently, I have also worked on the topic of requirements reuse capabilities. With all this knowledge in mind, I have defined a general, comprehensive classification framework for RE tool capabilities. The items that make up this classification framework directly map to desirable RE tool features; thus, the classification framework leads to a generic requirements specification for a new RE tool to be developed. The capabilities included in the classification framework could have more or less relevance and value in different cases if a commercial RE tool is to be chosen. I also wonder about what would be the most relevant features if a new

RE tool is to be developed. In other words, I aim at providing criteria ranking for RE tools capabilities or features. Secondly, since my last RE tools evaluation the situation may have changed. Therefore, my classification framework and, especially, my dataset probably do not fully represent the current state of the art on RE tools. My classification framework could be improved with new capabilities to reflect recent trends since my last data gathering, as well as new topics that are interesting for us (specifically reuse). This would represent an evident progress with regard to the previous version of my classification framework. Then I could launch the questionnaire to the RE tool vendors and update my dataset. From my previous survey I have learned that the resulting questionnaire, including all the items in the classification framework, might be too large and complex to be filled in by the vendors. Another option consists of designing a short questionnaire with a reduced set of items from the classification framework (possibly the updated version of it). With this strategy, I would try to guarantee a high participation rate of RE tool vendors; however, a comparison between the previous and the new scenes would be much more difficult if I do not keep the same survey approach. Finally, during the last years, I have thoroughly studied current RE tools, which allowed us to gather extensive data and information on their features and capabilities. Therefore, I can use this information now to provide practitioners with an assisted decision process when they face the responsibility of picking out an RE tool for their organisation. In particular, a recommendation system can be built to achieve this goal.

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"I am sure you will be completely all right, a little tired, nothing more."
"You appear very gay this morning."
"Delighted, my boy, delighted! We have arrived."
"At the end of our expedition?"
"No; at the edge of that sea which seemed endless. We will now resume our journey by land, and really plunge into the vitals of the Earth."

Jules Verne, *Journey to the Centre of the Earth*

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 recognised 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 his contribution to the included papers. All these requirements are fulfilled in this appendix.

The doctoral candidate has submitted four journal articles [49, 57, 58, 60] and a book chapter [50], whose full copies are included in the following sections. The references of these works are as follows:

- Juan Manuel Carrillo de Gea, Joaquín Nicolás, José Luis Fernández Ale-

mán, Ambrosio Toval, Christof Ebert, and Aurora Vizcaíno. Requirements engineering tools. *IEEE Softw.*, 28(4):86–91, July/Aug. 2011. ISSN 0740-7459.

- Juan Manuel Carrillo de Gea, Joaquín Nicolás, José Luis Fernández Alemán, Ambrosio Toval, Christof Ebert, and Aurora Vizcaíno. Requirements engineering tools: capabilities, survey and assessment. *Inf. Softw.Technol.*, 54(10):1142–1157, Oct. 2012. ISSN 0950-5849.

- Juan Manuel Carrillo de Gea, Joaquín Nicolás, José Luis Fernández Alemán, Ambrosio Toval, Christof Ebert, and Aurora Vizcaíno. Commonalities and differences between requirements engineering tools: a quantitative approach. *Comp. Sci. Inf. Syst.*, 12(1):257–288, Jan. 2015. ISSN 1820-0214.

- José Luis Fernández Alemán, Juan Manuel Carrillo de Gea, Joaquín Vidal, Joaquín Nicolás, Ambrosio Toval, and Ali Idri. Effects of using requirements catalogs on effectiveness and productivity of requirements specification in a software project management course. *IEEE Trans. Educ.* (*in press*). ISSN 0018-9359.

- Juan Manuel Carrillo de Gea, Joaquín Nicolás, José Luis Fernández Alemán, Ambrosio Toval, Aurora Vizcaíno, and Christof Ebert. Reusing requirements in global software engineering. In Walid Maalej and Anil Kumar Thurimella, editors, *Managing Requirements Knowledge*, pages 171–197. Springer Berlin / Heidelberg, 2013. ISBN 978-3-642-34418-3.

