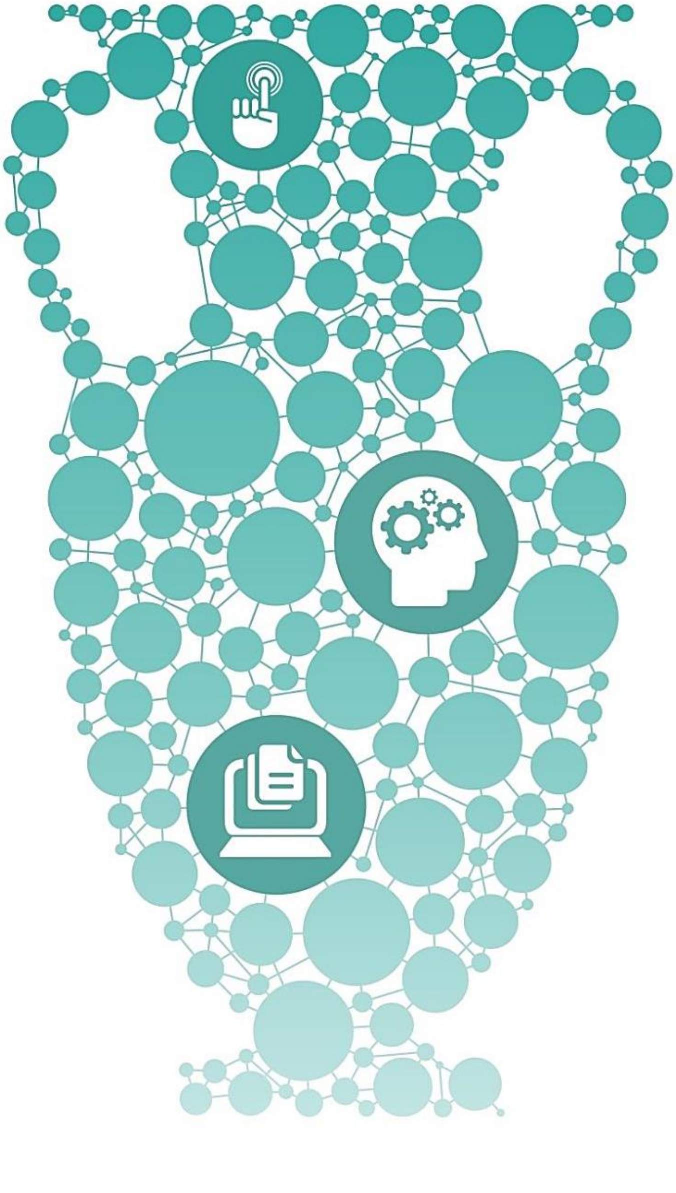
Patricia Martín Rodilla

Software-Assisted Knowledge Generation in the Cultural Heritage Domain:

A Conceptual Framework



Advisors:

Prof. Óscar Pastor López

Dr. César González Pérez

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Patricia Martín Rodilla

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A Conceptual Framework

PhD Thesis, June 2016

This report was prepared by Patricia Martín Rodilla.

Supervisors

Dr. Óscar Pastor López
Dr. César González Pérez

External reviewers

Reviewers:
Dr. Hernán Astudillo, Universidad Técnica Federico Santa María, Chile.
Dr. Irit Hadar, University of Haifa, Israel.
Dr. Costis Dallas, University of Toronto, Canada and Digital Curation Unit (DCU), Institute for the Management of Information Systems-Athena Research Centre, Greece.

Substitute reviewers:
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Dr. José Varela Pet, Universidade de Santiago de Compostela, Spain.
Dr. Agiatis Benardou, Digital Curation Unit (DCU), Institute for the Management of Information Systems-Athena Research Centre, Greece.

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Dr. Costis Dallas, University of Toronto, Canada and Digital Curation Unit (DCU), Institute for the Management of Information Systems-Athena Research Centre, Greece.

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Centro de Investigación en Métodos de Producción de Software
Universitat Politècnica de València
Camí de Vera s/n, Edif. 1F. 46022 - València, Spain
Web: http://www.pros.upv.es

To Miki.

To my parents and my sister.

For all those moments together that are coming…

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Abstract

Software Engineering provides a repository of techniques, methods and tools to manage, process, use and exploit information. In recent decades, this corpus has not only been applied to domains that traditionally act as a receivers of software solutions, but also it has been expanded and enriched by contributions from other disciplines and domains with needs related to the information produced. One of the most common needs in these disciplines is the software assistance to experts or domain professionals in performing processes ranging from the analysis of raw gathered data to the generation of new knowledge based on these, thus allowing the continuous advance of the discipline. Good examples are the software assistance in contexts of genomics research and in business decision-making processes. In order to assist knowledge generation processes through software, it is necessary a deep understanding of the Software Engineering corpus as well as the particularities of the domain assisted and how knowledge is generated inside it.

This situation appears too in the Cultural Heritage domain, whose professionals produce and manage large amounts of data about evidences of our past and present, from which they create new knowledge that constitutes the knowledge about heritage of a particular community. This knowledge defines the community at present, and is transmitted to the present and future generations. Despite their relevance and the regular application of Software Engineering solutions to the Cultural Heritage domain, the knowledge generation process in Cultural Heritage poses a challenge for Software Engineering, mainly due to the low presence of formal studies of the process, making it difficult to assist it through software. The lack of formal studies implies that we do not know which particular processes in Cultural Heritage we must assist and what should be the appropriate assistance in each case. Furthermore, the Cultural Heritage domain and, in general, the humanities, possesses some particular characteristics that are especially difficult to deal with by software, such as the presence of high subjectivity, the fact that much information is uncertain or vague, and the importance of the temporal aspect in the information.

In order to address these two challenges from a transdisciplinary perspective, this thesis presents a conceptual framework based on software models for the construction of software solutions to assist to the knowledge generation process in Cultural Heritage. Firstly, the thesis conducts a deep exploration of the knowledge generation processes in Cultural Heritage, whose inputs are mainly textual sources.

As a result, the thesis proposes a methodology and a modelling language to use discourse analysis in Software Engineering. By using this approach, it is possible to relate elements of a text with the domain entities that are referenced and the argumentative mechanisms used during the knowledge generation process and captured in the text. Subsequently, the thesis proposes a conceptual framework whose implementation allows to manage the domain particularities mentioned above, providing a software assistance to the Cultural Heritage professionals through information visualization techniques.

The proposed conceptual framework has been validated in two complementary ways. On the one hand, we have developed a full case study in the Cultural Heritage domain, for which we have instantiated all the software models proposed as part of the framework to represent a real-world scenario. This case study application has revealed the potential of the framework in terms of conceptual representation, technical support and software-assistance definition mechanisms. On the other hand, the proposed software models have been implemented as a functional iOS application prototype. The prototype has been validated empirically against professionals in Cultural Heritage, comparing the performance of knowledge generation processes using the proposed framework to the conventional ways without software assistance. The empirical validation has revealed how the proposed framework provides a robust solution —based on the software models defined as part of the conceptual framework— for the construction of software systems to assist to the knowledge generation process in the Cultural Heritage domain. In addition, the thorough validation performed in these two complementary forms has detected areas for improvement and future research lines that will allow us to conceive other software-assistance possibilities, not only looking for software-assisted knowledge generation in Cultural Heritage, but also in related but unexplored domains.

Resumen

La ingeniería del software ofrece un repositorio de técnicas, métodos y herramientas como soluciones para el manejo, tratamiento, uso y explotación de información. En las últimas décadas, este corpus no sólo ha sido aplicado a dominios tradicionalmente receptores de soluciones software, sino que se ha expandido y enriquecido con aportaciones de diversas disciplinas y dominios con necesidades relacionadas con la información que producen. Una de las necesidades más habituales es la asistencia a los profesionales de dichas disciplinas durante el proceso evolutivo que realizan desde el análisis de los datos más primarios hasta la generación de conocimiento nuevo que permita avanzar en la disciplina involucrada. Buenos ejemplos son la asistencia software en contextos de investigación genética y en asistencia a la toma de decisiones de negocio. Para poder asistir mediante software este proceso, es necesario un conocimiento profundo del corpus de ingeniería del software, pero también de las especificidades del dominio a asistir y cómo se genera conocimiento en él.

Este es el caso del Patrimonio Cultural, cuyos profesionales producen y manejan ingentes cantidades de datos acerca de evidencias sobre nuestro pasado y presente, y desde los cuáles descubren y generan conocimiento nuevo, que supone la herencia cultural propia de una comunidad. Este conocimiento define la comunidad en el presente y es transmitido a las generaciones presentes y futuras. Pese a su relevancia y a la habitual aplicación de determinadas soluciones de ingeniería software en el dominio, el proceso de generación de conocimiento en Patrimonio Cultural representa en sí mismo un reto para la ingeniería del software, debido fundamentalmente a la poca presencia de estudios formales acerca del mismo, lo que dificulta su asistencia mediante software. Esto implica que no sabemos qué tipo de subprocesos debemos asistir mediante software ni cuál es la asistencia más adecuada. Además, el corpus actual en ingeniería del software debe soportar especificidades del dominio patrimonial y, en general, de las humanidades, como son la presencia de una alta subjetividad, el hecho de que mucha información es incierta o vaga, y la importancia del aspecto temporal en los datos.

Con el objetivo de abordar estos dos retos desde una perspectiva co-investigadora y transdisciplinar, la presente tesis doctoral presenta un marco conceptual basado en modelos software para la construcción de soluciones software que asistan a la generación de conocimiento en Patrimonio Cultural. En primer lugar,

la tesis explora a fondo el proceso de generación de conocimiento en Patrimonio Cultural, cuyas fuentes eminentemente textuales han dado lugar a la propuesta de una metodología completa y un lenguaje de modelado para utilizar análisis del discurso en ingeniería del software. Esta propuesta permite que se puedan relacionar elementos de un texto con las entidades del dominio que se referencian, así como los mecanismos argumentativos que se emplean. Posteriormente, la tesis propone un marco conceptual completo cuya implementación permite gestionar las especificidades del dominio antes señaladas, ofreciendo una asistencia mediante técnicas de visualización de información software a los especialistas en Patrimonio Cultural.

El marco conceptual propuesto ha sido validado de dos maneras complementarias. Por un lado, se ha desarrollado un caso de estudio patrimonial completo, para el cual se han implementado todos los modelos software del marco conceptual propuesto, representando un escenario de aplicación completo del mundo real. Este caso de estudio ha permitido comprobar la potencia del marco conceptual propuesto en cuanto a representación, soporte y definición de mecanismos de asistencia software. Por otro lado, los modelos software que conforman el marco conceptual propuesto han sido implementados en un prototipo funcional en forma de aplicación iOS. Esto ha permitido contar con una implementación real de asistencia software en Patrimonio Cultural. Dicha solución se ha validado empíricamente con profesionales del dominio, comparándola con los modos de generación de conocimiento habituales sin dicha asistencia. La validación empírica ha permitido comprobar cómo el marco conceptual propuesto constituye una solución sólida para la construcción, a partir de los modelos software especificados en el mismo, de sistemas software para asistir a la generación de conocimiento en Patrimonio Cultural. Además, el profundo trabajo de validación en ambos sentidos ha permitido detectar áreas de mejora y líneas futuras de trabajo que permitan implementar otros tipos de asistencia software, buscando que la asistencia software a la generación de conocimiento sea una realidad no sólo en Patrimonio Cultural, sino en dominios similares inexplorados.

Resum

L'enginyeria del programari ofereix un repositori de tècniques, mètodes i eines com a suport per la manipulació, tractament, ús i explotació d'informació. En les darreres dècades, aquest corpus no sols ha sigut aplicat a dominis tradicionalment receptors de solucions de programari, si no que s'han extés i enriquit amb aportacions des de diferents disciplines i dominis amb necessitats relacionades amb l'informació que produeixen. Una de les necessitats més habituals és l'assistència als professionals d'aquestes disciplines durant el procés evolutiu que realitzen des de l'anàlisi de les dades més primàries fins la generació de nou coneixement que permet avançar en la disciplina involucrada. Bons exemples de tot açò són l'assistència de programari en contextesd de recerca genètica i l'assistència a la presa de decisions de negoci. Per tal de poder assistir mitjançant programari a aquest procés, és necessari tant un coneixement en profunditat del corpus d'enginyeria del programari, però també de les especificitats del domini que es pretén assistir i com es genera coneixement en aquest.

Aquest és el cas del Patrimoni Cultural, el professionals del qual produeixen i manipulen grans quantitats de dades sobre evidències del nostre passat i present, i des de les quals descobreixen i generen nou coneixement, que suposa l'herència cultural pròpia d'una comunitat. Aquest coneixement defineix a la comunitat en el present i es transmet a les generacions presents i futures. A pesar de la seua relevància i a la normal aplicació de determinades solucions d'enginyeria de programari al domini, el procés de generació de coneixement en Patrimoni Cultural representa, en sí mateix, un repte per a l'enginyeria del programari, fonamentalment per la poca presència d'estudis formals sobre aquest domini, cosa que dificulta la seua assistència per programari. Açò implica que no sabem quin tipus de subprocessos hem d'assistir amb programari ni quina és l'assitència més adient. A més a més, el corpus actual en l'enginyeria del programari ha de suportar especifitats del domini patrimonial i, en general, de les humanitats, com són la presència d'una alta subjectivitat, i el fet que molta informació és incerta o imprescisa, o la importància de la dimensió temporal en les dades.

Amb l'objectiu d'abordar aquestos dos reptes des d'una perspectiva de recerca colaborativa i transdisciplinar, aquesta tesi doctoral presenta un marc conceptual basat en models de programari per a la construcció de solucions de programari que

assistisquen a la generació de coneixement en Patrimoni Cultural. En primer lloc, la tesi explora en profunditat el procés de generació de coneixement en Patrimoni Cultural, les fonts de les quals són majoritàriament textuals han sigut l'origе per a la proposta d'una metodologia completa i un llenguatge de modelatge per emprar anàlisi del discurs en enginyeria de programari. Aquesta proposta permet que es puguen relacionar elements d'un text amb les entitats del domini que es referencien, així com els mecanismes argumentatius que s'empren. Posteriorment, la tesi proposa un marc conceptual complet amb una implementació que permet gestionar les especificitats del domini abans esmentades, oferint una assistència mitjançant tècniques de visualització d'informació de programari als especialistes en Patrimoni Cultural.

El marc conceptual proposat ha sigut validat de dues maneres complementàries. Per una banda, s'ha desenvolupat un cas d'estudi patrimonial complet, implementant tots els models de programari del marc conceptual proposat, representant un escenari d'aplicació complet del món real. Aquest cas d'estudi ha permés comprovar la potència del marc conceptual proposat en quant a la representació, suport i definició de mecanismes d'assistència de programari. Per una altra banda, els models de programari que conformen el marc conceptual proposat s'han implementat en un prototipus funcional en forma d'aplicació iOS. Aquest fet ha permés comptar amb una implementació real d'assistència de programari en Patrimoni Cultural. Aquesta solució s'ha validat empíricament amb professionals del domini, comparant-la amb els modes de generació de coneixement habituals sense aquesta assistència. La validació empírica ha permés comprovar com el marc conceptual proposat constitueix una solució sòlida per a la construcció, a partir dels models de programari especificats, dels sistemes de programari per assistir a la generació de coneixement en Patrimoni Cultural. A més a més, el treball en profunditat de validació en ambdós sentits ha permés detectar àrees de millora i línies futures de treball que permeten implementar altres tipus d'assistència de programari, buscant que aquesta assistència a la generació de coneixement siga una realitat no sols en Patrimoni Cultural, sinò en dominis similars inexplorats.

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PART I: Research Context and Problems

Not all who wander are lost

-J.R.R. Tolkien

Chapter 1: Introduction

Study the past if you would define the future. -Confucius

Cultural Heritage is defined by UNESCO (United Nations Educational, Scientific and Cultural Organization) as "the works of its artists, architects, musicians, writers and scientists and also the […] tangible and intangible works through which the creativity of that people finds expression: languages, rites, beliefs, historic places and monuments, literature, works of art, archives and libraries." This definition (World Conference on Cultural Policies, held in Mexico in 1982) and their continued revisions (the last UNESCO revision of immaterial Cultural Heritage dates from 2003), cover a wide range of disciplines and knowledge. This area is of vital importance as it envelopes not only what we know about our past, but also our current and future vision of what we are. In the words of the Director-General of UNESCO Koïchiro Matsuura during his inauguration speech for the United Nations Year for Cultural Heritage in 2002:

> *"Above the door of the Kabul Museum, ravaged by more than 20 years of warfare, this maxim was posted up by persons unknown a few days ago: "A nation is alive when its culture is alive". (…) The cultural heritage of a people is the memory of its living culture. It takes many different forms, both tangible (monuments, landscapes, objects) and intangible (languages, know-how, the performing arts, music, etc.). The origins of this heritage are multifarious, too. In retracing its own cultural lineage, in recognizing the many different influences that have marked its history and shaped its identity, a people is better able to build peaceful relations with other peoples, to pursue what is often an age-old dialogue and to forge its future." Koïchiro Matsuura, 2002.*

This fragment of his speech contains within it the motivation for and the cultural, social, economic and human importance of the study, preservation, dissemination and valorisation of heritage elements. All of these activities generate huge amounts of data and information, which then gives rise to the generation of new knowledge about our past. This information has traditionally been used in contexts associated with research, management or dissemination projects subject to specific needs and objectives or to a particular activity (Archaeology, Historiography, Museology, etc.). These uses of information are often determined by the context in which it was generated and do not allow the information acquired or generated to be used for other purposes. This situation, along with the need to deal with and assist all professionals working in this area, has already been identified, as can be seen in projects such as Europeana [88], Bamboo [26] and, more recently, Ariadne [17], all projects aiming to build infrastructures and software solutions to help these professionals.

Within this context, Software Engineering plays a relevant role as an information science, since it brings together the corpus of knowledge necessary for the conceptualisation, management, appropriate handling, exploitation and giving of assistance to researchers as they carry out their tasks and take decisions, from raw data to the generation of new knowledge. This is possible thanks to new approaches, techniques and sub-disciplines originating from the field of Software Engineering, which allow for assistance to be provided by means of software in the afore-mentioned generation of knowledge.

Thus, working in untraditional fields for the application of Software Engineering, as is the case of Cultural Heritage, allows Software Engineering as a discipline to test its achievements, to detect its limitations and to undertake new lines of research which may arise from the characteristics of the new field.

In summary, this thesis aims to connect the corpus of knowledge of Software Engineering to the needs of Cultural Heritage, thus representing an advance for both disciplines and establishing a conceptual and design basis between the two fields in the specific framework of assistance to the generation of knowledge.

Context

This research lies within the scope of the research line “Semantic Technologies for Cultural Heritage” of the Institute of Heritage Sciences (from here on in, Incipit), a research centre belonging to the Spanish National Research Council (CSIC). The knowledge, means and expertise acquired by the author in Software Engineering in the Polytechnic University of Valencia have been applied to this research line.

The research line on “Semantic Technologies for Cultural Heritage” aims “to create, select, develop, analyse, validate, demonstrate and disseminate the necessary technologies for the construction of meaning around the information that is generated and handled during work involving research on, and management of, cultural heritage” [18]. In order to understand its scope, it should be highlighted that, although UNESCO's previously mentioned definition of the term “Cultural Heritage” is widely accepted in the areas of international administration and management of heritage entities, there are, however, a host of visions, definitions and interpretations of the subtext of the concept of "Cultural Heritage", as well as the discussion of what features allow something to be classified as such [117]. Nevertheless, the objective of this thesis is not to offer or adopt a definitive definition of the term "Cultural Heritage", but to take as a starting point the fact that all the adopted mechanisms and/or those constructed during the research must allow for a flexible vision of the term.

In this context, efforts have recently been made to carry out research on the improvement of conceptualisation techniques [78, 108, 110], the management of and access to information [71, 88], the creation of service infrastructures [17] and the visualization [187, 265] of data in the Cultural Heritage field and of the information generated from it. However, the analysis of these studies reveals the need for a greater understanding of the processes of knowledge generation, taking it as an ensemble of cognitive processes carried out by a specialist in a certain field in order to generate information from raw data with the aim of then creating new knowledge in their discipline. Other recent studies along the same lines also show the same need, as well as the validity of this approach [80, 282]. We believe that this study of the processes of knowledge generation can be a differentiating element in the improvement of processes in which Software Engineering already plays a significant role within Cultural Heritage, as can be seen in the rise in sub-disciplines such as Digital Humanities [135], prestigious academic conferences [43], and research policies supporting the development of this role [87].

Motivation

A Cultural Heritage project generally involves many different disciplines and professionals with differing profiles and degrees of expertise as well as several research and management aims and organisations with different responsibilities and roles. This situation can mean that the data which is gathered and the information generated has a high degree of heterogeneity and, as has been mentioned previously, there is a tendency towards ad hoc solutions which are restricted to one particular project. For example, in 2010 the Incipit carried out a research project entitled "Procesos de Patrimonialización no Camiño de Santiago: tramo Santiago-Fisterra-Muxía", financed by the Plan gallego de I+D+i (Incite), with the reference code INCITE09606181PR. The main aim of the project was to carry out multidisciplinary research on a section which is not officially recognised by the Catholic Church as being part of the Way of St James. This stretch, however, from Santiago de Compostela to Finisterre, is becoming more and more popular among some pilgrims, who do not stop in Santiago but go on to Finisterre. The aims of the project were to characterise the most representative places along this section of the Way, which is also known apocryphally as the "Way of the Atheists" [262], to find out why pilgrims do it and to gather information about the traditions associated with it and what socio-economic impact the increased popularity of this section has had. Thus it was necessary to carry out collaborative work between historians and archaeologists (who focused on the material evidence from the different sites studied), anthropologists (who focused on the study of the relationship between modern-day settlements and the different sites by way of interviews and ethnographic work) and sociologists (whose interest was centred on the touristic phenomenon of this section of the Way and its socio-economic impact on the various groups which were studied: tourists, local population, businesses in the region, etc.). After several fieldwork campaigns had been carried out by professionals from the three disciplines, the project produced semi-structured data (basically the results of records and cataloguing of archaeological evidence and the results of surveys) and data in an unstructured format (reports on archaeological research, technical reports of excavations, transcripts of interviews, anthropological fieldwork diaries, etc.).

All of this raw data and information which was generated served as a basis to generate knowledge regarding our past. It allowed the professionals to establish, for example, the profile of the typical pilgrim who walks this section (if he/she is young or old, a believer or not, his/her motivation, if he/she walks alone or accompanied, etc.). It also allowed for elements of material heritage (hermitages, wayside crosses, etc.) to be catalogued for the first time on this section. It was, therefore, possible not only to gain isolated information about each element, but also to compare information about their relation to the stretch from Santiago to Finisterre and their usage, state of preservation and other parameters with other sites on the Way in the search for similarities and differences. But what is the process which allows for this generation of new knowledge?

If we consult the primary sources of the process, that is to say the researchers themselves who participated in the project, we discover that these results were obtained thanks to the conceptualisation of a common framework of data to be gathered regarding the heritage elements, which allowed them to compare, correlate and search for contrasts (in other words, to carry out cognitive processes) regarding the usage, the state of preservation, the localisation of the elements with respect to the Way and the results of the interviews. We shall also see that software was only used to support the spatial reasoning (Geographical Information Systems), and that manual drawings, diagrams and ad hoc visualisations were made in order to be able to visualise the data and to reason more deeply about the rest of the dimensions of the data. This allowed the data to be understood within its temporal context and meant that groups of data could be compared according to their characteristics (for example, the archaeological evidence and objects found) and where they appeared. An example of this manual outlining are the Harris diagrams [127], commonly referred to as the "Harris Matrix", which allow unearthed objects to be identified with their relative position in the excavation.

But can all this complex process be helped integrally by way of software? In what way? To what degree? Are there limitations? These informal questions form the initial motivation of this research. To put it more formally, two fundamental motivations can be established:

(1) The strong presence of studies in the research community which combine theories, techniques, and tools originating from Software Engineering in some aspect of the area of Cultural Heritage.

(2) The prior detection of needs of the aforementioned community for a deeper formalisation of that relationship.

Due to the existence of these two basic motivations, we believe it is necessary to carry out research on the process of knowledge generation in the area of Cultural Heritage and its relationship with Software Engineering, with a focus on addressing the possibilities of software assisting to this process from a co-research perspective allowing for state of the art advancement in both disciplines.

Objectives

The main objective of this research is determining the issue of whether it is possible for software to assist to the knowledge generation process as practised by specialists in the area of Cultural Heritage. In order to do this, it is necessary to study this process in depth. In addition, we shall attempt to identify possible improvements which can be made in the aforementioned process by way of software assistance and to propose software models which can provide systems with such a capacity of assistance. This assistance could materialise in the form of guidelines for the application of knowledge extraction techniques or in the proposal of the application of techniques for the visualisation of heritage information which are adapted to the characteristics of the knowledge-generation process.

Organisation of the Thesis Document

This thesis is divided into 5 parts:

- Part I: Research Context and Problems
- Part II: Exploration of the Problem
- Part III: Solution
- Part IV: Validation
- Part V: Final Considerations

Each part consists of a series of chapters containing the following information:

Part I contains three chapters: “Introduction”, “The Initial Hypothesis” and “Research Methodology”. Over the course of these chapters, the starting point of the research is presented: the motivational perspective and its disciplinary, historical and scientific context. In addition, the research methodology carried out over the course of the doctoral work is explained in detail.

Part II contains two chapters: “Techniques and Tools” and “Prior Empirical Results”. These two chapters outline the research problems identified, the techniques and tools used and developed for the in-depth exploration of the issue and some empirical results obtained from the application of these techniques and tools. These results consist of empirical evidence prior to the needs and justification of the solution presented later.

Part III consists of five chapters: “Framework Overview”, “Subject Matter”, “Cognitive Processes”, “Presentation and Interaction Mechanisms” and “Integration, Interoperability and Consistency between Framework Models”. These chapters describe the framework created as a solution to the problems identified over the course of the research. The chapter entitled “Framework Overview” presents a general overview of the framework-solution. The remaining chapters explain each of the parts of the framework, with the final chapter dealing with the conceptual and structural interrelation between the different parts of the framework.

Part IV consists of two chapters: “Analytical Validation: A Romea as a Case Study” and “Empirical Validation”. These chapters detail both the processes of evaluation and validation carried out on the framework-solution created, each one being of a different nature; one is an analytical-formal validation and the other an empirical validation.

Finally, Part V contains two chapters entitled “Discussion” and “Conclusions”, in which the impact, sphere of application and the implications of the results obtained throughout the doctoral research are addressed, as well as the future possibilities for each one of the original contributions presented both from the point of view of the research community and from a practical perspective of their application by real users, in this case by specialists in Cultural Heritage.

It is necessary to highlight the fact that Part II contains a broad revision of the literature, which was carried out with the aim of exploring the problem and identifying necessities. However, this thesis does not contain a specific chapter on the revision of the existing literature, although this thesis document structure is the most common in academia environments. Due to the interdisciplinary nature of this research, the decision was taken, once the aforementioned revision had been carried out, to address each technique and tool used and/or created in its own context. Therefore, bibliographic references to the research context will be found throughout the course of this thesis, albeit always making reference to the technique or tool used or created or to the solution proposed in each case.

Chapter 2: The Initial Hypothesis

Fantasy, abandoned by reason, produces impossible monsters. United with it, she is the mother of the arts and the origin of marvels. -Goya

Taking as a starting point the context and motivation outlined in the introductory chapter, and with the investigative objective defined (assisting to the knowledge-generation process in Cultural Heritage by way of software), a fundamental research question must be asked in accordance with our objective:

To what extent is it possible to improve knowledge generation processes in Cultural Heritage by way of software assistance to the user with knowledge extraction and information visualization techniques?

The formulation of the research question already includes the idea of how this software assistance will materialise. Let us detail each one of the terms implied in the main question:

- **Knowledge generation**: by the term knowledge generation we understand the process by which a human being, from the moment he/she comes into contact with descriptive data from real entities until, by way of cognitive processes based on analytical reasoning and "upward" changes in the level of abstraction, obtains previously unknown results regarding the analysed entities. This process takes place at the core of what has been described by many authors [7, 30, 51] as a model of layers or levels, in which the ascent from one layer or another is subject to these cognitive processes being carried out by the human being.
- **Cultural Heritage**: this is the cultural inheritance belonging to the past of a community, with which it co-exists in the present and which it passes from present to future generations. It includes the uses, representations, expressions, knowledge and techniques (as well as the instruments, objects, artefacts and cultural places which are inherent), which communities, groups and, in some cases, individuals recognise as part of their Cultural Heritage [287]. It should be pointed out here that, within UNESCO's definition, there are divergences when it comes to establishing criteria for defining the boundaries of the sphere of influence of Cultural Heritage [117]. In this thesis,

the decision has been taken to approach this definition from a flexible perspective.

- **Software Assistance**: by software-assisted, we understand the ensemble of services offered by a software system to human users in order to help them carry out certain (typically manual or well-defined) processes in any area. The term has become popular in certain fields, such as in software assistance for textual analysis. Good examples of this relate to the detection of plagiarism [277, 278, 307]), industrial processes [252] and certain software-assisted medical processes, such as the management of hospital discharges and the detection of relevant elements in medical analyses [119, 249]. Throughout this study, in a similar way to other current studies [67], software-assisted processes will be addressed as an ensemble of services offered by a software system to specialists in a particular field (in this case Cultural Heritage) in order to assist them in carrying out cognitive processes which will allow them to generate knowledge in their field.

- **Knowledge extraction:** this refers to the ensemble of techniques which allow for the creation of new knowledge based on structured data (relational databases, XML) and unstructured data (text, documents, images). The resulting knowledge must be in a format which is legible for the machine but which, at the same time, enables the human to carry out cognitive or inference processes [286]. The techniques included in knowledge extraction are applied with differing degrees of automatisation, from techniques based on ontologies [299] or annotation to the most automatic techniques related with the sub-discipline of the recuperation of information [25]. Throughout this study, the subgroup of these techniques which are manually and semi-automatically applied and are mainly based on domain ontologies and discourse analysis has been taken into account. However, the capacity of software-assisted processes for frameworks presented in the most automatic cases, such as the application to the discipline of data-mining techniques, the automatic recuperation of data and the automatic processing of natural language, has been considered as an area worthy of future study.

- **Information Visualization:** this is taken to be an ensemble of techniques which “use visual computing to amplify human cognition with abstract information.” [46]. It is “an increasingly important subdiscipline within HCI, (which) focuses on graphical mechanisms designed to show the structure of information and improve the cost of access to large data repositories” [22]. Over the course of this study, we shall look at existing techniques and creation mechanisms for new techniques within the discipline for their application to the visualisation of heritage data, proposing the most appropriate forms of visualisation as the natural way of assisting people through the use of software.

Having defined each of the relevant concepts in the principal research question, we can understand its scope more exactly. Taking as its starting point the principal research question, this study has the objective of validating the initial hypothesis on the premise that the answer to the question is affirmative. That is to say, we take the hypothesis that **it is possible to significantly improve knowledge-generation processes in Cultural Heritage by way of providing software assistance to the user with knowledge extraction and information visualization techniques**.

The backbone of the research will consist of verifying this hypothesis by means of hypothetico-deductive reasoning, gathering evidence of all types, both formal and empirical, in favour of and against the hypothesis. In the following chapter, the research methodology used in order to verify the hypothesis will be described in detail. Furthermore, the additional research questions which have arisen and been answered along the way will be detailed, as will the constructs which have been produced and the results and contributions which have been obtained. In addition, a description will be provided of how these elements fit into the structure of this document.

Chapter 3: Research Methodology

Whatever the scientific method in the hand of man will produce depends entirely on the nature of the goals alive in this mankind. Once these goals exist, scientific method furnishes means to realize them. -Albert Einstein

Underlying Theories in Research in Software Engineering

There are many studies on underlying theories in any research in the field of Software Engineering. Recently, Gregor [120] published an in-depth study of all of them, studying them on the basis of seven components of the theories which serve as criteria: means of representation, created constructs, relationships, scope, if they present causal explanations, if they present testable propositions and if they present prescriptive statements. The study of theories in Software Engineering in function of all these elements allows them to be classified into five subcategories:

- Theories for Analysis: this includes all those which attempt to describe or classify dimensions or characteristics specific to individuals, groups, events, etc. of the reality based on discreet observations. They respond, therefore, to "What?" questions about a particular phenomenon. Scientific contribution is produced when the phenomenon to be explained has not previously been described in detail or is being approached from a different perspective. Taxonomies and frameworks are examples of valid contributions in this type of theory.
- Theories for Explanation: these are theories which explain the how and the why of the phenomenon in question. They attempt to analyse causal components of a particular phenomenon. Scientific contribution is produced if we have managed to explain the cause of something which was previously unstudied, unknown or misunderstood. Scenario development and case studies are examples of valid contributions in this type of theory.
- Theories for Prediction: these are theories which explain what will be. It is not necessary, therefore, to find descriptions or causes to the phenomena, but to predict their future behaviour. Scientific contribution is produced when a factor or predictive model relevant for the field is discovered, whether we know or not the causes of its functioning.
- Theories for Explanation & Prediction (EP Theory): these are theories which unite the previous ones. That is to say, they attempt to predict the future

behaviour of a phenomenon and also describe and study the causalities of the current phenomenon.

- Theories for Design and Action: these are theories which explain how to do something. That is to say, they deal with "the principles of form and function, methods, and justificatory theoretical knowledge that are used in the development of IS" [121]. Scientific contribution is produced if a series of criteria are fulfilled when evaluating the constructs produced, such as the utility for the user's community or the novelty of the artefact. Methods and models are common products in this type of theory and can be evaluated from different perspectives: completeness, ease of use, simplicity, consistency, etc. [190].

Finally, Gregor makes reference to the possibilities of interconnecting the types of underlying theories in the same Software Engineering research project. Taking Gregor's work as a basis, the research presented here shows an interconnection which reflects its evolution among different subtypes of theories.

Initially, if we wish to prove to what point it is possible to assist to knowledge generation in Cultural Heritage by means of software, we must get to know this process in a much deeper way. Therefore, our initial aim in this point is analytical, since we wish to gain a deeper understanding of a phenomenon. This supposes that the studies relating to this phenomenon throughout this research will constitute type I theories.

During the course of this study we have tackled some causal aspects of the knowledge-generation process in Cultural Heritage. Why is knowledge generated in one way and not in another? This gives our research a more explanatory perspective. Later, we shall describe the scope and limitations of the causal aspects dealt with in the selection of a case study. This case study constitutes a type II theory.

Lastly, the final objective is to propose software models which allow us to use software to assist in an integral way to knowledge-generation processes in Cultural Heritage. In order to do this, we have designed a framework-solution. This framework encapsulates how assistance can be provided by way of selected techniques in knowledge generation in Cultural Heritage. Therefore, the underlying theory in this framework takes on a final nuance of action and design, moving towards a solution.

The Choice of Research Methodology

Having identified the underlying research theories which concern us, it becomes simpler to deal with the choice of which research methodology is most appropriate for the theoretical frameworks detected, as well as for the previously defined research objectives.

The fact of having an initial hypothesis to verify (set out in the previous chapter) is a determining factor in choosing which research methodology to use. A hypothetico-deductive approach must be followed which allows us to build on the initial hypothesis. This hypothetico-deductive approach is defined as a general scientific model [130, 244], established by the formulation of a hypothesis and theories whose particular ideas can be deduced and can, only in this way, explain the phenomenon and predict its behaviour [162]. The model is based on the idea that, unlike the observation of accumulative facts in order to explain a phenomenon [23], science is built on the basis of hypotheses, which constitute the proposal of generalisation. Therefore, it is necessary to verify these hypotheses by way of empirical evidence and refutations [244]. There are four phases in a hypothetico-deductive process [27, 103, 308]: the exposition of the problem, the creation of a hypothesis, the extraction of deductions of consequences of the hypothesis and the contrasting of the hypothesis by way of the aforementioned consequences.

However, the application of the hypothetico-deductive process varies considerably according to the research objectives, the domain of application, the end users of the results/stakeholders and other criteria.

The application to this specific case requires a methodology which implements hypothetico-deductive reasoning and adapts itself to the problems, objectives, domains and end users/stakeholders present in Software Engineering. Several authors have highlighted the application of “Design Science Methodology” [300, 305] as an appropriate methodological framework for research into Software Engineering. One of the main reasons for this is the fact that research in this area is “oriented towards solutions”. In contrast to more observational research “oriented towards problems”, in which the objectives focus on explaining and/or understanding a part of the reality, in Software Engineering a solution is sought for a given problem. This fact may imply a part of observational research (which explains a part of the reality) but it adds a component of definition, design and/or creation of a solution to that problem.

As has already been explained, taking Gregor's framework as a reference point [120], this research combines a more observational part (principally in the study of the field of Cultural Heritage and knowledge generation within it) and a part which is more oriented towards a solution. We believe that it is possible to use software to aid knowledge generation in Cultural Heritage and thus improve the state of knowledge generation in itself by varying the existing state of the art. Due to this, the hypothetico-deductive process to verify our initial hypothesis will be completed with methodological constructs from the field of “Design Science Methodology”.

The classic model of "Design Science Methodology" consists of five phases [190]: the phase of Awareness of the Problem, the phase of Suggestion, the phase of Development, the phase of Evaluation and the phase of Conclusion. The names of the phases are self-explanatory as far as the type of tasks which each one of them involves is concerned.

These phases are common in later models of "Design Science Methodology". However, many of the models which maintain the classic phases of "Design Science Methodology" are based on the fact that a research project begins from one perspective, generally oriented towards a solution. Nevertheless, the research presented here being an example of this, a research project can originate from a great variety of perspectives, each one of them beginning in a different phase of research methodology. This fact is particularly relevant and commonplace in multidisciplinary contexts, such as the one we are concerned with here. For example, we can take a more observational perspective oriented towards a problem during the exploratory phase. However, it is common to change to a more solution-oriented perspective once the problem has been identified and defined and we have moved on to the phase of designing a possible solution. Taking this into account, Peffers' model [234], as opposed to other existing models for the application of "Design Science Methodology", makes it possible to apply various perspectives or to vary the perspective over the course of the research, thus adding flexibility to the application of "Design Science Methodology" [290]. In Vaishnavi [290], relationships can also be found between the phases presented by Peffers and the classic phases of "Design Science Methodology" listed above.

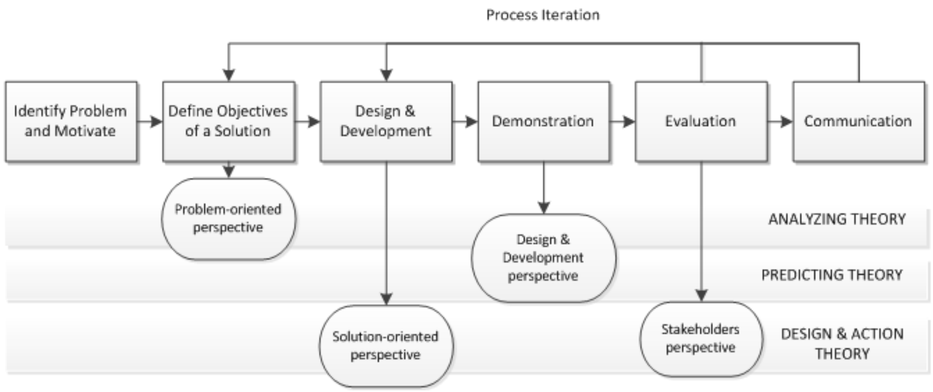

Fig. 1 Design Science Methodology applied during this doctoral research. The Design Science Methodology schema is based on Peffers [193] and establishes 6 iterative phases. At the bottom of the schema the figure shows the underlined IS theories by Gregor [103].

Fig. 1 illustrates the research methodology of "Design Science Methodology" followed throughout this doctoral thesis, based on Peffers' model [234], and its connection in this research with the underlying theories in Software Engineering according to Gregor [120]. The phases illustrated in the model and how they fit in with the verification of the proposed hypothesis will be detailed below, along with other relevant aspects of the applied methodology, such as the definition of research questions, objectives and end users/stakeholders [305].

"Design Science Methodology" in Practice

Identification of the Problem and Motivation

This phase allows us to define the research problem to be tackled and to justify the value and scientific contribution of the solution. Due to the fact that the definition of the problem will be used for the elaboration of an artefact which will provide a solution to the problem itself, it may be useful to break the problem down conceptually so that the solution can capture all its complexity. Justifying the value and contribution of the solution motivates the researcher and the audience of the research to accept the proposed solution and the results as well as assisting in the understanding of the reasoning applied.

In our case, this phase includes the detailing of the main research question, as well as the carrying out of a whole exploratory phase in order to identify the problem. On a general level, the problems and motivations for the research have been explained in previous chapters. On a more detailed level, the literature revision [39, 170] of the existing literature and the designing of tools to explore and characterise the problem is described in Part II of this thesis. The prior studies and results presented in this first phase of identifying the problem and the motivation correspond to the Type I/Analysis underlying theory [120].

The Definition of Objectives of the Solution

This phase allows the objective of the proposed solution to be established based on the previous definition of the problem, bearing in mind what is feasible as a solution and what is not. These objectives of the solution can be quantitative or qualitative. In this phase, the identification of the problem and the approach to the research questions posed in the previous phase allow us to categorise those questions as either Knowledge Questions or Practical Problems [305].

Knowledge questions embody the difference between what researchers know about the world and what they would like to know. In order to answer a knowledge question, the researcher gathers facts, reads the existing literature, makes inferences but does not alter the object of the knowledge.

Practical problems are the difference between the way in which the interested parts experience the world and the way in which they would like to experience it. They generally respond to questions such as "What do we have to do in order to X?" or "How do you do X?". In order to resolve the practical problem, the researcher specifies a change to be applied to the world and then applies it. This changes the state of the world.

More specifically, the model of our questions and their correspondence with their type is:

- It must be remembered that the wording of the main research question (from here on in, *MQ*) is: **To what extent is it possible to improve knowledge generation processes in Cultural Heritage by way of software assistance to the user with knowledge extraction and information visualization techniques?** In reality, the main question not only refers to the initial hypothesis (we believe that it is indeed possible to significantly improve these processes by way of software assistance) but also to what this assistance would be like. Therefore, by answering the question, we must change the state of the world. For this reason, it has been classified as a Practical Problem.
- In order to prove that this assistance is possible, it is necessary to know in depth how knowledge is generated in the field of Cultural Heritage. This necessity led to the emergence of a secondary question (*SQ1*): **What problems exist in knowledge-generation processes in Cultural Heritage as they are normally carried out?** This has been categorised as a Knowledge Question, as its objective is to find out something about the phenomenon being studied which was not known before, but without disturbing it.
- The study of the knowledge-generation process in the discipline allowed us to detect the need to formally characterise the cognitive processes carried out in the aforementioned process in order to improve it. This necessity led to the emergence of a secondary question (*SQ2*): **What are the most common cognitive processes carried out by specialists in Cultural Heritage in the generation of knowledge?** This has been categorised as a Knowledge Question, as its objective is to find out something about the phenomenon being studied which was not known before, but without disturbing it.
- Finally, the application of information visualisation techniques was included within the main research question (*MQ*) in order to produce the software assistance which we wish to provide. In this point, the need arose to study

which of these techniques would offer us the software assistance we proposed. This necessity led to the emergence of a secondary question (*SQ3*): **Which are some appropriate information visualisation techniques to assist each one of the cognitive processes identified within the field of Cultural Heritage?** This has been categorised as a Knowledge Question, as its objective is to find out something about the phenomenon being studied which was not known before, but without disturbing it.

It should be noted that, although the main research question also makes reference to knowledge-extraction techniques, such as the materialisation of software-assisted knowledge generation, these techniques have not been dealt with in the secondary research questions. This is due to the fact that knowledge-extraction techniques have only been worked on at an exploratory level and their incorporation into the framework-solution has been conceived of as an area for future study. However, the relationships between the cognitive processes identified in the generation of knowledge in Cultural Heritage and some knowledge-extraction techniques have been studied, with promising results. This is dealt with in Part II of this document and discussed in the Chapter 13 entitled “Discussion”

Using this model, the secondary questions which have arisen attempt to analyse and explain, in specific cases, specific phenomena which belong to the knowledge-generation process in Cultural Heritage, without disturbing it. The answers to these secondary questions allow us to design a solution to answer the main question. The proposal of this solution as a “change in the state of the world” gives an answer to a Practical Problem. The objectives of our solution are, therefore, qualitative, as we are able to categorise and list each one of the aspects which are involved in the knowledge-generation process in Cultural Heritage (categorising problems in the process, identifying the most common cognitive processes and finding out which visualisation techniques to assist these cognitive processes present the best results in the field). However, they are also quantitative, as we must define metrics to find out if the framework-solution helps specialists in the field in the generation of knowledge and, if so, to what degree. The metrics designed for this purpose are detailed in the Chapter 12 entitled “Empirical Validation”.

The prior studies and results presented in this phase of defining the objectives of the solution correspond to the Type I/Analysis underlying theory [120], and are detailed in Part III of this thesis.

Design and Development

This is the phase of the creation of the artefact-solution. These artefacts are potentially constructs, models, methods or exemplifications (each of them defined in general terms) [300], or "new properties of technical, social and/or informational resources or their combination." [158]. Conceptually, the artefact-solution can be any object within whose design scientific contribution is imbibed. Questions of the type “Practical Problem” [305] are, therefore, answered in this phase.

In our case, this phase includes the design and creation of all the software models which make up the framework-solution. Therefore, it is from this point that the underlying theory in the research undertakes the nuance of Type V/Design and Action [120], although validation will give way to a discussion on aspects of prediction and analysis when the main research question is answered. This phase corresponds structurally to Part III of this thesis.

Demonstration

This phase deals with the question of whether the use of the artefact allows one or more instances of the identified problem to be resolved. This could imply its use in experimentation, simulation, choice of case studies or scenarios or appropriate environments of activity. The resources needed for the demonstration phase include effective knowledge of how to use the artefact to resolve the problem while attempting to define the degree to which the design developed is valid to resolve the problem [305]

In our case, we must demonstrate the framework-solution proposed helps specialists in Cultural Heritage as far as knowledge-generation processes are concerned. In order to do this, the sub-discipline of Archaeology has been selected. The demonstration is detailed in the Chapter 11 entitled “Analytical Validation”, in which the complete framework has been applied to a real case study in the field of Archaeology. This corresponds to a laboratory demonstration within the typologies of evaluation commonly used in Design Science Methodology [305]. In the same way, and in terms of verifying the initial hypothesis, we would be in step 4 of the hypothetico-deductive method (contrasting the hypothesis), which includes the search for evidence to confirm or refute the initial hypothesis. This is detailed and discussed in depth in the Chapter 13 entitled “Discussion”.

Evaluation

In this phase, an attempt is made to observe and measure the degree to which the artefact-solution (in our case our framework-solution) resolves the problem. This consists of comparing the objective of the solution with the observed results of the use of the artefact in an empirical way. This phase requires, therefore, knowledge of the relevant metrics and techniques of empirical analysis. Depending on the nature of the problem and of the artefact-solution, the evaluation may take many forms (the comparison of the functionality of the artefact with the initial objectives, the results of satisfaction surveys, simulations, etc.). It could also include the measurement of quantifiable metrics identified in the system, such as response times and availability.

Following this activity, researchers can decide whether to iterate the previous phase to try to improve the efficiency of the artefact or whether to continue with the communication and leave some aspects for later improvements.

In our case, as well as the analytical validation carried out in the previous phase, an empirical validation has been carried out with the chosen case study. In order to do this, a validation of the prototype software was designed and built with specialists in Cultural Heritage, more specifically from the chosen sub-discipline of Archaeology. With this validation, an attempt has been made to prove the initial hypothesis by way of the suggested deductions. These deductions have been carried out in the form of qualitative (such as the degree of satisfaction of the specialist in Cultural Heritage) and quantitative (such as the precision of or efficiency in the performance of tasks relating to knowledge generation) metrics.

This empirical validation will allow us to establish whether the initial hypothesis has been proven or not, to what degree, with what scope and what possible generalisations can be made on the basis of the result obtained in that validation, as well as dealing with threats to the validity of the whole process. Having dealt with a complete case study, certain causal relations have been identified within it, which allows us to define part of this study as a Type II/Prediction underlying theory [120]. All of this is dealt with in the Chapter 12 entitled “Empirical Validation” and is discussed in detail in Part V.

Communication

Finally, the methodology includes a phase of dissemination of the results of the study to communicate the problem and its importance, the artefact-solution, its usefulness and novelty, the precision of its design and its effectiveness for the target stakeholders. Therefore, this phase is concerned with communicating all of these aspects to the scientific community via scientific activity (publications, presentations in congresses, etc.). This communication requires knowledge of the culture of the discipline or disciplines involved.

Due to the fact that the stakeholders were identified at the beginning of the research, in our case it has proven easy to identify the communities to which this dissemination should be directed. The corpus of the results, publications and other dissemination events shall be detailed throughout the thesis. Finally, the chapters 13 and 14, entitled “Discussion” and “Conclusions”, explain the main scientific contributions which have been made, the lines open for future research and the possible implications of this study.

It should be noted that Peffers [234] establishes these phases in an iterative cycle. Thus, it is possible to complete a full cycle for all the phases, for example for each secondary research question which we have posed or for each sub-problem identified in a research project. These iterative cycles have occurred throughout this research, as shall be seen over the course of this document. However, here, a lineal narrative of the methodology has been maintained since this chapter should give a generic overview of the research methodology carried out. Greater levels of depth will be given over the course of the following chapters.

PART II: Exploration of the Problem

No problem can stand the assault of sustained thinking

-Voltaire

Chapter 4: Techniques and Tools

Discontent is the first necessity of progress. -Thomas A. Edison

Introduction

The disciplinary division which has traditionally been imposed in the form of Humanities+Social Sciences vs. Natural Sciences+Engineering has not allowed for fluid two-way communication between the two worlds. In general, this connection has been produced by way of a hierarchical relationship of the disciplines, in such a way that any interdisciplinary study has typically had one discipline which takes on the main role and other, subsidiary, disciplines whose role is relegated to the application of the methods, techniques and tools which are of use to the main discipline. Nowadays, this situation is changing, thanks to the appearance of interdisciplinary studies which enable co-existence and collaboration at the same level between humanistic and engineering disciplines, such as computational linguistics and information documentation and retrieval, as well as natural and technological sciences, such as Biotechnology and Environmental Studies. In this context, attempting to verify the hypothesis which concerns us (**it is possible to significantly improve knowledge-generation processes in Cultural Heritage by way of by way of providing software assistance to the user with knowledge extraction and information visualization techniques**), could suggest a traditional approach as the basis for this study, in which Cultural Heritage as a discipline, is assisted by methods, techniques and tools originating from Software Engineering. However, this reading of the hypothesis to be verified is simplistic and is far from the true nature of the research which is put forward in this doctoral thesis. In fact, by stating the truth of the hypothesis, we are affirming that the process of knowledge-generation as an independent process from the field in which we are moving constitutes the true framework of the research which concerns us. In this context, the field in which this process of knowledge generation is set (Cultural Heritage) should be studied in depth, along with the field of Software Engineering as a co-existing field, due to the fact that both fields need to work in collaboration for the proposed assistance to be a success. It is for this reason that contributions from both worlds will be presented throughout this study, thus obtaining a true interdisciplinarity not only in approach, but also in terms of results. In this way, both the confirmation of the proposed hypothesis and the results of the research should be framed at the centre of an interdisciplinary and complex study, requiring an in-depth analysis of the problem from differing but complementary points of view.

Due to all of the above, and following the research methodology described in the previous chapter, we shall now go on to detail the exhaustive exploration of the problem to be resolved: providing software assistance to the knowledge generation process.

An Exploration of the Problem: Necessities in Software Assistance to Knowledge Generation in Cultural Heritage

This chapter outlines the ensemble of methods, techniques and tools adapted or created in the context of this research in order to explore the problem of software assistance to the knowledge generation process within the field of Cultural Heritage. For this purpose, three types of necessities have been identified which software assistance can present in the generation of knowledge in any domain, though here they are applied to Cultural Heritage:

- Conceptual necessities: the generation of knowledge should have solid conceptual bases which allow the issue of software assistance to be addressed. It is necessary to know the conceptual particularities of the field in question. In order to do this, we need tools which analyse the structure of the concepts normally handled in the field and which detect, embody and support their intrinsic characteristics.
- Process necessities: it is necessary to know how knowledge is generated in the field of Cultural Heritage on a procedural level and in which points software can assist to this process. In addition, a review shall be carried out of what processes are currently assisted by software in the generation of knowledge in other fields and disciplines, with the aim of finding points of connection with knowledge generation in Cultural Heritage.
- Interaction necessities: the initial hypothesis of this study proposes software assistance to the generation of knowledge through the use of information visualisation techniques (and, in the future, knowledge extraction techniques), which are cognitively adapted to specialists in the field of Cultural Heritage. It is necessary, therefore, to have methods, techniques and tools at our disposal which allow us to know which mechanisms of presentation and interaction of information are most appropriate in Cultural Heritage. This will allow us to decide on and/or adapt the visualisation techniques to be employed in software assistance.