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

- *IEEE Software* is a peer-reviewed scientific journal published by the IEEE Computer Society (United States) since 1983. This magazine delivers reliable, useful, leading-edge software development information to keep engineers and managers abreast of rapid technology change. It is considered an authority on translating software theory into practice. The magazine positions itself between pure research and pure practice, transferring ideas, methods, and experiences among researchers and engineers. It was included in the top quartile of the JCR list at the moment of publishing the article (JCR Science Edition 2011 impact factor: 1.508; Q1 (18/103): *Computer Science, Software Engineering*).
- *Information and Software Technology* is the international archival journal focusing on research and experience that contributes to the improvement

of software development practices. Its scope includes methods and techniques to better engineer software and manage its development. Formerly known as Data Processing, and published by Elsevier under its current name since 1987, it is considered the premiere outlet for systematic literature studies in software engineering. It was included in the top quartile of the JCR list at the moment of publishing the article (JCR Science Edition 2012 impact factor: 1.522; Q1 (23/105): *Computer Science, Software Engineering*; Q1 (33/132): *Computer Science, Information Systems*).

- *Computer Science and Information Systems* is an international refereed scientific journal published by the ComSIS Consortium, whose objective is to communicate important research and development results in the areas of computer science, software engineering, and information systems. The journal is sponsored by the Ministry of Education, Science and Technological Development of the Republic of Serbia. It was included in the third quartile of the JCR list at the moment of publishing the article (JCR Science Edition 2013 impact factor: 0.575; Q3 (101/135): *Computer Science, Information Systems*; Q4 (84/105): *Computer Science, Software Engineering*).

- *IEEE Transactions on Education* is a quarterly peer-reviewed academic journal that focuses on educational research, methods, materials, programmes, and technology in electrical engineering, computer engineering, and fields within the scope of interest of IEEE. It is published by the IEEE Education Society (United States) since 1963, but has existed under the name IRE Transactions on Education since 1958. The aims of the journal are both scientific and educational, grounded in the theory and practice of electrical and computer engineering, and allied disciplines. It was included in the second quartile of the JCR list at the moment of publishing the article (JCR Science Edition 2013 impact factor: 1.221; Q2 (123/248): *Engineering, Electrical & Electronic*; Q3 (18/36): *Education, Scientific Disciplines*).

- *Managing Requirements Knowledge* is an edited book published by Springer. The book focuses on potentials and benefits of lightweight knowledge management techniques applied to RE. With more than 200 Nobel Prize win-

ners among the authors of their books and journal articles, Springer is among the world's foremost STM publishers (STM is the leading global trade association for academic and professional publishers). The book editors are world-leading scientists. Dr. Walid Maalej brings in a unique multidisciplinary and internationally renowned research profile covering the fields of knowledge management, empirical software engineering and RE. Dr. Anil Kumar Thurimella has contributed a unique blend of industrial and academic experience on RE. All submissions were blind-reviewed by two other chapter-authors and by the editors. Among the most distinguished authors of the book chapters are renowned researchers and practitioners in the field of RE such as Dr. Daniela Damian, Dr. Anthony Finkelstein, Dr. Xabier Franch, Dr. Bashar Nuseibeh and Dr. Pete Sawyer, just to mention a few.

The doctoral candidate is the lead author of all of the mentioned articles but one, in which he is the second author. He worked both independently and also as part of a team with his generally more experienced colleagues. The doctoral candidate carried out the bulk of the work, he wrote the first version of the papers, he handled the manuscript revisions and finally he 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. In the case of the work that was not led by the doctoral candidate, he did not bear the primary responsibility for analysing the data, writing the paper and handling the reviewers' comments, although he actively participated in these activities. He leaded the rest of the research stages, from planning and carrying out the experiments to gathering data.

A.1 Article in *IEEE Software*

Abstract

Requirements engineering (RE) tools are increasingly used to ease the RE processes and allow for more systematic and formalized handling of requirements, change management and traceability. For developers and companies evaluating the use of RE tools it is thus essential to know which RE processes are supported by tools and how they fit to their own priorities. The answer isn't easy because many sales prospects highlight numerous features-yet leave out to which degree they're supported and whether all features really matter. To gain insight into how current RE tools adapt to RE activities, we ran a 146-item survey based on the features covered by the ISO/IEC TR 24766:2009, a new framework for assessing RE tool capabilities. We received responses from 37 participants, covering all relevant tools. In addition to the tools' score in each activity, we assessed their performance in three concrete use scenarios. Our findings can help practitioners select an RE tool as well as provide areas for improvement for RE tools developers.

DOI

`http://dx.doi.org/10.1109/MS.2011.81`

A.2 Article in *Information and Software Technology*

Abstract

Context: There is a significant number of requirements engineering (RE) tools with different features and prices. However, existing RE tool lists do not provide detailed information about the features of the tools that they catalogue. It would therefore be interesting for both practitioners and tool developers to be aware of the state-of-the-art as regards RE tools.