This chapter is structured according to this typology of necessities. Each section details the necessities found within Cultural Heritage and the methods, techniques and tools which are to be taken as the basis for the exploration of the problem are identified via a review of the corresponding bibliography.

Then will follow a description of how this exploration will be carried out by way of the method, technique or tool selected, which may be adopted or even created within the research, although it is based within the corpus of Software Engineering. It shall be stated in each section whether the method, technique or tool employed has been adopted or if it is a contribution born out of this research project. These methods, techniques and tools, in most cases, take a focus which is independent from the field whereas those which have been created during this study are original contributions in Software Engineering. Finally, the application of each method, technique or tool to the specific field of Cultural Heritage shall be described.

In the independent specification of the field of each method, technique or tool, a review of the corresponding bibliography shall be carried out, thus situating in this chapter the greater part of the review of the research in question. However, as was stated in the Chapter 1 entitled “Introduction”, the interdisciplinary nature of this research does not allow us to reduce this review to just one chapter. Therefore, contextual bibliographic information shall be given each time that the identification of a research gap or the justification of a contribution requires it.

Tools for Detecting Conceptual Necessities

Conceptual Characteristics and Particularities in Cultural Heritage

Conceptual Modelling in Cultural Heritage

The formal conceptualisation of information handled in the field of Cultural Heritage has been studied by several authors, all with different proposals and different degrees of application and success. Among the most complete proposals is that of the CIDOC-CRM model (CIDOC Conceptual Reference Model) [77, 78], an international standard (ISO 21127) especially designed for “the knowledge of museums”[77]. Although CIDOC CRM was originally aimed at representing the knowledge which experts possessed regarding collections in museums, it has been extended to other areas of Cultural Heritage and is able to absorb much wider types of information. Even so, it is still a model in which material entities are of great importance and non-expert points of view are not easily expressed [117]. Other models which are in existence have other aims, such as the modelling of excavation processes and the archaeological analysis of CIDOC CRM-EH [33] (an extension of the previous model); the composition of a detailed collection of terms relating to heritage in the case of the PHA Thesaurus (Tesauro de Patrimonio Histórico Andaluz) [5]; or support for the interoperability of spatial data regarding protected heritage sites in relation to the Directive 2007/2/EC of the European Parliament establishing an Infrastructure for Spatial Information in the European Community (INSPIRE) [94].

All of these proposals make an attempt to respond to one common characteristic: the existence of a tension between normalisation and personalisation, between the necessity to establish a common model and the necessity to take into account the fact that each project and effort has its own peculiarities and, therefore, cannot be the object of an inflexible rule [115, 116]. We can find, therefore, both broad and deep models. That is to say, models whose objective is to describe a broad scope (that of a whole discipline, or even a whole world) but which, at the same time, need to specify all the details. This type of model is often seen as being too prescriptive and inflexible, as it leaves little space for the peculiarities of each individual project. On the other hand, there are models which have a more reduced and more superficial scope. In other words, they occupy a limited range (for example, a model of an organization, or even of one project in particular) and avoid going into detailed descriptions. These models can be easily adopted, as it is probable that they are easier to use and more useful in specific cases. However, they are not so useful when it comes to guaranteeing conceptual and technical interoperability with other models. There is a wide range of possibilities between these two extremes. CIDOC-CRM, for example, has a broad focus in its scope and a moderate degree of depth. CIDOC CRM-EH, on the other hand, is much narrower and much deeper.

However, models whose scope is narrow and not very deep are rarely useful as they provide little added value and those with a more general and deep scope are hardly useable as they are too prescriptive. Viable combinations in terms of scope and level of detail are: 1) models with a general scope but with little detail, or 2) models which are narrower in scope but which have a deep degree of detail. The former are known as models of abstract reference, whereas the latter are called particular or specific models.

With the aim of resolving the tension described above, a semi-formal focus has been presented over the last few years which allows for the creation of models for Cultural Heritage taking this problem into account in an explicit way. This approach, known as CHARM (Cultural Heritage Abstract Reference Model) [110], is a semi-formal representation of Cultural Heritage in the form of an abstract model of reference. In other words, it is a model with a general scope which is not very deep as far as its level of detail is concerned. Therefore, CHARM claims to cover the greatest possible quantity of social and cultural phenomena which are known as Cultural Heritage, albeit at a high level of abstraction. In contrast with other models, such as CIDOC-CRM, CHARM is much broader, due to the fact that it is not only centred on one specific sub-domain (as is the case of CIDOC-CRM regarding museum collections) but on Cultural Heritage in general. In addition, due to its high level of abstraction, it is much less deep: CHARM was designed under the premise that it is necessary to apply extension mechanisms in order for it to be used, whereas other existing models, such as CIDOC-CRM, attempt to be a complete and final solution to be applied directly.

CHARM is expressed in ConML [144] a conceptual modelling language which broadens the conventional focus aimed at objects with characteristics such as temporality and subjectivity modelling, aspects which are especially relevant in areas such as Cultural Heritage [116, 143]. ConML also provides the management and extension mechanisms which are necessary for enabling the extension of CHARM to particular models.

Due to the advantages of CHARM's approach and the appropriateness of ConML to the field of Cultural Heritage [108], CHARM and ConML constitute the conceptual tools employed in this study with the aim of carrying out a structural analysis of the concepts commonly handled in the field of Cultural Heritage and detecting, reflecting and supporting its intrinsic characteristics.

Basing ourselves on CHARM as an abstract model of reference and using ConML as a modelling language, it is possible to create models which represent realities of differing natures and topics in the field of heritage but, at the same time, structurally maintaining the issue to be dealt with on a general level. This allows us to create extensions for CHARM for each problem or particular project without losing our structural and semantic reference points of what data is like in Cultural Heritage, what areas it covers and what particularities we should take into account. This makes CHARM (and ConML) the most appropriate proposal to be employed in this study as a model of conceptual and thematic reference as far as heritage is concerned. The adoption, extension and use which are made of CHARM throughout this doctoral thesis shall be detailed in the chapters included in Part III and Part IV.

Tools for Detecting Process Necessities

Consolidated Knowledge: A Methodological Proposal for Integrating Discourse Analysis in Software Engineering

Practices related with the generation of knowledge in Cultural Heritage, such as archaeological excavations, interviews, anthropological studies, geo-environmental analyses in the laboratory, architectonic studies and linguistic studies, produce a great deal of data. Due to the research methodologies traditionally employed in these disciplines, the majority of knowledge generated is contained in reports and monographs in the academic realm and in textual documents such as administrative reports. These documents (both research reports and monographs and administrative reports) are in the form of narrative and are barely structured. What is more, their use is normally limited to the scope of a project or activity, be it academic or administrative.

During the process of exploring the problem for this doctoral research, the need was detected to treat this consolidated knowledge as a source from which information could be extracted on how knowledge is generated in the field, what problems are presented by this generation of knowledge and what possibilities and necessities of software assistance there are. The following sections deal with the treatment given to this knowledge consolidated in textual sources.

Textual Sources in Software Engineering

As an initial approach to looking at the need arising from dealing with knowledge consolidated in the form of text, a literature review was carried out of existing studies on the analysis of textual sources and their use as a basis for extracting information regarding how that consolidated knowledge was generated. How is information from non-structured textual sources analysed and extracted?

The majority of information used as an input in software engineering is originally produced in non-structured formats, such as verbal communication or descriptive documents written in freestyle. We can cite for example documents specifying requirements or documents produced to translate contents into different languages. The non-structured form of these products emerges naturally from the way the participants involved in software engineering processes communicate. However, this situation impedes the rapid analysis of the information, due to the fact that the semantics which are implicit in the textual sources can only be understood by humans and not by way of a highly automated process of information extraction. What is more, non-structured information requires great human effort to be restructured and characterised before being able to be processed to any degree of automation, from the creation of an ad hoc database for the treatment and storage of data, via statistical analysis, to its processing by other semantically similar systems.

Due to this fact, the need for a better conceptualisation and structuring of textual information in Software Engineering has been detected in order, for example, to achieve a higher degree of extraction and fulfilment of the requirements, a significant integration of prior data into new software systems and the generation of appropriate tests for the application of data mining (TDM) [29, 212]. Years ago, Rolland [258] identified four types of strategies for dealing with the relationship between textual sources and conceptual modelling: (1) supporting the generation of models from NL input texts, (2) supporting model paraphrasing, (3) helping in the general understanding of NL input texts by way of modelling and (4) improving NL texts quality. Our work is related to the first strategy as the objective is to extract information existing in texts belonging to the field of Cultural Heritage. This information deals with how knowledge is generated within the discipline, in order to be able to characterise and, later, assist it. The extraction of information should generate software models from the text in such a way that we can later deal with this extracted information.

There are two main approaches which can cover the need we have detected: an approach based on information retrieval and an approach based on an ad hoc modelling of the field in question.

As far as the first approach is concerned, specialists in information retrieval have developed a large corpus of approaches in the analysis of textual information as an automatic process, via the use of heuristic and probabilistic approaches and even by the use of semantics [24]. The heuristic and probabilistic approaches focus their attention on the extraction of information from textual sources on a quantitative level [53, 129]. For example, they may extract counts of the number of instances in a specific text by looking at frequency indicators of terms or by implementing mechanisms of automatic indexing. In this way, these approaches allow for quantitative information to be obtained but, in most cases, they do not extract information relating to the semantic relations present between elements in the text. Approaches from within the field of information retrieval, but of a more semantic kind, allow for the analysis of textual sources based on thesauri or thematic maps [149, 229], enabling the extraction of semantic information regarding the underlying structure of the information in a particular text and the semantic relations existing among its elements. It is possible, for example, to detect relations of equivalence or hierarchy between elements in a text. These semantic approaches have been satisfactorily applied, for example, in order to find common lexemes in a word family, with the aim of analysing these words as a group [283, 284]. However, the semantic relations which these techniques are able to extract are not as strong as those obtained via other techniques which have a significant linguistic focus, such as those based on discourse analysis. The latter, as well as being able to extract equivalences and hierarchical relationships, can also detect and extract relationships of causality and exemplifications present in the text. In addition to the limitations mentioned regarding both approaches (heuristic and/or probabilistic and semantic), all approaches originating from fields based on information retrieval need to work at a high level of abstraction as far as techniques are concerned in order to be truly independent solutions from the field of application and to be able, therefore, to extract information from documents written in freestyle. This fact does not allow work to be carried out at a level which maintains the semantics implicit in complex narratives, as is the case of Cultural Heritage documents, an aspect which is taken into account by more linguistic approaches.

Continuing in the realm of information retrieval, in a later paper, Rolland [255] classifies the current techniques of the automatic generation of conceptual models from textual sources taking into account the following characteristics of the generated model: on the one hand, static or dynamic models; on the other hand, models based on rules or on ontologies.

As far as static aspects of the conceptual models are concerned, tools exist which enable us to discover and generate object models or class models concerning the specifications of textual requirements [126, 163, 206, 213]. As for the dynamic aspects, Rolland highlights studies which extract cases of use and scenarios of texts [172, 202, 256, 263]. As for whether the models are based on rules or on ontologies, there are approaches which attempt to discover business rules in business process models [133].

Even if all of these studies serve as a basis to enable us to approach our aim of structuring and extracting semantic information from textual sources, none of them take into account structural elements (phrases, clauses, etc.) of the text itself within the conceptual models they generate. This does not allow the model associated to the texts of origin to be maintained, an aspect which is of necessity in Cultural Heritage. What is more, the approaches listed here centre their attention on automatic processes, which generally do not form part of a complete Software Engineering methodology but rather they are carried out separately, and generally prior to the execution of the methodology (for example to extract requisites from texts before beginning with a specific methodology). We are seeking an approach which allows us to integrate this process of structuring and extraction of semantic information from textual sources within the complete methodology of Software Engineering, which is applied at all times. Therefore, the generation of these models is generally carried out by software engineers, who later evaluate the resulting models in collaboration with specialists in the field in question. In an attempt to maintain our aim of carrying out a genuinely interdisciplinary study which does not submit any of the disciplines involved to an auxiliary or user role, we are seeking a solution which allows specialists in Cultural Heritage to create their own models, thus adequately structuring the information and extracting from the text the most valuable information in order to generate knowledge in their field.

With regard to the second approach, the solutions based on ad hoc modelling of the field of application for the extraction of information originating from textual sources have undergone a significant increase in recent years, especially those related to the application of textual analysis to fields with a high degree of necessity for the structuring of information, such as the field of Biomedicine [57, 160]. These solutions have been applied satisfactorily to give structure to non-structured texts. However, they only work within a well-defined context within a specific field of application. Once this limitation is assumed, it is possible to create an extremely precise conceptual model which captures the semantic relations which appear among elements within a specific context. However, this resulting conceptual model needs to be created ad hoc for each application: a new textual analysis implies the creation of a new conceptual model. For these reasons, it is not possible to achieve a high degree of standardisation as far as the conceptualisation and structuring of information is concerned.

The limitations which appear in the structuring and extraction of semantic relations in texts written in freestyle which are used as a source in Software Engineering motivate our proposal for a methodology integrating techniques of discourse analysis in Software Engineering enabling the representation of the elements of textual information by way of a particular language in a structured way and describing the semantic relations which exist among them. The methodological proposal, as well as the language created, is based on the ISO standard *ISO/IEC 24744 Software Engineering — Metamodel for Development Methodologies [155]*, with the aim of facilitating the connection between the language and the methodological proposal and its integration into any other methodology of software development expressed in the standard.

The following section explains in detail the work carried out relating to two well-differentiated parts. Firstly, the work relating to the formalisation and analysis of textual discourse is described, detailing its potential for structuring and extracting semantic information compared with the existing approaches listed above. Then, a detailed explanation shall be given of the ISO standard *ISO/IEC 24744* [155], the chosen medium for expressing the methodological proposal and the language created as tools in order to structure and extract semantic relations in descriptive freestyle texts.

Background

Discourse Analysis

As has been mentioned in the Introduction to this chapter, over the course of this doctoral research, certain necessities have been detected when using texts written in freestyle as a source for the Software Engineering process. These necessities relate to the improvement in structuring and extraction of semantic relations present in this type of textual sources. In other words, although the semantics present in a text are self-contained within it, any Software Engineering process needs to make these semantics much more explicit and precise, avoiding ambiguity. Our proposal implies the use of discourse analysis techniques in order to give structure to these textual sources, which are in a non-structured format, and to extract the semantic relations present within them.

The term "discourse analysis" was originally coined by Zelling Harris [128], who defined it as "a method for the analysis of the connected speech or writing for continuing descriptive linguistics beyond the limit of a single sentence at a time and for correlating culture and language" [128]. All of the techniques which later arose from this first definition constitute a broad field in Linguistics, above all due to the need to discover meaning in terms of the narrative elements present in discourse and focusing analysis on the organisation of the language, above or below the levels identified as sentence or paragraph. The choice of one technique of discourse analysis or another depends on numerous factors, such as the sphere of application or the objective of the analysis: the structuring of the discourse in phrases or syntagms, the identification of functions of particular elements within the discourse and the representation of texts, etc. [118]
Currently, discourse analysis techniques are not only used in Linguistics, but are also satisfactorily applied, with different degrees of automation, to a significant number of fields in different contexts, albeit with the common necessity to study oral communications or textual sources. Good examples of their application can be found in Biomedicine [176] and the extraction of analytical information in legal texts [208] with applications focused on identifying relations of consequence among elements in the text in order to detect possible consequences of a certain legal action. In all these cases, the discourse analysis carried out allows the elements present in a text to be identified. These elements provide information about the structure of the narrative and the reasoning and intention of the author. In addition, these analyses help us to understand the most commonly used cognitive processes in the field in question.

The majority of approaches in discourse analysis with empirical aims attempt to characterise the semantic relations intrinsic to the discourse, joining elements of the discourse (typically phrases, although it is possible to work on a more detailed level, such as syntagms, or on a higher level of abstraction, such as complete paragraphs). These approaches with empirical aims follow three courses as far as the semantic relations to be extracted are concerned [274]: There are studies focused on creating a corpus or typifying coherence relationships, such as the RST corpus [48], the SFU Review Corpus [281], CAuLD (*Construction Automatique de representations Logique du Discours*) [20, 21] and the Penn Discourse Treebank [245]. There are also studies which have a clear psycholinguistic leaning, presenting empirical annotation experiments in which the subjects are presented with real data to be annotated or examples of textual fragments, with the aim of experimentally identifying which characteristics are important for the semantic relations in the text. Furthermore, there are studies which make use of an extremely extensive corpus (*Very Large Corpora*) in order to find, automatically or semi-automatically, characteristics of types and to identify different coherence relations by way of the identification of explicit connectors, such as Marcu [48], y Lapata Lascarides [178], Reitter [253], Chang and Choi [64].

In summary, all of the studies listed above illustrate the demonstrated potential of techniques of discourse analysis in identifying semantic relations and structuring textual sources on the level of discourse elements. It can be considered, therefore, that discourse analysis is a flexible and appropriate basis for structuring and extracting semantic relations from texts written in freestyle, including those which are used as a source in any Software Engineering process.

Although there are specific applications which allow us to analyse a set of documents, thus avoiding an ad hoc discourse analysis for each document, these are not formal or abstract enough to be integrated into a complete Software Engineering methodology. They are not formal enough because they are never expressed as a metamodel or a similar unequivocal mechanism and they are not abstract enough because, as has already been mentioned, they often require ad hoc work. For these reasons, we believe that a complete methodological proposal is necessary, along with a language with a general purpose which allows for the application of discourse analysis to heterogeneous areas as the use of the proposed language must present well-defined methodological components. Only by using a completely defined methodology can discourse analysis techniques work as part of an integral methodology for Software Engineering.

In order to achieve this, the decision was taken to follow Hobbs' [134] approach to discourse analysis, due to the fact that (1) it allows for the characterisation of semantic relations based on cognitive processes among elements of the discourse, (2) it presents a well-defined method of application which allows us to express the methodology of the discourse analysis in question as a formula and (3) it has been previously applied in software development [200, 241], although it has not been formalised either in terms of language or in methodological terms for this purpose. In addition, Hobbs' method has been used with narrative texts of different types and has been expressed in different languages [171], which guarantees us a certain degree of universality in these aspects.

Hobbs' work is based on the formal identification of relationships between elements of discourse, so-called coherence relations. Coherence relations in discourse, similar to those of contrast, generalisations or causal relations, contain information which is essential to understanding how the elements of a fragment of text and the underlying ideas referring to any domain are related. Any computational system which attempts to understand or generate information beyond the level of a simple phrase must deal with this kind of information. Hobbs' work [134] constitutes, as has previously been mentioned, one of the most important theoretical approaches in existence with proven applications.

The following section presents *ISO/IEC 24744* [155], and explains the choice of this standard as the basis on which the methodological proposal is designed in order to integrate discourse analysis into Software Engineering processes, including in the proposal a modelling language for discourse analysis.

ISO/IEC 24744 Standard

In general, a modelling language, whatever its scope or purpose, will be used in a specific methodological environment. That is to say, it will be used by different people playing different roles in tasks and/or processes which use, believe in, modify or reject physical or conceptual artefacts. Due to this fact, it is necessary for this methodological environment to be made clear and taken into account, along with syntactic and semantic aspects, when it comes to creating a new modelling language. Therefore, the language is generally expressed as an instance of a standard metamodel for methodologies. This option facilitates the methodological integration of the language, avoiding inconsistencies [111] and making the context of its use clear.

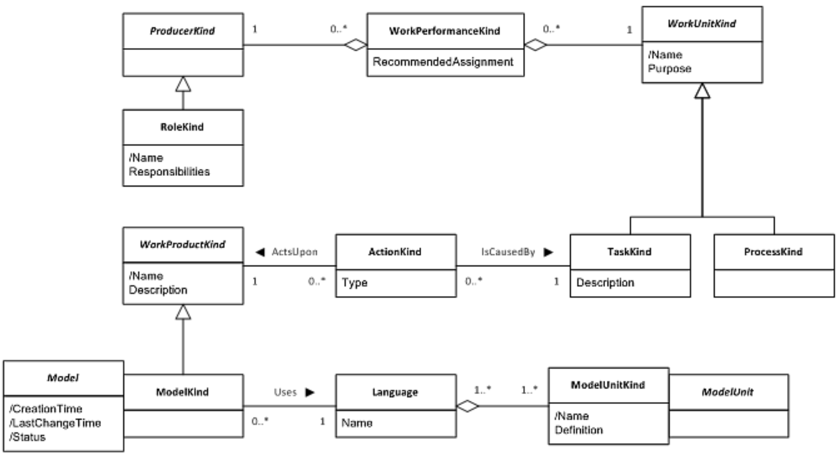

Fig. 2. Fragment of metamodel ISO/IEC 24744 with its main classes.

With the aim of making the methodological context of the modelling language which is created explicit, the ISO standard *ISO/IEC 24744* has been chosen as the metamodel of reference. *ISO/IEC 24744* provides us with the basic conceptual constructs to define a modelling language, as well as integrating it with previously defined processes which involve people, tasks, etc., an ability which is lacking in other metamodels such as OMG's SPEM [112, 222].

The ISO standard *ISO/IEC 24744* consists of several main classes:

- The ModelKind class represents a specific type of model which can be used in a methodology, for example, models of classes, of processes, etc.
- The Model class represents a particular model which is built and/or used within a performative action in the context of a methodology. For example, a model of classes in particular or a specific model of processes.
  Each model is of a specific type, and this is reflected in the ISO standard ISO/IEC 24744 via the concept of powertype, which plays a crucial role. The powertype concept was introduced in Software Engineering by Odell [220] and was applied to metamodeling in next works [113, 131]. In Fig. 2, the Model¬Kind model and classes are shown together as they constitute a powertype pattern. That is to say that Model¬Kind is a powertype of Model. This implies that the instances of Model¬Kind are also subtypes of Model and, therefore, any Model class in particular which we want to define following ISO/IEC 24744 would be shown by an object (an instance of ModelKind), likewise by a class (a subtype of Model); this situation, in which an object and a class represent the same thing gives rise to a hybrid entity known as a Clabject.
- Model Unit Kind and Model Unit, —see Fig. 2— These form another powertype pattern, in which Model¬Unit¬Kind represents a particular modelling primitive which may be part of a language, such as "class" or "attribute" in the modelling of classes, or "process" or "task" in process modelling. Model¬Unit, on the other hand, represents a particular case of ModelKindUnit, for example, a specific class or attribute, or a specific process or task following the analogy with process modelling.
- The Language class represents the language used to express each type of model.
- The methodological integration of a language based on *ISO/IEC 24744* is achieved via the semantics embedded in the metamodel: as can be seen in Fig. 2, the Model¬Kind class is related with TaskKind (via ActionKind). This permits the process which a model uses, creates or modifies to be easily captured through these types of action (creating, reading, modifying or deleting). In turn, TaskKind is related with Producer-Kind (via Work¬Performance¬Kind) so that people or tools participating in these actions can express themselves easily [155].

The remainder of the standard's metamodel will be used by way of the powertype mechanism detailed above and following clause 8.1.2 of the standard's specification [155].

Once the fundamental concepts of ISO standard *ISO/IEC 24744* have been reviewed, we will focus on the Language class, whose semantics provide us with the opportunity to create an instance of a modelling language which allows us to handle concepts of discourse analysis and apply them to any Software Engineering process in which it is necessary to structure and extract semantic information from textual sources. The following section will include a full description of the proposed methodology and the modelling language which has been created.

The Proposed Methodology

With the objective of structuring and extracting semantics from freestyle textual sources, as well as carrying out discourse analysis processes in an integrating way in any defined Software Engineering methodology, the proposed solution is organized into two parts: (1) a modelling language capable of capturing the structure and semantics implicit in a textual source and (2) a proposal to describe the methodological elements involved in the process of discourse analysis.

The Modelling Language for Discourse Analysis

This section contains a description of the proposed modelling language. Fig. 3 shows how the most specific classes of the metamodel corresponding to ISO/IEC 24744 have been used to form the basis of the proposed language.

Firstly, the Language class has been instantiated, creating an object *L1*, whose property Name presents the value "Discourse Language". This object represents the language itself.

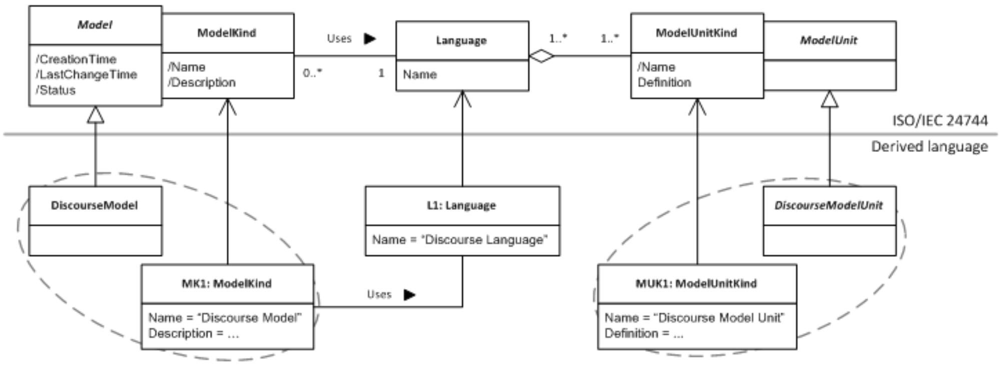

Fig. 3. Instances of ISO/IEC 24744 used for the creation of the defined modelling language.

In addition, as was mentioned in the previous section, the powertype patterns for *ModelKind* and *ModelUnitKind* have been used to create instances of the corresponding clabjects. In the case of *ModelKind*, the *Discourse¬Model* class has been created along with an object *MK1*, which are, respectively, a subtype of Model and an instance of *ModelKind*. Both of these form a clabject, represented in Fig. 3 by a dotted ellipse; this clabject represents the specific type of models which can be created by way of the use of the language *L1*, which we have just defined. This specific type of model is known as a "Discourse Model". Therefore, any model of discourse is expressed in the proposed language for discourse analysis.

Furthermore, the class *Discourse¬Model¬Unit* and an object *MUK1* have been created, which are, respectively, a subtype of *ModelUnit* and an instance of *Model¬Unit¬Kind*. Both of these form a second clabject, which represents the primitives of modelling units which form part of the language L1 and which can be used to compose models of the "Discourse Model" type.

Given that the final objective of the proposal is to provide structure and extract semantic relations in discourse analysis, the language should contain elements from three different and semantically relevant areas for this aim: elements from the discourse itself (narrative elements), elements from the field in question (what the discourse being analysed is about) and the coherence relations which may exist between them (the semantic relations defined by Hobbs). In the first place, we have to represent the discursive elements present in the textual source, such as phrases, clauses and their aggregates. This area is represented by the *DiscourseElement* class and all of its specializations, shown at the centre of Fig. 4.

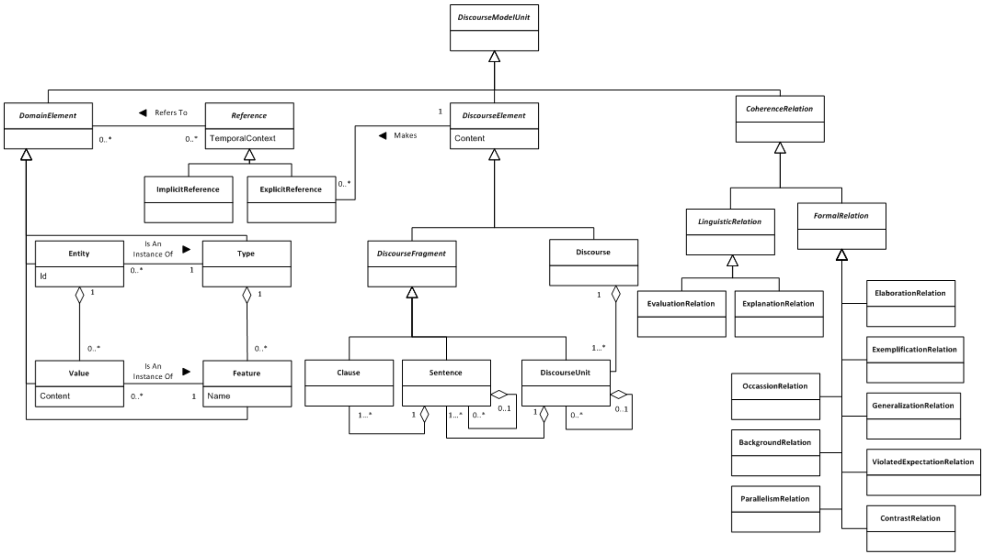

Fig. 4. The proposed Modelling Language. The image shows a complete view of the three areas represented, from left to right: the field described, the associated textual representation and the coherence relations which connect the two previous areas.

Secondly, any discourse always refers to a part of the reality and, therefore, the field in question should be taken into account. Following the modelling approach oriented towards objects, this field is structured around entities (objects) and their values, as well as types (classes) and characteristics (attributes). These primitives are not destined to substitute a complete modelling language such as UML [154] or ConML [144] but to work as a mapping point with the field in question in the process of discourse analysis. This area is represented by the DomainElement class and all of its specialisations, as shown on the left of Fig. 4.

Having specified these two areas in our language (the elements of the discourse and the entities of the reality which it refers to), we will then be able to model which fragment of the discourse refers to which specific entities in the field in question. The "Reference" class acts precisely as a connector between these two realities and, optionally, may maintain temporal information with the aim of supporting temporal changes in the references throughout the discourse. These references can also be divided into explicit references (*ExplicitReference*), those whose reference to determined entities of the field is made clear in the text being analysed, and implicit references (*ImplicitReference*), those which, in spite of referring to elements of the field in question, do not make reference to them in the text being analysed, thus working on an elliptic level. As can be observed in Fig. **4**, any *Reference* is mapped with the element of the field to which it refers. However, it is a common occurrence that in texts written in freestyle some references are implicit. In these cases, it is usual for the implicit references not to be formalised in the discourse analysis and the semantics related with them to be lost. With this mechanism, the proposed language is able to formalise implicit references and to deal with them in a coherence relation, thus maintaining their semantics.

Finally, a modelling language for discourse analysis must consider a third area, which, as has previously been mentioned, provides the maximum value of this contribution. Following Hobbs' approach, we modelled the different coherence relations which may be present in the discourse via the use of a class to represent each relation. This area is represented by the *CoherenceRelation* class and all of its specialisations, as shown on the right of Fig. 4.

Fig. 4 also shows that the coherence relations identified by Hobbs are organised into two categories which are reflected in two abstract classes: linguistic relations and formal relations (*LinguisticRelation* and *FormalRelation*). This classification is not present in Hobbs' work but has been incorporated into our contribution due to the fact that it is useful from the perspective of metamodeling. In this way we can deal with the degree of detail with which the entities of the field are referred to. On the one hand, formal relations allow us to formally describe which elements of the discourse refer to which entities and the values of these entities in the field with a high degree of detail. On the other hand, in linguistic relations, it has not been possible to reach this degree of formalisation. It has proven more difficult to abstractly assign the relations and the elements of the field in question. In spite of the fact that it is possible to do it case by case (in the models of created objects), we have preferred to maintain an unmapped metamodel specification of the proposed language.

Each type of coherence relation makes references to the field in a particular way, which is why each *Coherence¬Relation* subclass will be associated with the Reference class in a different way. The proposed language incorporates the ten coherence relations identified by Hobbs. The following sections shall explain in detail each coherence relation: the formalisation proposed for it, the metamodel expressed in the language of discourse analysis created and some OCL restrictions [302] added in order to guarantee the coherence and structural consistency of each metamodel.

Occasion Relation

According to Hobbs' definition, an "Occasion Relation" is one of coherence between two elements of discourse which describes two events: "the first event sets up the occasion for the second. In both cases we let S_1 be the current clause and S_0 an immediately preceding segment". There are two cases:

"A change of state can be inferred from the assertion of S_0, whose final state can be inferred from S_1."

"A change of state can be inferred from the assertion of S_1, whose initial state can be inferred from S_0".

According to Hobbs' definition, we describe the "Occasion Relation" with the formula:

$$V_{ijA}\ occ\ V_{ijB}$$

Where each $V_{ij}T$ is a fragment of the discourse which refers to a value V of the characteristic F_j of an entity E_i, in different temporal situations: T_A, named initial and T_B, named final. This means that the entity E_i changes state between moments T_A and T_B, as a result of the modification of the value V of its characteristic F_j. In Fig. 5, the proposed language captures the structure and semantics of the relation.

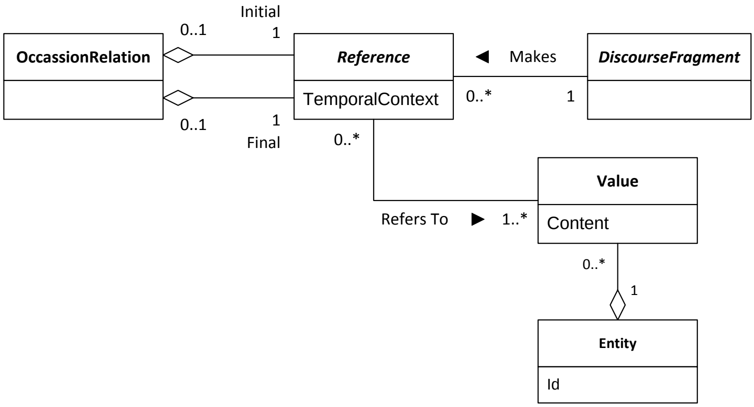

Fig. 5. Metamodel for the Occasion coherence relation.

As can be seen in Fig. 5, each *OccasionRelation* includes two references which play an initial role and a final role, mapping a fragment of discourse to one or more values. The values mentioned by each one of these fragments of discourse should belong to one common entity. Therefore, we can use the language to express the change in the values over time (given by the different instances of Value), in addition to the associated temporal sequence.

It should be noted that, both in the Occasion coherence relation and in the others defined by Hobbs [134], specific examples can be found referring to different fields in previous studies forming part of this doctoral research project [192].

Background Relation

According to Hobbs' definition, a "Background Relation" is one of coherence between two elements of discourse in which one element provides contextual information for a second segment. It provides the "geography" (in the words of Hobbs) in which the events of the second series of sessions are carried out. Hobbs clarifies this by establishing a formal definition: "Infer from S_o a description of a system of entities and relations, and infer from S_1 that some entity is placed or moves against that system as a background"

According to this more formal definition, we describe the "Background" relation with the formula:

$$E_i \; bkg \; A_i$$

Where each E_i is a fragment of the discourse which makes reference to an entity E_i. The fragments of discourse play the role of "subjects". Each A_i is a fragment of the discourse which describes contextual information about the entities of E_i, playing the role of "context". Therefore, we need at least a couple of fragments of discourse, an E_1 and an A_1, in order to identify a "Background" relation, according to Hobbs' definition. However, our formalisation allows us to identify more fragments of the discourse which act as context and which refer to the same entity E_i. The proposed language captures in Fig. 6 the structure and semantics of the relation.

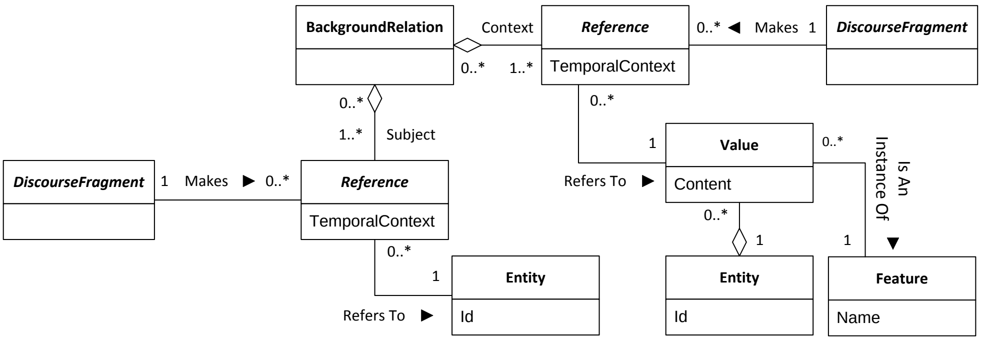

Fig. 6. Metamodel for the Background coherence relation.

Evaluation Relation

According to Hobbs' definition, an "Evaluation" relation is one of coherence between two elements of discourse in which "from S_1 infer that S_0 is a step in a plan for achieving some goal of the discourse: That is S_1 tells you why S_0 was said. The relation can also be reversed: From S_0 infer that S_1 is a step in a plan for achieving some goal of the discourse."

According to Hobbs' definition, we describe the "Evaluation" relation with the formula:

$$A \; eva \; B$$

Where A and B are fragments of the discourse which play different roles in the Evaluation coherence relation. A plays the role of "content", whereas B plays the role of "motivation". Therefore, the semantics associated with this relation is that B explains why A is present in the discourse. The proposed language captures the structure and semantics of the relation as shown in Fig. 7.

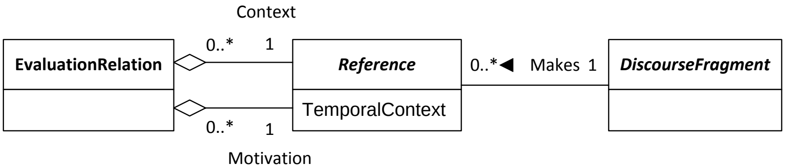

Fig. 7. Metamodel for the Evaluation coherence relation.

Explanation relation

According to Hobbs' definition, an "Explanation" relation is one of coherence between two elements of discourse which indicate a causal relation: "Infer that the state or event asserted by S_1 causes or could cause the state or event asserted by S_0."

According to Hobbs' definition, we describe the "Explanation" relation with the formula:

$$A \ exp \ B$$

Where A and B are fragments of the discourse which play different roles in the Explanation coherence relation. A plays the role of "cause", whereas B plays the role of "effect". Therefore, the semantics associated with this relation is that A causes B and that this causality may be implicitly or explicitly contemplated in the discourse. The proposed language captures the structure and semantics of the relation as shown in Fig. 8.

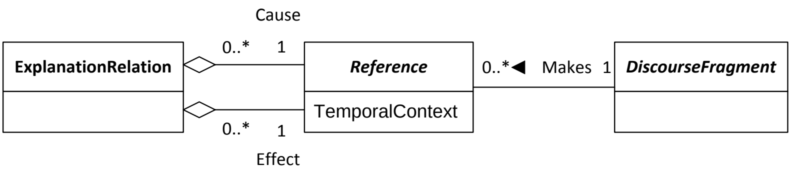

Fig. 8. Metamodel for the Explanation coherence relation.

Parallelism Relation

According to Hobbs' definition, a "Parallel" relation is one of coherence between two elements of the discourse with a structural relation between them: "Infer p (a_1, a_2,...) from the assertion of S_0 and p (b_1, b_2,...) from the assertion of S_1, where a_i and b_i are similar, for all i. Two entities are *similar* if they share some (reasonably specific) property."

According to Hobbs' definition, we describe the "Parallel" relation renamed it as Parallelism relation with the formula:

$$par\ E_i\ V_{ij}$$

Where E_i are fragments of the discourse which refer to entities E_i of the same type. V_{ij} are fragments of the discourse which describe values of a set of properties of E_i. Therefore, par E_i V_{ij} corresponds to a table in which each row corresponds to an entity E_i, each column represents a property F_j, and each cell contains a value V_{ij} of this property for each entity E_i. Semantically, the "Parallelism" relation establishes a structural organization of the discourse which allows us to compare the values of the properties in different entities, thus permitting new inferences to be developed. These inferences may be found explicitly in the discourse or not. The proposed language captures the structure and semantics of the relation as shown in Fig. 9.

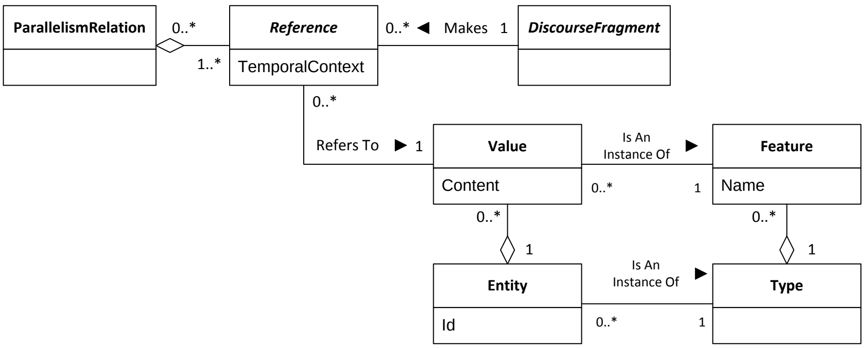

Fig. 9. Metamodel for the Parallelism coherence relation.

However, the metamodel of the "Parallelism" relation shown in the figure above is not enough to demonstrate the semantic implications of this relation in the discourse. For this reason, two OCL expressions have been added in order to increase the degree of formalisation of the metamodel:

- Firstly, the entities which participate in a parallel relation should belong to the same type:

```
context ParallelismRelation
self.Reference->forAll(
  r1, r2, r1.Value.Entity.Type =
  r2.Value.Entity.Type)
```

- Secondly, the whole of the characteristics for each entity has to be the same for all the entities involved:

```
context Entity
forAll(e1, e2, e1 <> e2,
  e1.Value as Set1, e2.Value as Set2)
Set1{n}.Feature = Set2{n}.Feature
```

Elaboration Relation

According to Hobbs' definition, an "Elaboration" relation is a particular case of the "Parallelism" relation explained above, in which "the similar entities ai and bi are in fact identical, for all i. It can be given the following definition: Infer the same proposition P from the assertions of S_0 and S_1."

$$elab\ E_i\ V_{ij}$$

Therefore, the metamodel of the "Elaboration" relation is the same as that of the "Parallelism" relation but in this case we must use OCL expressions to show the restriction that the V_{ij} values for a specific characteristic are identical for all the entities E_i. To sum up, the OCL restrictions at work in the "Elaboration" relation are:

- Firstly, that the entities which participate in an Elaboration relation should belong to the same type:

```
context ElaborationRelation
self.Reference->forAll(
  r1, r2, r1.Value.Entity.Type =
  r2.Value.Entity.Type)
```

- Secondly, that the whole of the characteristics for each entity has to be the same for all of the entities involved (just as in the "Parallelism" relation) but in this case we must guarantee with an OCL directive that the number of entity values is the same for all the entities involved:

```
context Entity
forAll(e1, e2, e1 <> e2,
  e1.Value as Set1, e2.Value as Set2)
Set1{n}.Feature = Set2{n}.Feature

context Entity
forAll(e1, e2, e1 <> e2,
  set->count(e1.Value) =
  set->count(e2.Value))
```

- Finally, for each characteristic involved, the content of its values should be identical for all of the entities:

```
context Feature
```

```
self.Value->forAll(v1, v2 | v1 <> v2 ->
  v1.Content = v2.Content)
```

Exemplification Relation

According to Hobbs' definition, an "Exemplification" relation is one of coherence between two elements of the discourse in which S_1 is the current discourse clause and S_0 a previous clause in the discourse. Thus, an exemplification relation is defined as: "Infer p(A) from the assertion of S_0 and P(A) from the assertion of S_1, where *a* is a member or subset of A."

According to Hobbs' definition, we describe the "Exemplification" relation with the formula:

$$V_{ij}\ exe\ W_{kl}$$

Where each V_{ij} is a fragment of the discourse which makes reference to a value V of a characteristic F_j of an entity E_i. Each W_{kl} is a fragment of the discourse which makes reference to a value W of a characteristic G_l of an entity D_k. It should be taken into account that G_l and F_j may make reference to the same characteristics of the same entities, coincide partially or differ completely. Likewise, the ensembles E_i and D_k may make reference to the same entities, coincide partially or be completely different.

V_{ij} are called "bases" and W_{kl} "examples". This means that one or several fragments of the discourse, playing the role of bases, may be exemplified by one or several fragments of the discourse playing the role of examples. The exemplification mechanism implies making references to values belonging to the same or different entities of the field. The exemplification is only produced when the values involved belong to the same entity, or when they belong to different entities which are strongly related. Due to the fact that exemplifying necessarily implies decreasing in the level of abstraction (that is to say, going from an abstract concept to a more specific one), the relations which make this possible should be those which implement an abstraction/precision connection. As can be seen in [31], these relations which decrease the level of abstraction have been characterised as "classification/instantiation", "generalisation/specialisation" and "whole/part". These relations between the entities in an exemplification relation are shown using the "ExemplificationEntityRelation" class. This class encapsulates what type of relation between entities is shown in a specific case of exemplification. In Fig. 10, the proposed language shows the structure and semantics of the relation.

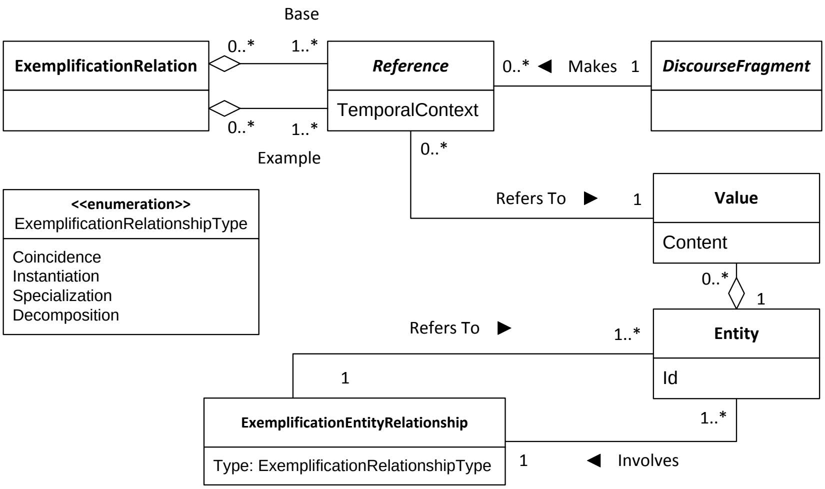

Fig. 10. Metamodel for the Exemplification coherence relation.

Generalization Relation

According to Hobbs' definition, a "Generalization" relation is one of coherence between two elements of the discourse in which S_0 and S_1 are inverted compared with the "Exemplification" relation.

According to Hobbs' definition, we describe the "Generalization" relation with the formula:

$$V_{ij} \; gen \; W_{kl}$$

Where each V_{ij} is a fragment of the discourse which makes reference to a value V of a characteristic F_j of an entity E_i. Each W_{kl} is a fragment of the discourse which makes reference to a value W of a characteristic G_l of an entity D_k. It should be taken into account that G_l and F_j may make reference to the same characteristics of the same entities, coincide partially or differ completely. Likewise, the ensembles E_i and D_k may make reference to the same entities, coincide partially or be completely different.

V_{ij} are called "premises" and W_{kl} "conclusions". This means that one or several fragments of the discourse, playing the role of premises, can support one or several ideas expressed in other fragments of the discourse, playing the role of conclusions. The mechanism of generalization implies making references to values belonging to the same or different entities of the field. The generalization is only produced when the values involved belong to the same entity or when they belong to different entities which are strongly connected. Due to the fact that generalization necessarily implies an increase in the level of abstraction (that is to say, going from a specific concept to a more abstract one), the relations which make this possible should be those which implement an abstraction/precision connection. As can be seen in [132], these relations of increasing the level of abstraction have been characterised as “classification/instantiation”, “generalisation/specialisation” and “whole/part”. These generalization relations are captured using the “GeneralizationEntityRelation” class. This class encapsulates what type of relation between entities is present in a specific case of generalisation. In Fig. 11, the proposed language shows the structure and semantics of the relation.

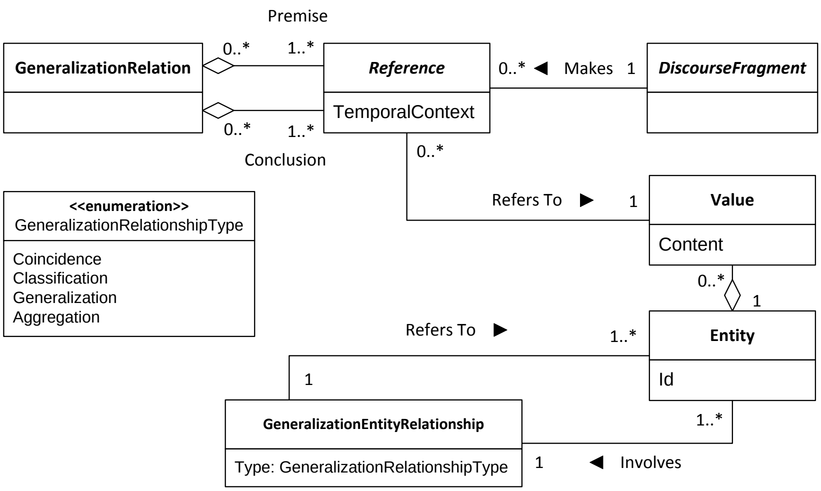

Fig. 11. Metamodel for the Generalization coherence relation.

Contrast Relation

According to Hobbs’ definition, a “Contrast” relation is one of coherence between two elements of the discourse which (1) present predicates of contrast made on similar entities or (2) present the same predicate regarding entities which contrast conceptually.

According to Hobbs’ definition, we describe the “Contrast” relation of type 1 with the formula:

$$VA_j \; con1 \; VB_j$$

In this first case of the “Contrast” relation, VA_j and VB_j are fragments of discourse which refer to different values of the same characteristics of two entities. The entities have a relation between themselves which is expressed by an increase or a decrease in the level of abstraction. As has previously been seen, the relations which make this possible should be those which implement an abstraction/precision connection. As can be explained before [132], these relations have been characterised as “classification/instantiation”, “generalisation/specialisation” and “whole/part”. These relations are captured using the “ContrastEntityRelation” class. This class encapsulates what type of relation between entities is present in a specific case of contrast. In Fig. 12, the proposed language shows the structure and semantics of the relation.

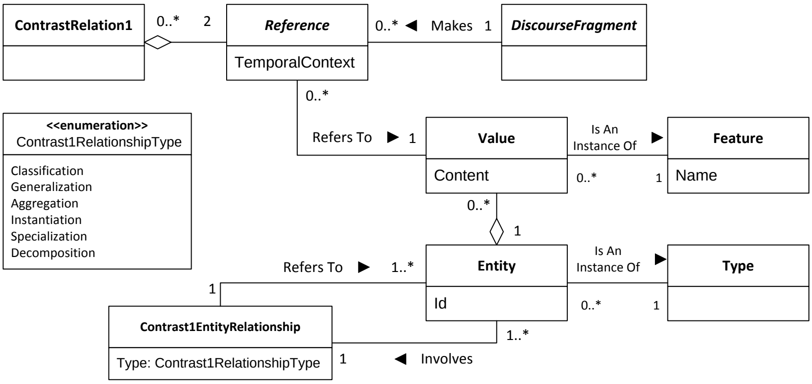

Fig. 12. Metamodel for the type 1 Contrast coherence relation.

In addition to the fact that the entities are similar, we must use OCL expressions to capture the fact that the values V to which both fragments of the discourse refer are different. The similarity of the entities and the difference between the values of the elements are what establish the semantic contrast. Thereby, the OCL restrictions, which are at work in the type 1 “Contrast” relation, are:

- Firstly, the whole of the characteristics for each entity has to be the same for all the entities involved:

```
context Entity
forAll(e1, e2, e1 <> e2,
  e1.values as Set1, e2.values as Set2)
Set1{n}.feature = Set2{n}.feature
```

- Secondly, for each characteristic involved, we have different contents in the value of that characteristic:

```
context Feature
self.value->forAll(v1,v2 | v1 <> v2 ->
  v1.content<>v2.content)
```

As for the type 2 contrast relation identified by Hobbs, we can describe it with the formula:

VA_j con2 VB_j

In the second case, VA_j and VB_j are fragments of discourse which refer to the same value of the same characteristics of two entities. However, the entities which take part in the contrast relation present a conceptual contrast in their very nature, in their definition or in some aspect related to the reality which they represent, thus establishing semantics of contrast in the discourse. In Fig. 13, the proposed language shows the structure and semantics of the relation.