Objective: This paper presents the results of a survey answered by RE tool vendors. The purpose of the survey was to gain an insight into how current RE tools support the RE process by means of concrete capabilities, and to what degree.

Method: The ISO/IEC TR 24766:2009 is a framework for assessing RE tools' capabilities. A 146-item questionnaire based principally on the features covered by this international guideline was sent to major tool vendors worldwide. A descriptive statistical study was then carried out to provide comparability, and bivariate correlation tests were also applied to measure the association between different variables. A sample of the tools was subjected to neutral assessment and an interrater reliability analysis was performed to ensure the reliability of the results.

Results: The 38 participants sent back their answers. Most tools are delivered under a proprietary license, and their licenses are not free. A growing number of them facilitate Web access. Moreover, requirements elicitation exemplifies the best supported category of features in this study, whereas requirements modeling and management are the most badly supported categories.

Conclusion: The RE process seems to be well covered by current RE tools, but there is still a certain margin for amelioration, principally with regard to requirements modeling, open data model and data integration features. These subjects represent areas for improvement for RE tool developers. Practitioners might also obtain useful ideas from the study to be taken into account when selecting an appropriate RE tool to be successfully applied to their work.

DOI

http://dx.doi.org/10.1016/j.infsof.2012.04.005

A.3 Article in *Computer Science and Information Systems*

Abstract

System and software developers are concerned to gain insight into how current requirements engineering (RE) tools support processes. There is an important number of RE tools currently available on the market but, unfortunately, existing RE tool lists do not usually provide detailed and precise information about the tools they catalogue. In this paper, we study and compare current RE tools in the quest to answer the following research question: What level of variation, in terms of functionality, is observable in state-of-practice RE tools? A 188-item survey was designed, aimed at major tool vendors worldwide and based principally on the features covered by the ISO/IEC TR 24766:2009. Extensive data obtained from 29 participants was used to classify and group the RE tools, based on their capabilities. First of all, an inter-rater reliability analysis was performed to ensure the trustworthiness of the data. Descriptive statistics, hierarchical cluster analysis and statistical hypothesis testing were then applied. The tool scores for each candidate were calculated. A total of three clusters were identified. Statistically significant differences in coverage of features among these groups came to light. Our findings can help practitioners to decide which tool is the most suitable among several alternatives, according to their particular needs.

DOI

`http://dx.doi.org/10.2298/CSIS131201001C`

A.4 Article in *IEEE Transactions on Education*

Abstract

This paper presents the results of two educational experiments carried out to determine whether the process of specifying requirements (catalog-based reuse as opposed to conventional specification) has an impact on effectiveness and productivity in co-located and distributed software development environments. The participants in the experiments were 76 students enrolled in three courses on project management for software development at the University of Murcia, Spain, and the Mohammed V University of Rabat, Morocco. The results of a fixed effects meta-analysis (Hedges' g) obtained a medium effect (-0.495, $p = 0.034$) for productivity, and a large effect (-1.077, $p < 0.001$) for effectiveness, in favor of using a catalog-based reuse process rather than a conventional specification process. The other co-factor examined, distribution (either global or co-located), had no statistically significant interaction with the process used (catalog-based reuse or conventional specification) for either effectiveness or productivity. Further research is required to study the effectiveness and productivity of the catalog-based requirements engineering learning method so that it can be taught in software engineering courses and applied in real software engineering projects.

DOI

`http://dx.doi.org/10.1109/TE.2015.2454472`

A.5 Chapter in *Managing Requirements Knowledge*

Abstract

Knowledge sharing and reuse in global software engineering (GSE) are challenging issues. Knowledge management (KM) is specifically impacted because on top of distance, culture and language mismatches, there is also the perceived risk of sharing something which could mean that others could take over some work. Mistrust and protectionism are often the consequence, leading to insufficient reuse. This is visible specifically in requirements engineering (RE), where all reuse should start. In this chapter, we will look to reuse in RE with a detailed look on how to improve knowledge sharing and collaboration in distributed environments. We first look into the state of the practice. Then we present a lightweight, reuse-based, global RE method called PANGEA (*Process for globAl requiremeNts enGinEering and quAlity*), based on natural language requirements and software engineering standards. Based on this method, we also build a prototypical tool, called PANTALASA (*PANgea Tool And Lightweight Automated Support Architecture*) which provides automated support for PANGEA. Its features are drawn from PANGEA and the state of the practice commercially available RE tools. A prototype of PANTALASA was developed by using Semantic MediaWiki and Facebook and applied to a case study in the domain of hotel management. We could show with this method and prototype that collaboration and thus KM and reuse in RE are improved.

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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.