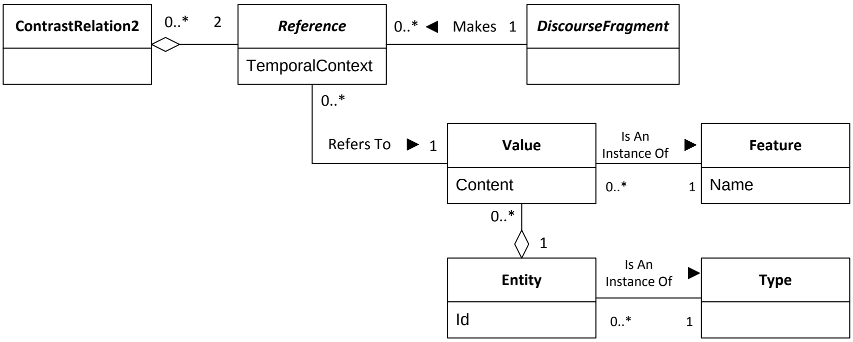

Fig. 13. Metamodel for the type 2 Contrast coherence relation.

It should be noted that entities A and B belong to the same type as they must show common characteristics. In addition, we must use OCL expressions to capture the fact that the values of V to which both fragments of the discourse involved in the relation refer are the same. Therefore, the OCL restrictions which are at work in the type 2 "Contrast" relation are:

- Firstly, the entities which take part in a contrast relation (case 2) should belong to the same type:

```
context ContrastRelation2
self.Reference->forAll(
  r1, r2, r1.Value.Entity.Type =
  r2.Value.Entity.Type)
```

- Secondly, the whole of the characteristics for each entity has to be the same for all the entities involved:

```
context Entity
forAll(e1, e2, e1 <> e2,
  e1.Value as Set1, e2.Value as Set2)
Set1{n}.Feature = Set2{n}.Feature
```

- Finally, for each characteristic involved, we have the same content in the value of that characteristic:

```
context Feature
self.Value->forAll(v1,v2 | v1 <> v2 ->
  v1.Content = v2.Content)
```

Violated Expectation Relation

According to Hobbs' definition, a "Violated Expectation" relation is a particular case of the "Contrast" relation, in which there is only one entity involved and the contrast situation is between the real and expected values for certain properties of this entity. In the words of Hobbs: "Infer P from the assertion of S_0 and ¬ P from the assertion of S_1."

According to Hobbs' definition, we describe the "Violated Expectation" relation with the formula:

$$V_{ij}\ vex\ W_{ij}$$

Where V_{ij} and W_{ij} are fragments of the discourse which refer to the values of V and W of characteristics of the same entity. This coherence relation indicates that the values of W contradict an unexpressed perception in the discourse which is generally assumed when we analyse V or when some of the characteristics of the entity are evaluated. In Fig. 14, the proposed language shows the structure and semantics of the relation.

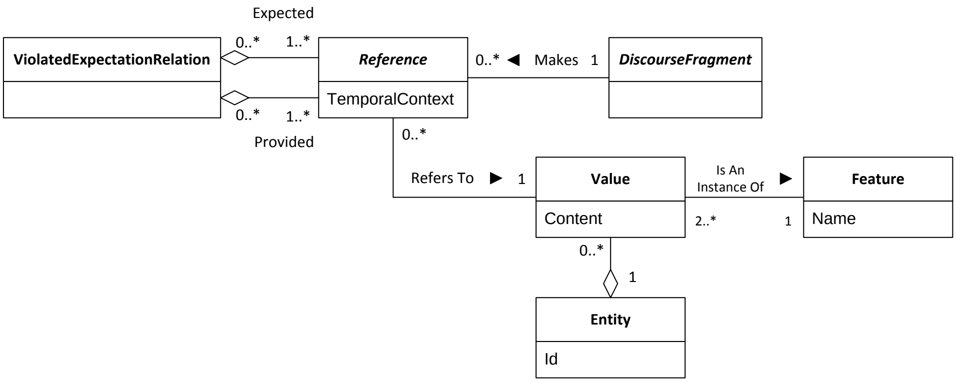

Fig. 14. Metamodel for the Violated Expectation coherence relation.

It should be noted that the values V and W should belong to the same entity, thus making necessary the OCL restriction:

- The values of the entities involved should belong to the same entity:

```
context ViolatedExpectation
self.Reference->forAll(
  r1, r2, r1.Value.Entity =
  r2.Value.Entity)
```

A Methodological Proposal for Discourse Analysis in Software Engineering

According to the literature reviewed at the beginning of this section, the process of discourse analysis is generally carried out *ad hoc*, albeit with some exceptions explained above, such as its application in certain legal texts [208]. In no case does this process have a formal mechanism to precisely express, without ambiguity, the structure of a specific text and the semantics contained within it: The modelling language for discourse analysis described in the previous section allows us to structure and extract the semantics contained in textual sources written in freestyle, mapping the elements of both the discourse and the field in question and identifying the coherence relations defined by Hobbs [134]. It, therefore, becomes a formal mechanism for analysing textual sources written in freestyle, independently of the field of application in which we are moving. However, if we wish to completely integrate the process of discourse analysis as part of any Software Engineering methodology with the need to analyse textual sources, it is necessary to establish the relation between the formal mechanism created and other methodological elements (tasks, agents, products, etc.) involved in this process. This section describes the methodological elements necessary in order to integrate discourse analysis into the process of software development, along the lines of the ISO standard *ISO/IEC 24744*, which has previously been outlined.

Hobbs describes the process of discourse analysis as an iterative process in which, in order to analyse any textual source, four steps should be taken:

In the first place, long fragments of text (typically paragraphs) are identified which maintain a semantic coherence (a global idea, a theme, etc.). The identification of these large units of text, known as fragments of discourse, in an iterative process in which the groups obtained in the first iteration are analysed recursively in order to identify fragments inside them until the smallest possible units (typically sentences or individual noun phrases) are obtained.

Secondly, each pair of syntagmas or sentences is labelled with a particular coherence relation. Hobbs' method includes coherence relations such as causal arguments, consequence relations, contrast arguments, exemplifications and generalisations of arguments. The choice of coherence relation for any given pair of discourse fragments is based on two aspects:

- The structure of the clauses which participate in them: in the aforementioned language it is possible to see how each one of the coherence relations responds to a specific structure, which we have captured in a metamodel. This structure and certain other elements, such as the presence of certain key words or grammatical connectors, determine the choice of one coherence relation or another for each pair of discourse fragments. For example, the presence of causal grammatical connectors generally indicates that the causal coherence relation is a good candidate to label that pair of discourse fragments.

- The semantic references which the clauses make to elements of the field. For example, if the two clauses describe an entity which undergoes a change in time, it is extremely probable that one of the coherence relations implying a temporal change is a good candidate to label those two discourse fragments.

The third step is to identify the components which make up the coherence relation chosen as the label within each pair of associated discourse fragments. Each particular coherence relation follows a given formal structure with a well-defined set of components. For example, it is expected that all Occasion coherence relations refer to one or more entities in two different temporal situations; the entity (or entities) and the two temporal situations must be components identified within the pair of discourse fragments labelled with the Occasion coherence relation. Using the language created during this doctoral research project, these structures have been formalised in the form of metamodels, thus making it easier to identify and to verify whether a pair of discourse fragments respond to one particular coherence relation.

Steps two and three are carried out recursively with a *bottom-up* focus, taking simple clauses as a starting point and following the structure of the breakdown of the discourse "upwards" until the longest fragments of discourse have been analysed. Therefore, coherence relations are not only established between clauses but also between larger units of discourse, such as simple phrases, complex phrases and even between whole paragraphs.

Finally, Hobbs' approach includes a fourth validation step. A common practice in validating the results of an analysis of a discourse is to evaluate the conclusions with experts in the field in question or, if possible, with the original author of the text.

Following the specifications of the process of discourse analysis defined by Hobbs, we have defined a complete methodology expressed in the ISO standard *ISO/IEC 24744*, which formally encapsulates all the methodological elements necessary to carry out an analysis of discourse in Software Engineering contexts and using our own modelling language, which has been explained above.

Fig. 15 provides an overview of the process of discourse analysis expressed in a *ISO/IEC 24744* process diagram. In this way, the process of discourse analysis is divided into four tasks, which correspond to the four steps identified by Hobbs. In addition, the diagram of the process shows other details, such as the agents involved in each task (*producers* in the terminology of *ISO/IEC 24744*. The fourth step, the task of validation, is represented by a plus sign, which indicates that it is a recommended, though not obligatory, task in order to complete the process of discourse analysis.

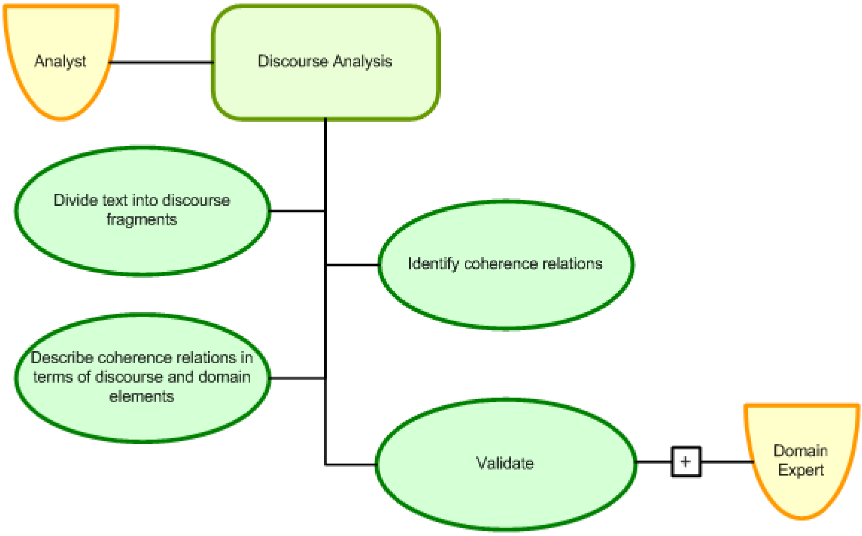

Fig. 15. ISO/IEC 24744 process diagram representing the process of discourse analysis.

Furthermore, the ISO standard *ISO/IEC 24744* defines an action diagram to complete the full representation of the described methodology. This type of diagram also shows the tasks involved in the defined process but in relation to the products (source, intermediate or end) implied in the proposed methodology, as well as the different actions which must be carried out in order to obtain the said products (a product can be read, created, modified, etc.).

Fig. 16 shows the action diagram defined to methodologically represent the process of discourse analysis with two products identified within it: the specific textual source to be analysed and which is read in different tasks and the discourse model created by using the proposed modelling language. This discourse model is created in the first task and continuously evolves throughout the whole process of the discourse analysis. The discourse model as an end product allows us to add structure and maintain the underlying semantics in the text of origin.

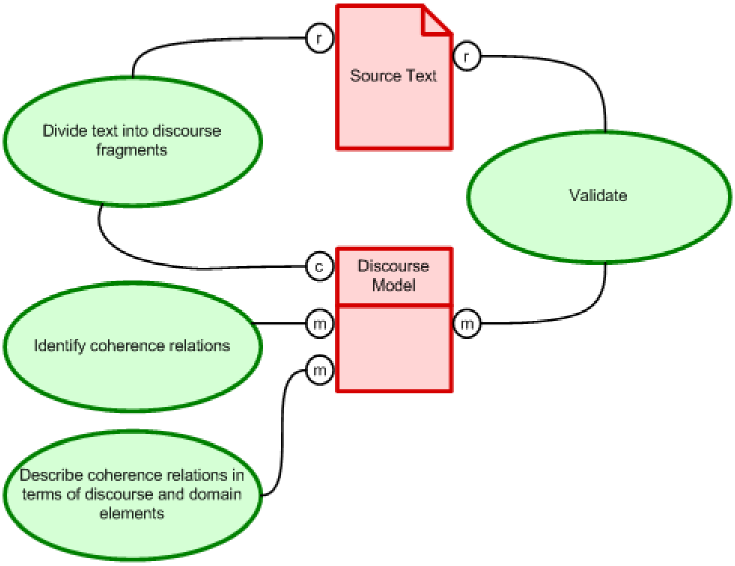

Fig. 16. The ISO/IEC 24744 action diagram representing the methodology of discourse analysis.

It should be noted here that the use of the ISO standard *ISO/IEC 24744* to describe the methodological components involved in the analysis of discourse allows for the inclusion of this methodology in any Software Engineering methodology which can be expressed following the afore-mentioned standard. Therefore, the methodology presented here can be inserted into those parts of the software development process in which it is necessary to structure and analyse the semantics of texts written in freestyle. In the same way, the choice of this standard for the origin of the language and the definition of the methodology allows the whole solution to be independent of the field of application, enabling it to be used to analyse texts from other fields and to integrate the process of discourse analysis in other specified processes which follow *ISO/IEC 24744*. The application of the methodology described here, including the modelling language, for discourse analysis in Cultural Heritage allows us to provide structure and to extract both semantic and inferential information from textual sources in the field, thus constituting our method of information extraction regarding how knowledge is generated in Cultural Heritage. This application shall be described in later sections contained in both Part II and Part III of this thesis.

The Characterisation of Expressed Knowledge: A Characterisation of Cognitive Processes in Cultural Heritage

As has already been mentioned in previous sections of this chapter, the large amount of data produced by the practice of research in Cultural Heritage is generally managed and used within the framework of individual projects. However, new trends in the management of heritage data have appeared over the last few years which show the emergence of a new way of managing this data which enables our objective of implementing software assistance to the generation of knowledge in Cultural Heritage to be fulfilled. This has been shown by numerous projects aimed at creating exchange infrastructures within Humanities disciplines [17, 26, 70], which have the objective of generating collaborative knowledge and reusing data. But what do we need to be able to assist to the generation of knowledge in these areas? Maintaining the objective of providing software assistance to Cultural Heritage experts in the generation of knowledge, while taking into account the fact that knowledge generation processes are traditionally related with layer models, such as the DIKW hierarchy (data-information-knowledge-wisdom) [7] or others of a similar structure [30, 51], an in-depth study of two lines is necessary: 1) how cognitive processes are characterised, especially those relating to the generation of knowledge and 2) what are the most common cognitive processes in Cultural Heritage. This is necessary in order to obtain a base-line which will allow us to provide software assistance to these cognitive processes. These necessities have already been studied in areas relating to cognitive Psychology [36, 243], in which multi-level characterisations of cognitive processes have been used as a way of modelling them and applying these formalisations to other fields, such as Philosophy, Education, Anthropology, etc. Over the course of this research, these same needs have been detected in the context of software assistance to knowledge generation in the field of Cultural Heritage.

The following section contains a review of studies relating to the characterisation of cognitive processes and their relation with software assistance. Later, a description will be given of the contribution made in this area, consisting of our own characterisation of the most commonly used cognitive processes in the field of Cultural Heritage, which allows software assistance to be used in the generation of knowledge.

Cognitive Processes

Theoretical Models for Knowledge Generation

Some theoretical models regarding knowledge generation exist which constitute the main corpus of this research. All of the existing models follow a hierarchical structure based on layers: Cleveland [55] establishes a model with four layers: Facts and Ideas, Information, Knowledge and Wisdom. Cleveland's model lays the foundation for a theory of human understanding. The intermediate processes between layers are not detailed in this study. Later, Ackoff [7] went a step further with five layers: Data, Information, Knowledge, Understanding and Wisdom. This model of knowledge generation has been used for years as a point of reference in Psychology and Cognitive

Studies. Taking Ackoff's model as a reference point, other authors have proposed their own models, always similar in structure but different in terms of the semantics of the cognitive processes involved. Carpenter and Cannady [52], for example, take other characterisations of the intermediate process between layers as a basis [30] and incorporate feedback between layers. They propose a model with six layers: Environment, Data, Information, Knowledge, Wisdom and Vision.

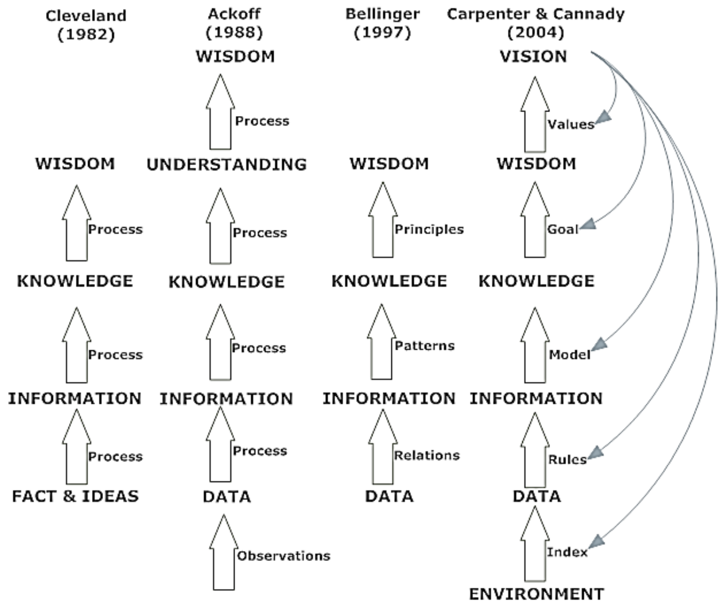

Fig. 17. Existing theoretical models to characterise cognitive processes in knowledge generation. Image based on Scott A. Carpenter [50].

In summary, the existing models for knowledge generation coincide in determining a model based on layers or levels, in which each transition from one layer to the next is brought about by humans carrying out cognitive processes, whose names and spheres differ according to the author. A summary of the models describe can be seen in Fig. 17.

The Role of Cognitive Processes in Software Engineering

The cognitive aspect is an area which is currently gaining in interest and importance both within Industry and in the research area of Software Engineering. Over the last few years, both the human and the specifically cognitive aspects within Software Engineering and Information Systems Engineering have received growing attention in the literature and in relevant conferences, proving that these aspects are just as important as the technical ones, which have traditionally been dealt with in greater detail. A good example of this is the upsurge in scientific forums which treat cognitive processes as a central theme in Software Engineering, such as the COGNISE workshop [56] and the numerous papers which, from different perspectives, consider that cognitive aspects in the field play an essential role.

Although previous studies exist which deal with cognitive processes in Software Engineering (always from the perspective of the developer, designer or creator of the software) [41], the decision was taken to carry out this review of the most recent studies carried out regarding cognitive processes in the discipline, due to the fact that it was not until recent times that these cognitive processes were treated as an instrument to assist to the process of knowledge generation.

On the one hand, there are recent studies which deal with cognitive processes within the process of software development itself, providing answers to questions such as: What cognitive processes do the agents involved perform in the development of software? How do they perform them? These studies focus on cognitive processes which are carried out during the tasks of modelling [237, 238], design and programming of software artefacts [125, 288], in addition to dealing with issues of collaborative work/teamwork in these environments. Furthermore, similar studies carry out research on what cognitive processes are performed by the users who receive the software products generated during the process of software development [301].

On the other hand, studies [230, 292] can be found which are more oriented towards the study and in-depth description of specific cognitive processes. These studies, in spite of being situated within Software Engineering contexts, have a more theoretical and independent approach from the field and provide answers to questions such as: What is the role of the cognitive process of classification in Software Engineering? Is this cognitive process of general classification for any discipline or does it present particularities in the field of Software Engineering?

Due to the growth of both areas of study, the task of carrying out a review has become a difficult one and lies beyond the scope of this research. However, a review of the area which concerns us has been carried out. Due to the fact that the final objective of this research is to assist in the carrying out of cognitive processes through the use of software, our efforts have been focused on identifying studies which describe cognitive processes in contexts of software assistance to knowledge generation independently of the techniques used for assistance.

The majority of assistance software systems which were identified have the aim of assisting the user to carry out physical processes (involving tasks with the software itself), for example, in industrial contexts with a high degree of automation, or in Medicine, etc. There are other systems which are closer to assistance to the generation of knowledge, mainly in arithmetical studies and decision-making assistance, the analysis of textual argumentation and information visualisation.

As far as the former are concerned, these systems focus on the access and conceptualisation of the data which is being handled [313], and very few of them incorporate models of cognitive processes. The incorporation of these models is defined in some studies in the field of Applied Psychology to studies in mathematical analysis, such as those revised by Ashcraft [19]. The characterisations shown in this type of study cover reasoning of a purely arithmetical kind, with generally very high levels of abstraction in the definition of the cognitive processes and quite underdeveloped formalisations. For example, characterisations of cognitive processes can be found referring to Association, Confidence Criterion and Search Length [45] or in terms of Categorisation/Discrimination [28]. This same problem presents more current characterisations based on those previously mentioned, with spheres of application focused on decision-making. These characterisations prove useful for the context of application in empirical studies with human beings or when working on the definition of systems with a high degree of abstraction, though not in contexts of software assistance, in which a specific characterisation of certain cognitive processes to be assisted is needed. Later, the importance of certain specific cognitive processes identified in these studies, such as classification and discrimination, has indeed given rise to specific conceptualisations [230] and applications for those processes, albeit without comprising a wider characterisation of cognitive processes in software assistance.

In the case of studies which deal with cognitive treatment from textual sources, it must be highlighted (as has already been explained in detail in previous sections of this chapter) that some approaches to discourse analysis deal specifically with cognitive processes of argumentation, such as their classification in the form of Hobbs' coherence relations [134], explained above.

In the case of systems relating to information visualisation, there are studies which do imply cognitive processes in an explicit way and which relate them with the other elements of a specific framework. They are designed independently from the field of application and are only focused on cognitive processes which play a relevant role in information visualisation. Good examples of this are Zhou [316], Amar [12] and Yi [313]. All of these characterisations show low or average levels of abstraction and are used successfully in the area of information visualisation. However, the cognitive processes which they characterise are only focused on visualisation tasks. Therefore, the direct use of one of these characterisations for our objective of software assistance to knowledge generation would leave out any other assistance technique which we may wish to include at a future moment (such as the techniques relating to knowledge extraction which were outlined in Part I of this thesis).

Within the sphere of information visualisation, Chen's work [67] is worthy of note due to the fact that, although it does not present a specific characterisation of cognitive processes, it includes a full model for knowledge generation via software assisted visualisation. This model has been applied in a satisfactory way, mainly in the field of Biomedicine, with its definition being independent of the field of application. Chen proposes a model which captures the actions of the user, establishing how he/she is generating knowledge. In the next step, the system adapts its behaviour to the user and offers him/her assistance by way of specific visualisation tools. The authors of this model make reference to the DIKW hierarchy as the framework for their model, thereby situating it within a sphere of application which is appropriate for our purpose. In spite of the fact that this model could be of use to us as it is, we consider it necessary to include a specific characterisation of cognitive processes within the model itself. In addition, our objective is to characterise a framework for Cultural Heritage, not only with software assistance by way of visualisation but also taking into account possible future extensions through the use of knowledge extraction techniques. Bearing this in mind, Chen's model serves us as a point of reference which will be looked into fully in later sections.

In conclusion, the majority of studies focus on cognitive processes related to the development of the software itself and not on studying them from the point of view of software assistance, in spite of the importance which cognitive aspects have acquired in Software Engineering in recent years. The studies which have most in common with our aim of providing assistance either work at a high level of abstraction with a low degree of formalisation (studies in cognitive Psychology, Arithmetics and decision-making), thus impeding the inclusion of these characterisations as a part of a software model, or produce characterisations for a specific sub-domain (for example, information visualisation or the analysis of textual argumentation).

Characterisations of Cognitive Processes in Cultural Heritage

Just as in Software Engineering contexts, the characterisation of the cognitive processes involved in the specific field of Cultural Heritage has gained relevance in recent decades with studies such as those by Stockinger [279], Gardin [100] and, more recently Doerr, Kritsotaki and Boutsika [79] in the sub-discipline of Archaeology. Another important set of studies which work on a greater level of abstraction are those related to the identification of methodological primitives in Cultural Heritage, such as those by Unsworth [289], Palmer [225], Blanke [34] and Bernadou [31] which focus more on defining cognitive processes as tasks within the characterisation of the process of knowledge generation.

However, the level of formalisation of these studies is not high enough to enable us to verify our initial hypothesis and to obtain results which can be used directly in software assistance systems in knowledge generation. Table 1 provides a synthetic and comparative vision of the specific characterisations of the cognitive processes which have been studied. The comparison has been made based on four criteria:

- The level of abstraction: There are four possible values (HH=EXTREMELY HIGH, H=HIGH, M=AVERAGE AND L=LOW), according to whether the characterisation concerns very specific cognitive processes (involving specific tasks) or more general ones.
- The disciplinary sphere of origin: This indicates in which discipline the definition of the characterisation is set, using the following abbreviations: (PSY= PSYCHOLOGY, SE-DSS= SOFTWARE ENGINEERING-DECISION SUPPORT SYSTEMS, INFOVIS= INFORMATION VISUALISATION, LING= LINGUISTICS, CH-METHOD= CULTURAL HERITAGE-METHODOLOGY STUDIES, CH= CULTURAL HERITAGE).
- The degree of formalisation: There are four possible values (HH=EXTREMELY HIGH, H=HIGH, M=AVERAGE AND L=LOW). A high or extremely high degree of formalisation corresponds to characterisations in which we have not only identified the cognitive processes but have also defined and structurally described them, for example in the form of mathematical parameters, algorithms, rules of association, etc. Average or low degrees of formalisation correspond to characterisations in which we have only narratively defined the primitives of the characterisation.

Source	Characterisation	Level of abstraction	Disciplinary Sphere	Degree of formalization
Groen & Prakman 1972 [123]	Direct Memory Retrieval, Back-up Counting	HH	PSY	M
Ashcraft 1987 [19]	Retrieval, Spreading Activation	HH	PSY	M
Campbell 1989 [45]	Association, Confidence Criterion, Search Length	M	PSY	M
Beale 1995 [28]	Categorisation, Discrimination…	H	PSY	L
Poldrack 2006 [243]	Attention, Language, Memory, Music, Reasoning, Soma, Space, Time	H	PSY	HH
Schwenk 1984 [268]	Goal Formulation, Problem Identification, Alternative Generation, Evaluation/Selection	H	SE-DSS	H
Chen & Lee, 2002 [66]	Case Memory, Cognitive Mapping, Scenario Building	HH	SE-DSS	M
Zhou & Fenier 1998 [316]	Associate, Background, Categorise, Cluster, Compare, Correlate, Distinguish, Emphasise, Generalise, Identify, Locate, Rank, Reveal, Switch, Encode	L	INFOVIS	H
Amar 2005 [12]	Retrieve Value, Filter, Compute Derived Value, Find Extremum, Sort, Determine Range, Characterise Distribution, Find Anomalies, Cluster, Correlate	M	INFOVIS	H
Yi 2006 [313]	Select, Explore, Reconfigure, Encode, Abstract, Filter, Connect	M	INFOVIS	H
Hobbs 1985 [134]	10 Coherence Relations: Causal, Generalization, Exemplification…	M	LING	H
Unsworth 2000 [289]	Discovering, Comparing, Selecting, Linking, Sampling, Referring, Illustrating,	H	CH-METHOD	M
Palmer 2009 [225]	Browsing, Collecting, Rereading, Assembling, Consulting, Notetaking	H	CH-METHOD	M

Source	Characterisation	Level of abstraction	Disciplinary Sphere	Degree of formalization
Blanke 2010 [34]	Discover, Compare, Collect, Deliver, Collaborate	H	CH-METHOD	M
Bernadou 2010 [31]	Berry-Picking, Chaining, Combining, Annotation, Thematic Organization, Translation, And Database Development	H	CH-METHOD	M
Stockinger 1990 [279]	Logic Propositions: analogies, if-then structures and conceptual inference (as a higher level of abstraction)	H	CH	L
Gardin 2002 [100]	Logic Propositions: analogies and if-then structures	H	CH	L
Doerr 2011 [79]	Factual Argumentation, Inference Making, Belief Adoption	HH	CH	M

Table 1. Main characterisations of the cognitive processes studied. The codes used for their classification are explained in the text preceding the table.

The Proposed Characterisation

As can be seen in the previous section, the existing characterisations work on very different levels of abstraction, have arisen from within the context of various disciplines and have been applied to very different contexts. The choice of one characterisation or another to be used in the software assistance to knowledge generation in the field of Cultural Heritage will, therefore, be determined by the following principles:

- Although the software assistance to knowledge generation which we are seeking lies within the field of Cultural Heritage, we believe that the chosen characterisation should work on a medium-high level of abstraction, which will not allow us to refer to extremely specific cognitive tasks and should be as independent from the field of application as possible.
- The chosen characterisation should, however, adapt itself to the particularities which have been detected previously in this chapter as far as the generation of knowledge in Cultural Heritage is concerned, especially in terms of data [108] and the predominance of textual sources [192].
- Although the software assistance to knowledge generation will show itself in terms of adapted visualisations, the solution that we propose should allow for the later incorporation of other assistance methods, especially knowledge extraction techniques. For this reason, the chosen characterisation should be defined not only in terms of visualisation primitives, but also of true primitives of the cognitive processes to be assisted.

Having analysed these principles, we believe that it is appropriate to take the characterisation described by Hobbs as a basis, given the fact that it fulfils the three criteria highlighted above (a certain degree of independence from the discipline of Cultural Heritage and an average degree of abstraction, adaptation to the characteristics of the textual sources being handled and vague in terms of the definition of the existing primitives of information visualisation). What is more, we believe that the fact that this characterisation of cognitive processes has previously been used in software contexts in the fields of Biomedicine and legal texts proves its flexibility in terms of fields of application, having a strong presence in textual sources and its appropriateness for use in software contexts. Having said this, it should be pointed out that, as far as we have been able to discover during the writing of this thesis, Hobbs' characterisation has not been included in any framework whose objective has been to provide software assistance, but has been used in more automatic contexts [171, 208].

Therefore, the coherence relations defined by Hobbs serve as a basis for the characterisation of the cognitive processes in which we aim to assist. However, following several iterations with real users, which will be described in Chapter 8, the coherence relations were organized into four groups, due to the fact that the need arose to include semantics related not only with the specific cognitive process being assisted but also related with the aim of the Cultural Heritage specialist when carrying out this process. The advantages regarding the flexibility of the definitions of cognitive processes on various hierarchical levels have been dealt with by several of the authors mentioned above [191].

In the end, the final characterisation was organised into two hierarchical levels, one corresponding to the coherence relations defined by Hobbs and another, designed for the purposes of this research, grouping the coherence relations around the final objective of the Cultural Heritage specialist. The definitions of the primitives of the level created are:

- Building: inferences based on the structure of the data, rather than on particular values.
- Clustering: inferences based on the grouping of the data.
- Situating: inferences based on situating the data in a particular context or setting.
- Combining: inferences on the basis of the combination and/or the comparison of the values of the different elements of the data.

The complete characterisation can be seen in Table 2.

Coherence Relations (Hobbs)	Type of inference according to the objective of the specialist
Parallel (termed Parallelism in this thesis) Elaboration Exemplification Generalization	Building
Contrast Violated expectation	Clustering
Background	Situating
Occasion Explanation Evaluation	Combining

Table 2. Proposal for the characterisation of the most common cognitive processes in the generation of knowledge in Cultural Heritage.

This proposed characterisation shall be used as a basis for the formalisation of the cognitive processes carried out by specialists in the field of Cultural Heritage, in such a way that they constitute the cognitive processes involved in the process of knowledge generation which we aim to assist in this area via the use of software.

It should be noted that the proposed characterisation constituting the scientific contribution of this research, in spite of the fact that it has arisen as a result of analysing the specific field of Cultural Heritage, has been expressed as primitives independently of the field of application. This decision can be attributed to two fundamental reasons (1) the field of Cultural Heritage draws together different disciplines which require their cognitive processes to be characterised independently of the sub-discipline involved and (2) we believe that, although our contribution will only be validated via this research in the field of Cultural Heritage, this approach (independent of the domain) could serve to take these primitives as a basis, and validate and/or adopt them as a reference point in later studies involving software assistance to cognitive processes independently of the field of application or the case studies presented. Now, we shall go back to the initial objective and explain in detail the application of the proposed characterisation to the field of Cultural Heritage.

The Application of the Characterisation Obtained to Cultural Heritage

The characterisation presented above serves as a basis for the formalisation of the cognitive processes carried out by specialists in the field of Cultural Heritage. But how can we apply this characterisation to software assistance in Cultural Heritage?

We can take Chen’s model outlined above as a reference for software assistance to knowledge generation. As was explained above, Chen’s pipeline model for software assistance to knowledge generation is a framework which captures information on the cognitive process being carried out by the specialist in the field in question and uses it to adapt the way the system works. In this point, we propose to integrate the characterisation of cognitive processes, as described above, into this model. The complete process can be seen in Fig. 18.

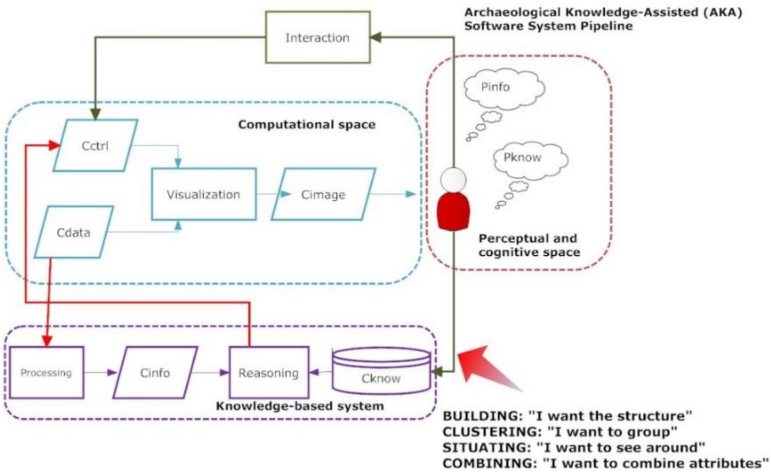

Fig. 18. The proposed model for assisting to knowledge generation, based on Chen's model, including the characterisation of cognitive processes in Cultural Heritage defined during this research.

What would the complete process of software assistance in carrying out these cognitive processes be like? Let us consider an example:

Let us imagine that a set of data regarding an archaeological site is available to a group of specialists in Cultural Heritage. These specialists can interact with this data in many ways: by comparing different attributes of the data, by grouping data, establishing causal relations, searching for bibliography relating to this data, etc. All of these possible behavioural patterns of the users are captured in the system and are described in terms of the different categories of cognitive processes and coherence relations. Thus, during an interactive session with a user, this model is used so that the system can adapt as needed. For example, if a user is attempting to verify the correlation between two attributes, the system will identify this task as belonging to the Combining category and possibly to the Evaluation coherence relation, according to Hobbs. So, the system adapts to the user by presenting the most appropriate elements of the user's interface and the visualisation options for this particular type of task.

The assistance lent by this pipeline model allows specialists in Cultural Heritage to carry out analytical tasks on structured data and to be more aware of why and how they have reached this particular piece of knowledge: What data has been used as a basis in the generation of this knowledge and/or what types of reasoning have they used? This self-knowledge of their discipline's cognitive processes and their application is not possible through the use of traditional methods. The inclusion of the characterisation of cognitive processes created during this doctoral research allows this to be done, which represents an interesting advance in the state of the art of the discipline.

In addition to studies which have the objective of characterising cognitive processes, there are studies within the field of Cultural Heritage which show the possible ways in which this characterisation of cognitive processes can be applied, not only referring to software-assisted knowledge generation (the fundamental objective of this doctoral thesis) but also in other related areas, such as those focused on the automation and simulation of social processes from the past (Barceló, etc.). The characterisation presented in this section opens new possibilities for this type of approach.

The Empirical Validation of Characterisations of Cognitive Processes: The Design of Thinking Aloud Empirical Studies in Software Assistance Contexts.

Although the characterisation of cognitive processes detailed in the previous section arose within the contexts of Cultural Heritage and their extraction process included empirical activities, their validity in the field must be confirmed. This need for validation gave rise to a bibliographic review of the methods used to validate this type of characterisations in Software Engineering (in areas with cognitive necessities such as the usability and extraction of software requirements) and in other disciplines which provide methods for the validation of such characterisations, such as sociological or psychological studies.

In this section, we shall describe this bibliographic review and the reasons why the decision was made to use Thinking Aloud Protocols [180] (hereinafter TAP) in order to validate the existing characterisation. Later, we shall go on to describe the design of the validation model created based on TAP, with the aim of validating cognitive processes in software assistance contexts. This design represents a scientific contribution in itself, given that, at the time the review of the studies listed here was carried out, no bibliographic sources were found documenting empirical TAP studies with this aim, although some were found in other contexts of Software Engineering. The proposed design was applied in order to validate the characterisation of cognitive processes proposed for Cultural Heritage, the empirical studies of which are described in the following chapter.

The Validation of Cognitive Processes in Information Systems

There are many methods of very different types for performing validations in Software Engineering, ranging from scenarios or case studies [240], to statistical experimentation [309], prototyping and concept tests [272]. Within the types of validations with an empirical component, approaches based on observation, documentation and formalisation of the resolution of problems or tasks are the most common [169, 309].

Due to the nature of the product to be validated (the characterisation of cognitive processes in software assistance contexts), it was necessary to select techniques which would allow us to obtain as much information as possible regarding how the cognitive processes were carried out during this validation work. This necessity led us to consider the TAP protocol as a possible basis for the validation of the proposed characterisation.

The term TAP (Thinking Aloud Protocols) is applied to a set of techniques which originated in the field of experimental cognitive Psychology, in which experts in the field being studied are asked to voice the words in their minds or, in other words, to manifest each idea that they think of when carrying out certain selected tasks which they must perform. Although this technique had been used in the past, it was in the 1980s that its use became generalised, especially in connection to studies such as that of Ericsson and Simon [85], who developed the use of these techniques for studying high level cognitive processes, especially those relating to memory, from a scientific and methodologically rigorous perspective. Years later, studies such as those by Olson [221], indicated that the use of TAP is one of the most effective ways to evaluate the highest level of cognitive processes (for example, those involving working memory) and that the technique could also be used to study the cognitive differences between individuals when carrying out the same task. Ericsson and Simon [85] concluded that, although the vision of cognitive processes provided by a TAP session may prove incomplete, the results represent a reliable source as far as the cognitive processes being carried out are concerned. Due to these ideas, TAP protocols have become common as a technique employed in research contexts studying areas which are traditionally verbal or narrative, such as psychological or linguistic [221] and idiomatic [63, 174] studies. They are also commonly used in problem-solving contexts in different fields, such as Physics and Mathematics or Biomedicine [267, 295]. These two approaches (more textual and/or narrative or more focused on problem-solving) employ their own application methodologies of the protocol.

The studies found which use TAP protocols in the field of Cultural Heritage are worthy of special mention. The majority of them employ the protocol as the base methodology for ethnographic work or for interviews relating to tourism [54] but they do not characterise the cognitive processes which are performed during the sessions. Therefore, their application of the TAP protocol is of no use to us as a basis for our objective. Studies of Humanities students regarding their temporal reasoning

[96, 310] or the extraction of specific sub-processes, such as the transcription of ancient texts [282], are the only reference found regarding the application of TAP for an objective similar to our own, showing satisfactory results in both sub-disciplines.

As for how and why TAP protocols have been used in Software Engineering, there are numerous studies which extract cognitive processes during the carrying out of modelling tasks [237], decision-taking in programming [41] and prototyping and validation tasks [137, 175, 216, 297]. Furthermore, TAP protocols have been used for tasks more closely related to the extraction of cognitive processes during software-assisted knowledge generation, such as in recommender systems [315], on-line search tasks [298], ontological work [90] and the creation of knowledge [311]. However, there is no defined and agreed upon methodology for the application of TAP in the validation of characterisations of cognitive processes in software assistance contexts. The methodological consensus regarding the application of TAP in Software Engineering or its sub-disciplines is more developed in visualisation contexts, as we shall see further on.

In general, "the literature of think-aloud research shows its strong theoretical foundation and confirms its value as a way of exploring individuals' thought processes" [65]. In addition, it gives satisfactory results in its application in Software Engineering contexts, thus confirming its value as a way of exploring cognitive processes [65]. The absence of a specific methodology for the application of TAP protocols to validate characterisations of cognitive processes in software assistance contexts, as well as the need to resort to a hybrid context combining the experience of TAP application in textual and/or narrative contexts and in problem solving, makes it necessary to design a specific method for applying the TAP protocol in order to validate characterisations of cognitive processes in software assistance contexts. This design would allow for a method of reference, which would aid researchers in the validation of the cognitive processes they have identified as relevant in their field of application, allowing them then to integrate them in the software assistance process which they may design.

The Proposed Model of Validation Based on Thinking Aloud

As other authors have established [65], before designing a plan of application involving TAP protocols, researchers must decide which type and what level of tasks will be carried out during the sessions, the appropriate dynamics for the sessions, the use of other possible data to support inferences based on the results of the TAP sessions and the method of analysis of these results. Below, we shall outline the literature found on each aspect and describe our own choice with a view to validating characterisations of cognitive processes in software assistance contexts.

Tasks

One of the most important aspects to be taken into account is that of selecting the tasks which the participants in the TAP sessions are to carry out. Requiring tasks with a high cognitive level could lead to interference in their verbalisation [9]. For this reason, many authors recommend the selection of tasks of a simple or intermediate level of difficulty, with a certain verbal load and organised into ascending levels of difficulty [9].

Tasks involving a software assistance system show a high level of heterogeneity as far as their number and level of difficulty are concerned. Therefore, in this point, it is considered necessary to determine at least one specific task for the validation of each cognitive process present in the characterisation which is to be validated. This allows the degree of possibilities to be reduced, along with the confusion associated with them, in the defined tasks and the cognitive processes which are to be validated. In addition, the tasks defined should arise spontaneously from the direct observation of everyday work in the field being validated. That is to say, they should be tasks which the participants carry out (independently of the method and with different tools) as part of their habitual work in the discipline. In our case, they should be tasks relating to the generation of knowledge carried out by specialists in Cultural Heritage as it is these tasks that we wish to assist via the use of software. The tasks selected should be of a low level of difficulty.

The Dynamics of the Sessions

There are a large number of approaches relating to the way data is to be extracted during TAP sessions. The majority of them advocate recording the sessions though minimising the presence of recording equipment and locating it, along with the person conducting the sessions, beside the participant or at a certain distance, not in front of them, in order to minimise the degree of intimidation of the participant [218]. Other authors complement the sessions with questionnaires [9] or include control groups which carry out the same tasks outside of the TAP session [85].

Another important aspect regarding dynamics is the need, or lack thereof, for training the participants and/or giving them prior explanations. Ideally, the participants should not require previous training [65], although on occasions they may be offered a prior orientation session in order to reduce tension levels at the start of the session (the so-called “cold start effect”)[101].

As far as the number of participants is concerned, TAP sessions generally involve a reduced number of participants, basically due to two reasons: (1) The objectives of the sessions are normally qualitative, so it is not necessary to carry out a huge number of sessions in order to obtain results and (2) The great and time consuming workload which the design of the sessions implies.

In our case, we opted to record the sessions, attempting to minimise the degree of intimidation to the participant as we believe that they are a valuable source of information for future study in the discipline. Furthermore, some simple instructions were given to the participants in the sessions regarding the characterisation of the processes being validated and the tasks to be carried out, although they were not trained in TAP techniques beforehand. The decision was also made to carry out a reduced number of sessions.

The Analysis of TAP Results and Complementary Data

Finally, it is necessary to take into account aspects related to the analysis of the results when designing TAP sessions. One of the most relevant aspects is the choice of the subject of the tasks to be performed in the sessions as this will, later, affect the results. In this context, studies [65] demonstrate the effectiveness of the choice of a specific case study to be carried out during the TAP sessions as a way of, later, being able to interpret the results from a general and applied point of view.

Furthermore, the subsequent method of analysis and enrichment of the TAP results varies notably. Charters carried out a review in which the majority of the TAP sessions analysed combine qualitative focuses with a certain quantitative classification of the results. Although there are also purely qualitative studies [63], the presence of quantitative indicators is a constant in the analysis of results [246], obtaining them by way of answers to interview questions. However, a certain lack of structure should be maintained in some parts of the sessions as this permits valuable data to be obtained which is impossible in an entirely structured format [95].

In our case, we opted for a quantitative and variable-based analysis of the data obtained during the TAP sessions (see following chapter), although the recording of the full session allowed us to create and gather data in less structured conditions during the session itself, which we believe may be of interest for future studies in this area.

Taking into account all of these aspects, a validation model of cognitive processes in software assistance contexts, shown in Fig. 19, has been designed.

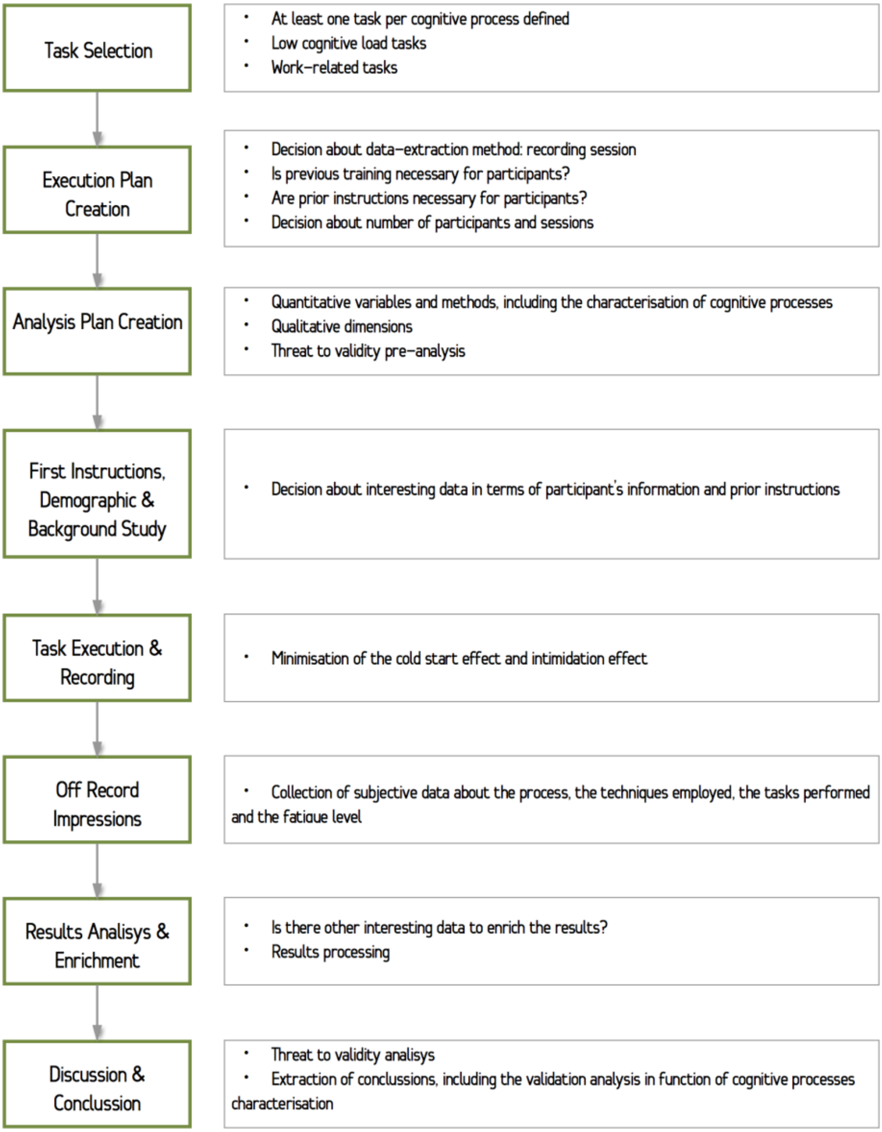

Fig. 19. A validation model of cognitive processes for software assistance contexts.

The proposed method of validation of characterisations of cognitive processes in software assistance contexts was followed with the aim of applying it in the validation of our characterisation of cognitive processes in the field of Cultural Heritage. The design of the specific empirical studies carried out, as well as the results obtained, is contained in the following Chapter 5 entitled “Prior Empirical Results”.

Tools for Detecting Interaction and Presentation Necessities

Suitability of Software Presentation and Interaction with the Aim of Providing Assistance: A Study of Information Visualisation Techniques in Cultural Heritage

In any software system, independently of whether its main function is to assist to the generation of knowledge or not, the delicate line between the system itself and its form of "communicating" or interacting with its users is of crucial importance. This can be seen in the many areas and sub-disciplines within the field of Software Engineering which are dedicated specifically to different aspects of this human-machine relationship: HCI, adaptive systems, information visualisation, etc. All of these sub-disciplines have developed a significant corpus, whose main message is that the presentation and interaction which we conceptualise and design in our system plays an essential role in terms of fulfilling the objectives, functionality, usability and quality of our system. This delicate line becomes compounded when the main function of the system is more directly related to the "human" component. For example, an industrial control system with very little interaction with humans does not require the same degree of attention as adaptive software systems for medical prosthetics or those systems whose main function is to educate or train human beings. Among the objectives of the latter type of systems is attention (in some of its facets) to human beings: health, leisure, education, etc. We can consider, therefore, that software to assist to the generation of knowledge can be classified in this group as its main function consists of helping human beings to generate better knowledge based on data. In order to do this, the component of interacting and presenting information to human beings plays a fundamental role.

For this reason, we consider it necessary to empirically study which widely used and accepted visualisation techniques and methods of interaction would be most appropriate for an assistance system for the generation of knowledge in Cultural Heritage. This section deals with the literature review carried out on this matter and the proposal of studies designed in order to extract empirical results which may allow us to discover which methods of interaction and data presentation are most suitable for providing assistance to the generation of knowledge in the field of Cultural Heritage.

Determining the Suitability of Interaction and Software presentation mechanisms

Many approaches have been adopted to determine whether a mechanism of interaction and/or the presentation of information via software is appropriate or not for its purpose, with studies on heterogeneity, the methodology of application and links to other disciplines, such as Psychology or Sociology. Due to the fact that the purpose of this doctoral thesis is not to carry out an in-depth analysis of all these aspects, only those techniques and methods employed in the current literature which allow us to determine the suitability of existing information visualisation techniques to specific aims have been selected. In this area, validation studies also abound [13, 214], grouped into frameworks [22], although they coincide in the empirical approach to these validations. In 2009, Munzner [214] carried out an in-depth study regarding techniques with an empirical focus which are used in the validation of information visualisation techniques. She analysed a set of groups: algorithm complexity analysis, field study with target user population, implementation performance (speed, memory), informal usability study, laboratory user study, qualitative discussion of result pictures, quantitative metrics, requirements justification from task analysis, user anecdotes (insights found), user community size (adoption) and visual encoding justification from theoretical principles.

Due to the fact that our objective is to determine the suitability of existing mechanisms in information visualisation techniques for carrying out cognitive tasks in the field of Cultural Heritage, we considered it necessary to design a series of empirical studies using techniques which involve not only the appearance but also the cognitive processes which they support. In addition, we believe that a mixed analysis, which allows for the extraction of quantitative (and thereby scientifically reproducible and verifiable) and also qualitative (allowing specialists in Cultural Heritage to express themselves in a less structured way) information, will work better in the context which concerns us. For these two reasons, studies with users in the laboratory, though partly defined in terms of quantitative experimentation in Software Engineering [173], constitute the most appropriate formal framework for determining the suitability of certain existing interaction and software presentation mechanisms to be validated in the field of Cultural Heritage.

The Proposed Studies

Two different types of empirical studies were selected. The first type consists of the application of a testbed [136] to be able to identify the existing information visualisation techniques which show the best results in carrying out cognitive tasks with specialists in Cultural Heritage, as well as allowing us to obtain information regarding the perception of specialists in this field.

Testbeds have been defined as a set of artefacts associated to a software system with the necessary infrastructure for carrying out empirical studies (controlled experiments on the whole) in that system [184]. By artefact, we refer to documentation of the software, an experimental plan, test plans, the source code, different versions of the software and any other artefact which is used in the real project [184]. They are widely used in Software Engineering for a multitude of purposes, such as testing or other types of validations [183]. With this type of artefacts, the infrastructure of the testbed (its methods and tools) allow empirical studies to be carried out, favouring their repetition, as the studies themselves also come to form part of the testbed and, therefore, are available for use by other researchers. In our opinion, testbeds provide a straightforward, agile and flexible framework for carrying out validations aimed at obtaining quantitative results regarding one or several artefacts. For this reason, this study shall focus on obtaining quantitative information on the suitability of existing visualisation techniques in the field of Cultural Heritage.

Furthermore, as has been stressed throughout this chapter, TAP protocols have been widely used with good results as a tool for empirical validation in Software Engineering, especially as far as usability [54, 161, 175] and visualisation [13, 49, 264, 269] are concerned. They have a much higher degree of methodological maturity for this objective than in the case of their use for the validation of characterisations of cognitive processes. For this reason, the second type of empirical studies will include TAP sessions which will allow us to measure the degree of suitability of certain interaction and software presentation mechanisms for the carrying out of tasks involving the defined cognitive processes. This study will also permit qualitative information of interest to be obtained via the TAP protocol.

The design of the specific empirical studies carried out, along with the results obtained from them, is described in the following Chapter 5 entitled “Prior Empirical Results”.

Conclusions

This chapter has presented the ensemble of methods, techniques and tools which have been adopted and produced for this doctoral research during the process of exploring the issue to be addressed, namely software assistance to the generation of knowledge, and which have allowed us to identify what needs exist and how it is possible to assist to the process of knowledge generation in Cultural Heritage via the use of software.

Table 3 illustrates the methods, techniques and tools dealt with in this chapter, exploring the differences between the methods adopted and those which are original contributions, along with their fields of application.

Method/Technique/Tool	Type	Description	Application Area
CHARM	Adoption	Conceptual model.	Cultural Heritage
ConML	Adoption	Conceptual modelling language.	Cultural Heritage
Discourse Analysis	Adoption	Technique of analysis of textual sources: structuring and extraction of semantic relations in textual sources.	Independent of the field
Methodology for integrating discourse analysis in IS	**Original contribution**	Methodology for applying discourse analysis in Software Engineering	Independent of the field
Modelling language for discourse analysis	**Original contribution**	Modelling language for the application of discourse analysis in Software Engineering	Independent of the field
Characterisation of cognitive processes in Cultural Heritage	**Original contribution**	Identification and characterisation of cognitive processes in Cultural Heritage to be assisted by software	Cultural Heritage
Thinking Aloud Protocols (TAP)	Adoption	Technique for empirical experimentation	Independent of the field
Model for the validation of cognitive processes in textual sources via TAP	**Original contribution**	Model for validating characterisations of cognitive processes in software assistance contexts	Independent of the field
Empirical validation of visualisation techniques	Adoption	Techniques for empirical experimentation	Independent of the field
Empirical studies designed for the empirical validation of visualisation techniques in Cultural Heritage	**Original contribution**	Testbed and TAP designed for the empirical validation of visualisation techniques in Cultural Heritage	Cultural Heritage

Table 3. Ensemble of methods, techniques and tools adopted and produced throughout the course of this doctoral research.

It should be noted that the solutions proposed in this chapter are the result of a close interdisciplinary research process, between aspects of Software Engineering and Cultural Heritage, as is detailed in the organisation of each subsection. This interdisciplinary research has led to problems in software-assisted knowledge generation being tackled which, without this approach, would have been impossible to deal with, such as the specific characteristics of data in Cultural Heritage (which allows for the inclusion in Software Engineering methods of solutions to deal with them) or the overwhelming presence of knowledge generated in freestyle textual sources (which makes it necessary to develop techniques and methodologies to analyse them, within engineering processes).

The following chapter will present the results of each empirical study carried out by way of an initial validation of the methods, techniques and tools dealt with here. Both chapters 4 and 5 form the basis of the definition of a solution in which software assistance to the generation of knowledge in Cultural Heritage will be dealt with in an integral way.

Chapter 5: Prior Empirical Results

Everything must be taken into account. If the fact will not fit the theory, let the theory go. -Agatha Christie

Introduction

In the previous chapter, an in-depth exploration of the problem (how to use software to assist to the generation of knowledge in Cultural Heritage) was given, along with a description of existing studies in related areas. Furthermore, a narrative was provided of how a series of techniques and tools were created during the exploratory process which allowed us not only to explore, characterise and analyse the problem in more depth but also to identify what dimensions of the situation can be tackled to propose a solution. The techniques and tools created are original contributions of this research and, therefore, require a prior validation in order to be able to be used as instruments in the solution to be designed. Due to this fact, this chapter deals with the empirical validation which has been carried out on each one of the original contributions, the results of which constitute empirical evidence in favour of (or against, as the case may be) the initial hypothesis, and reveals lines of action to be taken into account in order to give direction to the proposed solution.

It should be noted that, although each of the empirical studies carried out has been designed following the usual protocols for experimentation in Software Engineering (the details are provided below), these studies do not attempt to establish causal relations for general application as a product of their results. Rather, they aim only to validate the suitability of the tools created for the exploration of the problem in the field of Cultural Heritage and to confirm some intuitive lines of action with a view to designing the solution to the problem. They are exploratory solutions prior to the design of a solution and, therefore, it is not thought necessary to carry out an analysis of the results of the experimentation in terms of representativeness of the population or other similar statistical variables. Instead, the aim is to extract information on a qualitative level regarding the suitability of the techniques and tools created for our purpose and the possible lines of action. The final empirical validation which will be carried out on the proposed solution (described in Chapter 12), however, will imply empirical experimentation in which the results obtained will be statistically evaluated in an attempt to confirm the initial hypothesis.

This chapter introduces the methodology employed in the design, carrying out and analysis of the empirical studies and, later, provides the aggregate results obtained for each of the four empirical studies carried out to make an initial validation of each one of the contributions. The complete process of the design, carrying out and analysis of each study (according to the selected methodology), as well as the results of each of them, is included in Appendix I of this document. It should be noted that empirical studies have not been carried out in the case of the tools employed for the detection of conceptual needs presented in the previous chapter. This is mainly due to the fact that the chosen conceptual structure is, on the whole, an adopted contribution (ConML, CHARM). It should be highlighted, however, that both the extension and the use of certain modelling mechanisms (clusters, etc.), which shall be described in Chapter 7, do constitute original contributions of this doctoral thesis. In any case, it has not been considered necessary to validate these contributions empirically prior to their inclusion in a possible solution. This validation, both analytical and empirical, will be carried out when the whole proposed solution is validated. Therefore, the studies are aimed at validating the created tools for the detection of necessities regarding processes, interaction and the presentation of information.

The Design of the Empirical Studies

As other authors have pointed out [309], empirical validations in the field of Software Engineering can prove complex, due to the large number of aspects to be taken into account. In addition, the interdisciplinary nature of the research which concerns us here increases this complexity to a certain degree. Therefore, and in order to guarantee the rigour of all the studies and empirical validations carried out throughout the course of this doctoral research, a reference framework for experimentation in Software Engineering [309] has been selected which allows us to design with precision all the aspects to be taken into account in the validation and guides us throughout the entire process.

According to Wohlin, any process of experimentation in Software Engineering begins with an informal idea which leads us to sense that carrying out empirical studies or may be appropriate in order to verify whatever research hypothesis it is which concerns us. Taking this initial idea as a starting point, the process of experimentation in Software Engineering can be defined in five phases:

- Scoping: In this phase, the scope of the empirical study is marked out and the problem and general aim of the research in which the study is set is clearly defined, along with the specific objectives of the study. These specific objectives are defined by way of a template with five sections: object(s) of study, purpose, quality focus, perspective and context. For this purpose, Wohlin establishes a template in which the objective is defined in the following terms:

Analyze the <Object(s) of study > for the purpose of <Purpose> with respect to the <Quality focus> from the point of view of the <Perspective> in the context of <Context>.

All of these shall be explained and defined for each study in the following section.

- Planning: this phase proceeds to the complete design of the study to be carried out, the instruments are defined and the possible threats to the validity of the study are established. This phase has seven stages:
    - Context selection, in which the context in which the empirical study will be carried out is described (on-line or off-line according to whether it is carried out in its real context of industrial and/or professional application), along with who will carry it out (students or professionals), if it is based on a *toy example* or is performed with real objects and if the study is valid for a specific or a general context.
    - Hypothesis formulation, in which the null and alternative hypotheses for the planned study are formulated.
    - Variables selection, in which the independent and dependent variables in the study are defined.
    - Selection of subjects, in which the characteristics of the participants in the study are described.
    - Choice of design type, in which the number of factors which are to be studied is chosen.
    - Instrumentation, in which the objects of the study are designed.
    - Validity evaluation, in which a prior analysis of the possible threats and risks of the study which has been designed is carried out.

  This phase condenses the most important part of the process of experimentation as it establishes the steps to be followed in the subsequent stages, laying the foundations for the possible conclusions which can be reached by analysing this experimentation.
- Operation: this corresponds to the carrying out of the empirical study itself, in which the data is gathered according to the previously created design. It consists of three stages: preparation, execution and data validation.
- Analysis and Interpretation: in this phase, the data obtained is analysed in three stages: descriptive statistics analysis, data set reduction and hypothesis testing.
- Presentation and Package: in this final phase, the way in which the results are to be presented is decided and the necessary reports are prepared. In

this case, this chapter, along with Appendix I, corresponds to the presentation of the results of each one of the four initial empirical studies carried out.

A summary of the process defined by Wohlin and used in this empirical validation can be seen in Fig. 20.

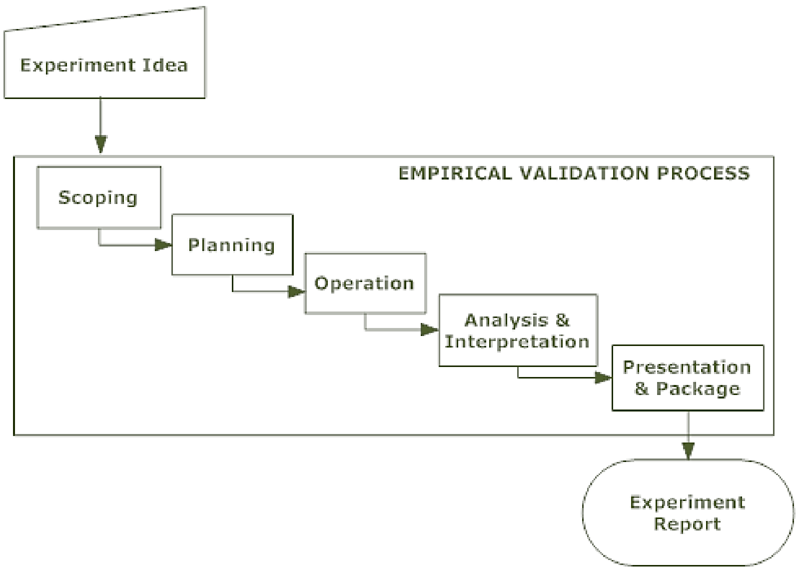

Fig. 20. Overview of the process of experimentation defined by Wohlin [309] and employed in this research for the design of studies and empirical validations.

Empirical Studies

Tools for Detecting Process Necessities: Results

As was explained in the previous chapter, the exploration of the problem on the level of process necessities led to two groups of original contributions: 1) The methodology to integrate discourse analysis into Software Engineering and the modelling language for the analysis of the related discourse. 2) The proposed characterisation of cognitive processes in Cultural Heritage, along with a specific proposal for the validation of this characterisation based on TAP protocols.

In this section, we shall examine the empirical studies which were carried out and the results obtained from them with the aim of validating each of the groups of contributions.

EMPIRICAL STUDY 1: An Analysis of Textual Sources Using our Discourse Analysis Methodology

Our objective was to obtain an empirical and intuitive idea regarding the suitability of the methodology and the proposed language associated with it for the analysis of discourse in Cultural Heritage, structuring and extracting information from each fragment of discourse analysed.

In order to do this, an empirical study was proposed in which specialists in Cultural Heritage could execute the proposed methodology, express their degree of satisfaction with it and interact with and evaluate models created both by themselves and by other modellers regarding fragments of discourse within the field of Cultural Heritage. Thus, a corpus of 40 fragments of discourse taken from six different textual sources was selected and the proposed methodology for discourse analysis was applied, creating models using the language for discourse analysis which was also created during this research. Each fragment, therefore, produced its corresponding associated object model (See action model and process model diagrams in the previous chapter).

The participants had to make an initial outline of a model of the fragment of discourse, pointing out any problems deriving from the comprehension and application of the steps. Later, they were presented with a finished model corresponding to the fragment of discourse which they had attempted to model and they were asked to evaluate it and point out any problems regarding their understanding of the model or the language itself, etc. Finally, they were asked to evaluate their level of satisfaction with the methodology and with the language on a Likert scale [181] of five values. The definition and the full results of the study can be seen in Appendix I.

Summary of Results and Conclusions

This empirical study enabled us to obtain an initial idea of the degree of suitability of the methodology and of the language proposed for its purpose (the modelling of discourse) and the later use of this information. However, it did not allow us to infer any generalisations or causal relations about it, which will be proved in later statistically representative studies.

It must be noted that, thanks to this study, we were able to discover some features which provide this series of techniques and tools with suitability and a higher degree of satisfaction:

- The semantics of the language should be clear and contain precise definitions and examples in the field of application (in this case Cultural Heritage) in such a way that the participants can identify when to model or positively evaluate a specific inference present in a specific fragment of discourse.
- When observing the complete model of a fragment of discourse, the reaction is always positive, the advantages of the structuring of the discourse and its possibilities with a view to reflection about how knowledge is generated in the discipline is understood.

Furthermore, the planning and execution of the empirical study enabled us to obtain a corpus of analysed, and later modelled, textual fragments with their evaluation by specialists in Cultural Heritage. This situation enabled a small analysis of the presence of cognitive processes in the analysed fragments to be carried out, producing an interesting and broad sample. In Fig. 21 the results of this analysis can be seen.

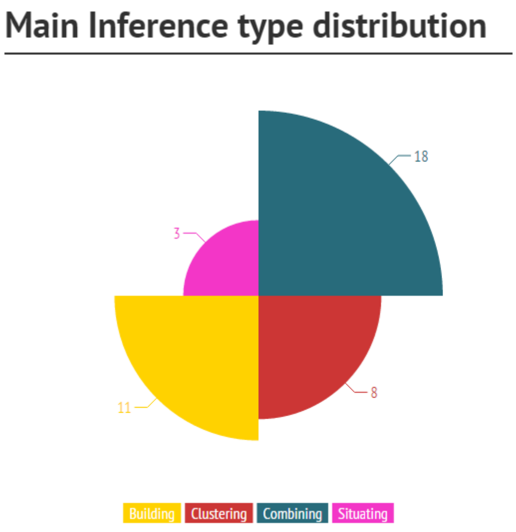

Fig. 21. The distribution of cognitive processes in the corpus of textual fragments analysed.

As can be seen, all the types of cognitive processes defined in our characterisation are present, with the most common being those based on combinations of values (Occasion, Explanation, Elaboration, and Evaluation) and the changes of levels of abstraction (Exemplification/Generalisation). These relations generally imply temporal and geographical components in the text in which they are referenced. These a posteriori conclusions enable us to support the idea that our solution must deal with cognitive processes on different levels within the process of knowledge generation, in such a way that we can know which ones we should assist, and their close relation with how heritage knowledge is generated at the present time, as reflected in the analyses carried out on textual reports.

EMPIRICAL STUDY 2: The Empirical Validation of the Characterisation of Cognitive Processes in Cultural Heritage Via the Use of TAP Protocols

At this point, it is not only necessary to carry out an initial validation of the methodology and the modelling language created but also to validate the characterisation of cognitive processes in Cultural Heritage. This is due to the fact that these cognitive processes form the foundations for the software assistance which we aim to propose as a solution. In order to do this, a study based on an original application of TAP protocols [180] was carried out.

Our objective here was to evaluate whether the proposed characterisation of cognitive processes was appropriate for the categorisation of underlying cognitive processes in practical use in Cultural Heritage, mainly concerning the degree of agreement among specialists in the field when using this characterisation. This aspect is particularly relevant when it comes to using the characterisation as a basis for any solution within the scope of this doctoral research as it establishes, to a certain extent, the degree of generalisation and acceptance that this characterisation will obtain in the field in question. Therefore, textual sources were taken as a starting point (heritage reports) and the underlying cognitive processes of 20 fragments of discourse within these reports were initially categorised. Then, these fragments were shown to specialists in the field of Cultural Heritage, along with several random possibilities of cognitive processes from which the fragments were to be categorised. At all times, they were asked to execute the TAP protocol (*thinking aloud protocols*). Thus, the participants stated out loud if they understood the task, if they understood the fragment of discourse to be analysed and if they understood the semantics of the proposed characterisation. They also expressed the reasons which led them to characterise the fragment as one type of cognitive process or another. Following all of this process, data was extracted regarding the degree of agreement reached by the specialists in the characterisation of each fragment. The definition and the full results of the study can be seen in Appendix I.

Summary of the Results and Conclusions

This empirical study enabled us to gain an initial idea of the degree of agreement among the specialists regarding the categorisation of certain fragments of discourse depending on the underlying cognitive process. The results of the *Thinking Aloud* empirical study showed a high degree of agreement in the community, with average percentages of coincidence of around 66%, which increases if we only deal with the first level of hierarchy of our characterisation (more abstract and with only four possible values (*Situating, Building, Clustering* and *Combining*) as the greater disagreements were in the choice of sub-levels within the same level.

Thanks to the use of the Thinking Aloud Protocol, we were able to detect other aspects of interest, which, although they have not been formalised in the study, provide important qualitative information with a view to using the evaluated characterisation. For example, disagreements may also occur due to the fact that the participants state that cognitive processes reflected in the text are not solidly supported or are expressed with confusion, although the characterisation still allows the underlying cognitive process to be identified.

Furthermore, this study enabled us to compare the categorisation carried out by experts in the field with that which was previously carried out by this PhD candidate, whose area of expertise differs significantly from that of the participants in the test. In this case, the degree of agreement remained stable, maintaining a greater degree of agreement on the first level of abstraction of the proposed characterisation.

Due to this fact, we believe that the characterisation can work as a key element in the definition of what cognitive processes we want to provide assistance for in the field of Cultural Heritage.

Both empirical studies 1 and 2 reaffirm our intuitive idea of the need for the treatment of cognitive aspects on a formal level in software assistance in the field of Cultural Heritage. Due to the fact that they are hardly dealt with in the solutions we analysed (in the Chapter 4 entitled “Techniques and Tools”), this formal treatment constitutes one of our main aims for improving software assistance in this field and will, therefore, form part of our proposed solution.

Tools for Detecting Interaction and Presentation Necessities: Results

As was explained in the previous chapter, the exploration of the problem on the level of interaction and presentation led to the creation of a group of original contributions: our own studies and results regarding the suitability of software assistance to knowledge generation in Cultural Heritage of certain information visualisation techniques. That is to say, in addition to validating how to identify, characterise and model the cognitive processes to be taken into account in software assistance in Cultural Heritage, we should extract certain lines of action regarding what techniques of presentation and interaction are the most appropriate in order to provide assistance to these cognitive processes. Although some approaches were identified in the review which was carried out of the literature (see Chapter 4 entitled "Techniques and Tools"), it was considered necessary to extract empirical data directly from specialists in the field.

EMPIRICAL STUDY 3: The Study of Information Visualisation Techniques in Cultural Heritage

The empirical study carried out attempted to evaluate aggregate information visualisation techniques, as standard data plotting techniques, commonly used in scientific contexts but which are used infrequently in Humanities contexts, especially in Cultural Heritage [193]. This evaluation has the aim of determining whether some are more suitable than others for supporting certain cognitive processes of our characterisation. In addition, an attempt was made to find lines of action regarding the method and degree of interaction desired by specialists in Cultural Heritage with these visualisations.

The choice of these types of visualisations (bar charts, bubble-based visualisations, etc.) can be attributed to the fact that preliminary studies with other, more complex and recent, information visualisation techniques produced worse results [193]. These studies concluded that perhaps a lack of visual training on the part of these specialists in certain visualisation strategies, along with the particularities of data in Cultural Heritage, could be the reasons why these proposals presented problems. Of course, these investigations are preliminary and more work is needed along these lines in order to be able to conclude that techniques outside of those evaluated in this study show better or worse behaviours than those used. However, the search for a compromise between the specialists' familiarity with the most widely used visualisation techniques and the use of innovative visualisation techniques, as well as the large number of studies which relate these aggregate visualisation techniques with cognitive processes referred in previous sections, led to us selecting them to verify their behaviour when supporting our characterisation of cognitive processes.

In order to do this, interviews were carried out with professionals in the field (of different affiliations, personal and professional profiles and degrees of training in the visualisation techniques in question) who were asked to carry out common data analysis tasks using these visualisations, measuring the errors and correct answers shown. In addition, they were questioned about their visualisation preferences with regard to the tasks carried out. The definition and the full results of the study can be seen in Appendix I.

Summary of Results and Conclusions

This empirical study enabled us to gain an initial idea of which mechanisms for the visualisation and presentation of information provide better results, with a lower mistake rate, among specialists in Cultural Heritage. In addition, qualitative information was gathered on the specialists' preferences regarding the visualisations.

In summary, the grouping tasks showed better results with mechanisms based on bubble charts, detecting the need for improvement in the choice of colours used (the participants looked for and/or attributed a meaning by colour) in the relative situation of groups on the screen.

In tasks relating to the analysis of the structure of the information, treemaps [271] were selected as the most suitable type of visualisation. However, they presented bad results and the data of the mistake rate (MR) and the preference distribution (PD) corresponding to the rest of the visualisations used to infer the structure of the information does not allow us to extrapolate a clear preference for any type. Work must be continued on visualisation in order to provide support for this type of cognitive processes.

As far as the tasks relating to the combination of values are concerned, bubble charts gave the best results, although the specialists later expressed preferences for both bubble and scatter charts.

Last of all, context situation tasks presented good results with almost any type of visualisation, due to the fact that they are dealt with as yet another combination value. However, the specialists requested a geographical map of spatial location in the context for this type of data, although it did not allow them to then carry out the rest of the tasks.

In addition to this information, the diversity of visualisations offered enabled us to extract some intuitive lines of action, the generalisation of which is not possible due to the fact that they are not specifically instrumented in the study but they are of interest for future studies in this area:

- A good control of "*detail on demand*" systems was observed in all types of visualisation, with search tasks relating to the structure of information providing better results.

- The specialists expressed quite a high degree of confusion regarding the meaning of positions on the screen, especially in categorisation or grouping tasks: the position of the groups on the screen must have a semantic relation.
- The specialists expressed quite a high degree of confusion regarding the definition of phases in temporal visualisations: the visualisation mechanisms shown did not prove sufficient to carry out the task without prior explanation.

In conclusion, we believe that these types of visualisations can provide good results when it comes to assisting the cognitive processes defined in our characterisation, although it is necessary to deal with each of these cognitive processes individually and to work on several levels of abstraction with the mechanisms of presentation and interaction so that the proposed solution gains in flexibility and capacity for adaptation. Therefore, a more formal definition of the mechanisms for presentation and interaction will be necessary in order to be able to integrate them into our software assistance solution.

EMPIRICAL STUDY 4: The Empirical Validation of Visualisation Techniques Via the Use of TAP Protocols

The final empirical study carried out as far as presentation and software interaction are concerned, consisted again of the application of TAP protocols in an attempt to compare the perception of the participants, in terms of ease of use and understanding of aggregate information visualisation techniques compared with their usual methods of data analysis (based on spreadsheets such as Microsoft Excel). In addition, an attempt was made to extract information about which factors are decisive in both techniques for the analysis of data, which visual aspects are noticed first in the analysis of data using both methods and which aspects are lacking in both methods which, in their opinion would enable them to analyse data more effectively.

In order to do this, real data from a case study from the sub-discipline of Archaeology was selected and the traditional method of analysis which was used to analyse the data was maintained (several Excel spreadsheets containing raw data accompanied by small pie charts serving to clarify the distribution of the data to the specialists). The same data was also presented in the eight types of visualisation techniques being evaluated. The definition and the full results of the study can be seen in Appendix I.

Summary of the Results and Conclusions

This empirical study enabled us to gain an initial idea about the perception of specialists in the field regarding readability and ease of understanding in both methods (the traditional method using Excel and that based on aggregate information visualisation techniques). In general, the visualisation techniques were evaluated more positively that the traditional method, both in terms of readability and ease of understanding, except in some specific visualisations which must be reviewed with a view to the general proposal of a software assistance solution. Furthermore, the study enabled us to extract data on how the behaviour of the user changes when he/she analyses data with visualisation techniques instead of using the Excel spreadsheet method. It was possible to verify that their behaviour varied considerably: the participant pays more attention when analysing data on aspects relating to more global analysis and less when using the visualisations offered to them. In the same way, the aspects which the participants claim are lacking differ when changing method, with the use of visualisations proving to be more abstract and aimed at the generation of knowledge. All of these details allow us to corroborate software assistance to the generation of knowledge through offering this type of adapted visualisations as a line of action.

Both empirical studies 3 and 4 reaffirm our intuitive idea for the need to deal with aspects of interaction and presentation on a formal level in software assistance in the field of Cultural Heritage.

Conclusions

The empirical studies carried out have enabled us to confirm intuitively, though not in terms of statistical representation, the importance of expressly taking cognitive processes and their support into account in terms of how data is visualised in Cultural Heritage with the aim of improving the knowledge generation process in the discipline by way of software assistance. More specifically, the software assistance we provide should:

- Respond to the most common cognitive processes in Cultural Heritage using the proposed hybrid characterisation which links Hobbs' coherence relations, originating from discourse analysis in Cultural Heritage, with our own level of cognitive processes defined for assistance in 4 keys and/or directions depending on the objective of the Cultural Heritage specialist: Building, Clustering, Situating, Combining.
- Integrate the temporal and geographical perspective in the assistance itself as a key aspect in Cultural Heritage data but not as a separate cognitive

process. It was proved that reasoning in terms of space and time was integrated into the presented typology of cognitive processes.

- Design mechanisms for presentation/interaction based on aggregate information visualisation techniques, adapting these techniques to the cognitive process which we wish to assist.
- Establish mechanisms which allow us to monitor the software assistance offered in each case, integrating its different perspectives.

To conclude, and to refer back to the initial hypothesis of this doctoral thesis (**it is possible to significantly improve knowledge-generation processes in Cultural Heritage by way of by way of providing software assistance to the user with knowledge extraction and information visualization techniques**), the literature review of the state of the art and the results obtained in the empirical studies described in this chapter allow us to state that: **in order to provide software assistance to the generation of knowledge in Cultural Heritage, all the elements involved in this assistance (the conceptualisation of data, cognitive processes to be assisted and mechanisms of interaction and presentation identified as being the most suitable) should be dealt with integrally and on a conceptual level**. This has led us to opt for the development of a framework as a solution, which will be described in the following part, enabling us to deal with all these aspects relating to software-assisted knowledge generation.

PART III: Solution

Action is the foundational key to all success

- Pablo Picasso

Chapter 6: Framework Overview

The Analytical Engine has no pretentions whatever to originate anything. It can do whatever we know how to order it to perform. -Ada Lovelace

Introduction

Over the course of the previous chapters, a description has been made of the objectives to be achieved, the research methodology to be followed and the ensemble of techniques and tools created in order to explore and define the problem. In addition, the search for evidence both for and against the initial hypothesis has been outlined. Taking the empirical results and the evidence in favour of the confirmation of our hypothesis which have been gathered throughout the research process (as described in Part II) as a foundation, we propose a conceptual framework as a solution integrating the three aspects identified as relevant in order to achieve software-assisted knowledge generation: subject matter, cognitive processes and presentation and interaction mechanisms.

By conceptual framework we understand an analytical tool [270] used in order to capture conceptual structures and distinctions between their elements, as well as to organize, communicate and prescribe these structures. Such a tool should be intuitive and easy to recall.

The use of conceptual frameworks in order to express proposals and solutions is widespread in the field of research [156], both in the contexts of deductive or inductive research methodologies and in different disciplines, such as in business [159] , natural sciences and engineering [15, 168], humanities and social sciences [8, 179, 250, 259]. According to Shields & Rangarajan [270] a conceptual framework is "the way ideas are organized to achieve a research project's purpose."

In our case, the conceptual framework takes the shape of a set of conceptual models which represent the differing perspectives to be taken into account as far as software-assisted knowledge generation in Cultural Heritage is concerned.

This chapter will look in detail at the need to create a specific framework for this objective and the process which has been followed for its design. Furthermore, this chapter will present the structure and general characteristics of the proposed framework. In subsequent chapters, each part of the framework will be described in detail and discussed separately.

Our Proposal: Subject Matter, Cognitive Processes and Presentation and Interaction Mechanisms

According to the "design science" methodology applied in the case of this thesis [300, 305] , in order to resolve a problem, it is necessary for the researchers involved to identify the stakeholders of the solution to be proposed and their objectives. The researcher can derive from them the criteria in which action can be taken to resolve the problem identified and to propose a solution, which can later be validated. According to this premise, in this point we thought it necessary to explicitly define three fundamental aspects of the proposed framework-solution prior to its presentation:

- **Stakeholders**: a biological or legal person affected by solving a problem. The term arose in the field of Software Engineering during the 1990s, specifically in the field of Requirements Engineering (commonly abbreviated RE), in the form of more specific terms such as "client" or "user" [248]. Later, studies such as those carried out by Mitroff [207] & Macaulay [188] broadened and specified the term. Eventually, Wieringa [305] defined it as "a person or organization who influences a system's requirements or who is impacted by that system". In Software Engineering, it is common to come across the use of roles instead of individuals to designate stakeholders, for example: end user, project sponsor, client, architect, developer, tester, quality engineer, project manager, product manager, etc. However, as Wieringa affirms, the term "stakeholder" is also used in other fields for a person or organization that has an interest in the outcome of, or is impacted by, a project, service, or decision". [305]
  Taking these definitions into account, we can define our profile for stakeholders of the proposed framework-solution as any person, group or institution who/which possesses expertise in the speciality of Cultural Heritage and counts among their/its principal functions the generation of new knowledge formed from present data. Some good examples of this are any researcher, professor or manager working in the field of Cultural Heritage, as well as research centres, museums and cultural associations.
- **Objectives:** As has been set out over the previous sections of this thesis, the objectives of specialists in Cultural Heritage are diverse, although all those with whom we had dealings over the course of this research were involved in the generation of new knowledge. Indeed, we can define them even more

by clarifying that this generation of knowledge takes place by way of the carrying out of pre-characterised cognitive processes, as has been described in the previous chapters. Therefore, the specific objectives of our stakeholders are to carry out each of these cognitive processes in order to generate new knowledge in the discipline.
The objective of the proposed framework-solution, therefore, will be to assist Cultural Heritage specialists in carrying out these cognitive processes by way of information visualization techniques and, in the future, knowledge extraction techniques.

- **The field of application:** As has been described throughout the course of this thesis, the proposed solution in the form of a framework throughout Part II lies within the field of application of Cultural Heritage. That is to say that the proposed framework has the aim of assisting Cultural Heritage specialists in the generation of knowledge and significantly improving those processes. This field of application has not impeded (indeed, in our opinion, it has actually promoted) the identification of necessities and problems in Software Engineering and the generation of independent contributions in the discipline, as has been outlined in the Chapter 4 entitled "Techniques and Tools". Later, the validation of this aspect has been carried out by a case study in the sub-discipline of Archaeology. The implications regarding the degree of generalization obtained thanks to this validation and the possibilities of applying the proposed solution to other fields are discussed in the Chapter 13 entitled "Discussion".

The General Structure

The created framework has three complementary perspectives to be examined: subject matter, cognitive processes and presentation and interaction mechanisms.

As far as the first part is concerned, as will be detailed throughout Chapter 7, Cultural Heritage specialists deal with a large quantity of raw data, that is to say, primary heritage data in need of analysis, which forms the basis of knowledge generation in the field. In other words, Cultural Heritage constitutes the subject matter on which new knowledge will be generated. As other authors have already identified [117], there are specific needs as far as the conceptualisation and treatment of heritage information in concerned. The proposed framework adopts the *Cultural Heritage Abstract Reference Model* (CHARM) [110] as its abstract model of reference, which provides a solution to a large part of the problems detected in these studies. It should be noted that, although the framework adopts CHARM as a solution for this part of the framework, it is necessary to extend it for each specific implementation, due to CHARM's nature as a reference model.

As far as the first part is concerned, as will be detailed in Chapter 8, the generation of knowledge is, by definition, an ensemble of cognitive processes which human beings carry out based on some kind of data. As has been seen in Part II regarding the exploration of the problem, approaches from the fields of Software Engineering and Cultural Heritage to this cognitive dimension in software frameworks are scarce, especially as far as those relating to the generation of knowledge are concerned. However, cognitive processes are an intrinsic element which must be modelled if we wish to assist to knowledge generation, given that the carrying out of these processes is what enables a rise in the DIKW hierarchy of levels of knowledge generation [7], as they form an intrinsic part of them. The proposed solution consists of models which allow these cognitive processes to be incorporated into the framework and, therefore, into the software systems which are designed based on the aforementioned framework.

As far as the third part is concerned, as will be described in Chapter 9, we believe that the model of software assistance which fits best in the field of Cultural Heritage should implement this assistance in the form of heritage information visualizations adapted to the theme being dealt with and to the cognitive processes which the user performs on them, according to Chen's model [67]. In order to do this, it is necessary for the framework to incorporate software presentation and interaction models which define how this assistance is implemented via visualization in each case. Other types of assistance, which were considered initially, such as the application of knowledge extraction techniques, have been taken into account in the definition of the framework and have been implemented into it by way of iteration mechanisms, although they have not been completely developed (this will form part of future research after the completion of this doctoral thesis).

Later chapters shall deal with the different parts of the framework, their associated software models and the scientific contributions which they present.

Chapter 7: Subject Matter

If you torture the data enough, nature will always confess. -Ronald Coase

Conceptual Modelling and Cultural Heritage

If we take into account the fact that the main objective of this research is to demonstrate the hypothesis that **it is possible to significantly improve knowledge-generation processes in Cultural Heritage by way of by way of providing software assistance to the user with knowledge extraction and information visualization techniques**, it becomes necessary to characterise the nature and specific characteristics of the data used as a source by the Cultural Heritage specialist for the generation of knowledge. As has already been explained in Chapter 4 entitled "Techniques and Tools", conceptual modelling proves an appropriate technique for a definition on a conceptual level of the sphere of application or the subject matter of the framework proposed as a solution.

Conceptual modelling applied to the field of Cultural Heritage has gained special relevance in recent years, as has been described in the Chapter 4. However, the need for a more engineering-based focus and the fact that existing solutions lack a mechanism to resolve the tension identified between prescriptive models and their necessary personalisation has led to the appearance in Cultural Heritage of modelling approaches from a formal, but integrative, perspective such as CHARM [110] or the language in which it is expressed (ConML) [107]. Both projects constitute the conceptual basis from a subject point of view of the framework-solution which we propose.

CHARM (Cultural Heritage Abstract Reference Model)

The Cultural Heritage Abstract Reference Model (CHARM) is a semi-formal representation model of Cultural Heritage on a conceptual level. As a reference model, it is broad and shallow, aiming to cover as far as possible the social and cultural phenomenon which we know as Cultural Heritage, albeit at a high level of abstraction. This allows it to be used by a wide range of users and provides it with a great degree of flexibility for a wide range of objectives and purposes [110]. Below, we shall describe CHARM's approach and its most relevant characteristics for this research and what specific contributions have been made to it, deriving from its use as a foundation for the proposed framework-solution.

The Characteristics of CHARM

CHARM is expressed in ConML [107, 108], a conceptual modelling language which broadens the conventional focus oriented towards objects with its own characteristics:

- ConML is specifically designed to be used by people who are not experts in the fields of Information Technology and Conceptual Modelling. Therefore, it attempts to eliminate complexity, technical vocabulary and the steep learning curve required by non-experts in Information Technology when it comes to modelling with other existing languages such as UML [224]. By using ConML, Cultural Heritage experts are able to create a conceptual model of their objects of study, draw up a data and/or information model based on it and guarantee a conceptual connection and interoperability with other existing CHARM models.
- ConML incorporates support for "soft aspects" of modelling, such as temporality and subjectivity, which are not supported by other modelling languages which have a more general purpose, and which are especially relevant in modelling in the field of Cultural Heritage [107].

CHARM is made up of 163 classes [142] in version 0.8 and 173 classes in version 0.9 [145]. This thesis uses CHARM 0.8, although the stratigraphic information is based on version 0.9, as detailed below. CHARM describe 3 fundamental areas of Cultural Heritage, taking into account the broad definition of Cultural Heritage adopted for the purposes of this thesis, in which any entity is susceptible to being defined within Cultural Heritage, receiving cultural value from individuals or communities. Therefore, CHARM allows an entity to be documented apart from the different evaluations which individuals and/or communities may make of it. Thus, within CHARM we find an area entitled "Evaluable Entities" and another named "Valorizations". In the end, both kinds are able to be captured by way of representation, which delimits a third fundamental area within CHARM: "Representations". If we go deeper into the conceptual sphere of the three areas, they can be defined as:

- Evaluable entities: those entities belonging to reality which have received, receive or are susceptible to receiving cultural value from individuals and/or communities. They are, therefore, entities from which heritage is built socially, such as a building, a song, an archaeological site, a painting, etc.

- Valorizations: those entities of a narrative and/or discursive nature which add cultural value to an evaluable entity, generally by way of subjective interpretation mechanisms by a well-defined individual and/or community. They represent, therefore, the added cultural value which converts an evaluable entity into a heritage entity. Good examples of this may include technical reports on the historical importance of a building or a work of art or a manifestation of attachment to a particular place on the part of an association of neighbours.
- Representations: those entities which capture characteristics or properties of other evaluable entities (known as "content") and reflect them onto another evaluable entity (known as "embodiment"). Thus, these entities become representations of existing evaluable entities, such as a painting, a photograph or a 3D model of a building.

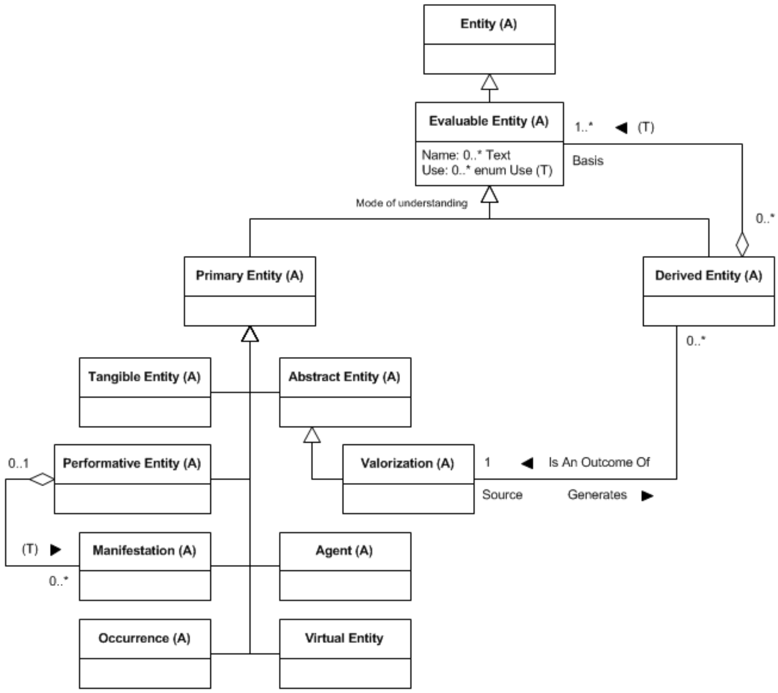

Fig. 22. Evaluable entities and their hierarchy of classes in CHARM Model, expressed in ConML language.

In addition to these three areas, the CHARM model also includes other aspects which are especially relevant for Cultural Heritage, such as geographical locations, temporal aspects, processes, measurements and dimensions and agents which define, interact, modify or take decisions regarding Heritage, among others. This allows those cross-cutting aspects to be included in any of the three previously defined areas. Fig. 22, Fig. 23 and Fig. 24 show the three areas which have been explained. For more detail on each of the classes, as well as on other cross-cutting aspects dealt with in CHARM, see [145].

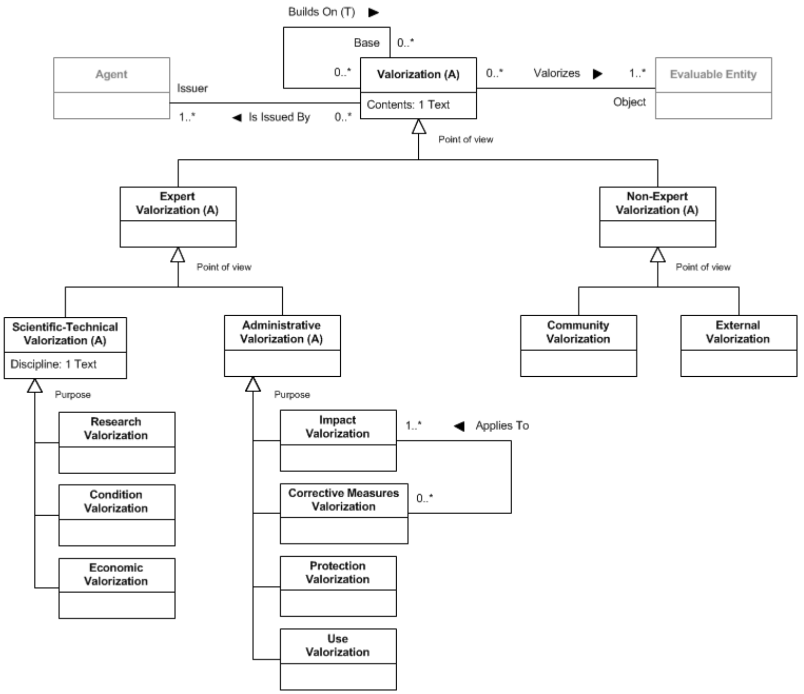

Fig. 23. Valorizations in CHARM Model, expressed in ConML language.

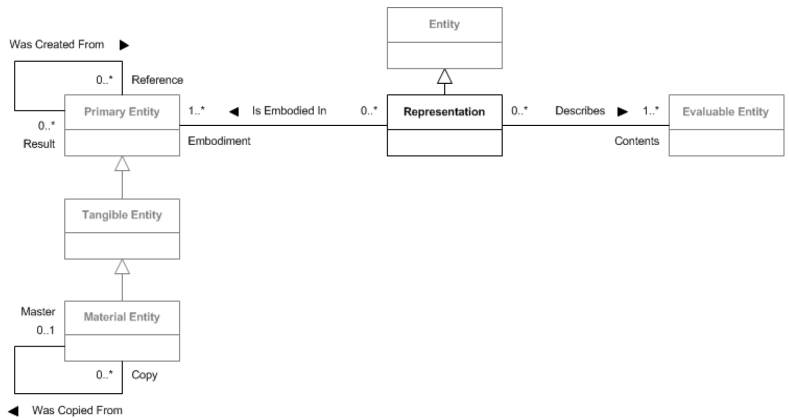

Fig. 24. Representations in CHARM Model, expressed in ConML language.

In brief, CHARM expresses concepts relating to real entities which may receive heritage value, what type of evaluation each entity receives and if a specific entity is represented in, or represents, others. In addition, it expresses where the entities are located, which of their temporal aspects and processes we wish to deal with, how we conceptualise their dimensions and what agents interact with them. Therefore, it offers the necessary conceptual support to express in the framework-solution the subject area which the Cultural Heritage specialist is dealing with in each case and upon which he/she is generating new knowledge. However, CHARM is an abstract reference model, which is to say that it is not conceived to be used by itself for practical objectives. Rather, it needs to be extended and adapted for each case in which it is applied. In the following section, we shall introduce CHARM's extension mechanisms and describe how they have been used in the proposed framework-solution.

CHARM's Extension Mechanisms

By extending CHARM, its scope is reduced and its depth and precision in the level of abstraction are increased, so that the subject area or the project being dealt with can be perfectly described. Both the ontological and epistemic reasons which determine the suitability of a model for a particular situation are complex, as has previously been mentioned [109, 236]. Therefore, the extension of CHARM always implies the production of a particular model, a CHARM super-set, so that each class in the particular model which is not in CHARM is compatible in Liskov's terms [185] with a CHARM class. Being compatible in Liskov's terms means that each entity represented in the particular model is also represented by CHARM and, therefore, can also be dealt with, from a more abstract point of view, as the corresponding class in CHARM. This is achieved via the specialisation mechanism within the Object Oriented Paradigm [35].

When a particular model is created, it is initially equivalent to CHARM. Later, CHARM extension mechanisms can be used, based on those provided by ConML, which can be combined when necessary and which allow the user to achieve a particular model which is closely adjusted to his/her personal purpose. CHARM/ConML extension mechanisms include actions such as:

- The addition of classes to the particular model by way of the specialisation of one or more existing classes in CHARM.
- The elimination of CHARM classes which are not connected with other classes with a minimum cardinality greater than zero.
- The addition of attributes to CHARM classes in the particular model.
- The addition of associations between the classes in the particular model.

- The addition of enumerated types and elements to the particular model.

These extension mechanisms offer us a great degree of flexibility due to the fact that, by adopting CHARM as a basis for expressing the subject conceptual model of the framework, they allow the framework to always be able to handle a personalised subject model for the area which the Cultural Heritage specialist is studying, whilst preserving the advantages of having CHARM as a reference model [143]. Another example developed by the author of this thesis, among others, regarding these advantages can be consulted in [116].

Other Structural Aspects in CHARM

CHARM, like any model expressed in ConML [144], has different modelling mechanisms at its disposal, provided by ConML's metamodel, which lends it flexibility when it comes to representing perspectives of heritage reality. The adoption of CHARM for this research mainly takes into account two modelling mechanisms which take on special relevance in the proposed framework-solution and which are provided by ConML's metamodel [144]: the package mechanism and the cluster mechanism. Due to their use in and specific interest to this research, both structural mechanisms are described below.

Packages

According to ConML's technical specification, a package is a group of related classes, enumerated types and possibly sub-packages [144]. Fig. 25 shows the part of the ConML metamodel in which the package mechanism is specified.

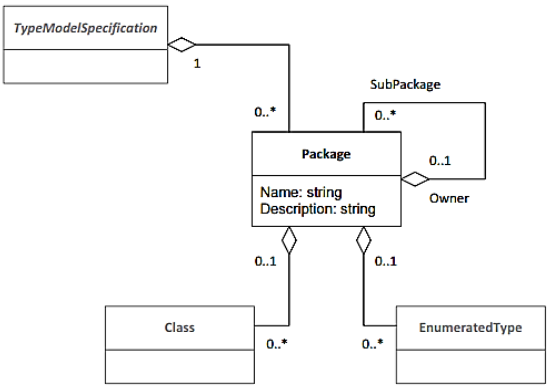

Fig. 25. Package metamodel fragment of ConML 1.4.4. technical specification.

It should be noted that CHARM's official specification does not determine any default packages in the model. This, according to the specification of ConML [144], allows the user of a model expressed in ConML, such as CHARM, to define his/her own criteria in the definition of packages in the extensions which he/she carries out when working with CHARM. In our case, this mechanism constitutes a conceptual tool to delimit the subject sphere (a sphere is defined by a package) upon which the Cultural Heritage specialist is to generate knowledge and, therefore, the subject sphere to be assisted by the framework-solution presented in Part III.

Clusters

According to ConML's technical specification, a cluster is a group of tightly related classes that usually work as a whole under a particular view of the target type model. A cluster always has a main class, which determines most of its semantics, plus a collection of participant classes. For this reason, the cluster name coincides with the main class's name. Clusters may be related between themselves. One instance of a Cluster is named Bundle in ConML [144]. Fig. 26 shows the part of the ConML metamodel in which the cluster mechanism and its corresponding structure in the model of instances are defined.

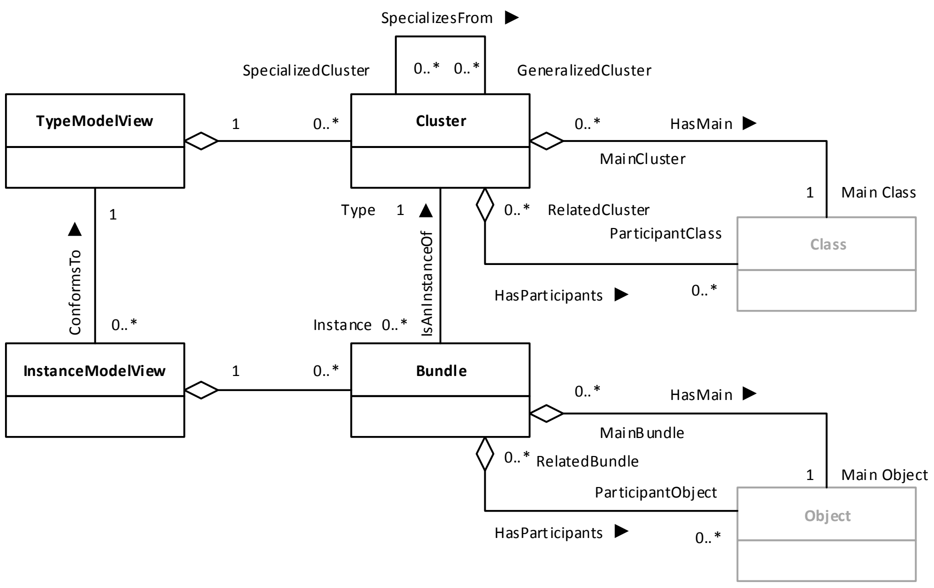

Fig. 26. Model Views structure in the metamodel of ConML 1.4.4. technical specification.

It should be noted that CHARM's official specification does not determine any default clusters in the model. This, according to the specification of ConML [144], allows a user of a model expressed in ConML, such as CHARM, to define his/her own criteria in the definition of clusters in the extensions which he/she carries out when working with CHARM. In our case, this mechanism constitutes a conceptual tool to delimit sub-areas of the subject with structural and semantic features which are of relevance for the framework-solution.

The package and cluster mechanisms work independently. Packages are conceived with the aim of providing a subject class structure to a model, whereas clusters form a view of the model for a specific aim. This allows clusters to work as a layer which is superimposed on the model organised into packages, overlapping several of them. In the following section we shall describe the complete proposal for the integration of CHARM and the mechanisms described above into the proposed framework-solution.

Our Proposal: CHARM as the Basis for the Knowledge Generation

We propose the use of CHARM as a reference model and its consequent extension to reflect, in each case, the subject matter about which knowledge is generated. Furthermore, the proposal is completed with the integration into the framework-solution of the particular models of CHARM which are created. This integration requires the use of the modelling mechanisms provided by the ConML metamodel [144] (packages and clusters) explained above, with the aim of delimiting the subject spheres and their subsequent treatment in the proposed assistance to the generation of knowledge.

The Use of the Package Mechanism

The package mechanism provided by the ConML metamodel [144] shall be used in the framework-solution in order to delimit sub-areas of the subject within the particular model being worked with in each case of software assistance. This particular model (an extension of CHARM) will be able to be subdivided into as many packages as necessary, which can fit inside each other, according to the defined ConML metamodel. For example, an extension of CHARM for a specific project will have as many packages as sub-areas of the subject contemplated in the project. The name of the package should correspond to the main subject concept of each selected sub-area. In other words, it should correspond to the class with the greatest semantic load within the package.

The Use of the Cluster Mechanism

The cluster mechanism enables us to identify sets of classes with their own semantics. In this way, we will be able to know which classes are relevant within the model and which of them have an auxiliary nature. The latter will be dealt with in the framework-solution as characteristics or features which are specific to the main class of the cluster. All of this information will be defined in the interoperability model defined by the framework-solution (see Chapter 10).

Clusters can be defined according to the following criteria:

- The definition of clusters formed by at least one participating class, as well as the main class, is recommended. The structure of clusters formed by only one main class is not taken into account when later assigning them a behaviour in the framework-solution.
- The main class of each cluster brings together its main semantics, whereas the participants will act as auxiliary characteristics to the main one.
- The cluster is defined at the highest level of abstraction possible at which we wish to work in the model, inheriting affiliation to the cluster by all the specialised classes of each of the main and participating classes which were originally defined in the cluster.

This proposal for the use of the package and cluster mechanisms existing in ConML aimed at software assistance to knowledge generation is exemplified and validated on an analytical level via the case study of A Romea, which has been selected for this doctoral thesis. The resulting models (instances of this proposal) for A Romea are implemented in a functional prototype. Both validations are detailed in Part IV.

Conclusions

As a result of what has been seen in this chapter, the reasons for the choice of CHARM (and, therefore, ConML) as the conceptual and modelling basis of the subject matter in the framework for assistance to the generation of knowledge presented throughout this thesis can be summarised as follows:

- The modelling language employed is specifically designed for specialists in Humanities and Social Sciences and supports the specific characteristics of these fields.
- The extension mechanisms it has allow us to achieve a high level of personalisation as far as subject matter is concerned in the particular models which are created. This personalisation is necessary as software-assisted knowledge generation depends on the subject sphere of the field in question in the framework-solution. However, the particular models maintain a common semantic and structural reference via CHARM, which allows them to obtain high degrees of compatibility and interoperability, as has previously been explained.

- The package and cluster mechanisms it has have allowed us to propose their use within the context of the framework-solution, which is especially appropriate in order to be able to incorporate structural information into the interoperability model which is to be defined later and which establishes a bridge on a conceptual level between the remaining parts of the framework. This bridge will be seen in more detail in Chapter 10.

The use of the package and cluster mechanisms described in this chapter is an original contribution as it allows us to carry out personalized characterisations of subject aspects of the particular models in order to then connect them through the interoperability model of the framework-solution with the rest of the dimensions dealt with (cognitive processes and software presentation and interaction mechanisms). To conclude, it should be highlighted that this first part of the framework-solution and its application to the case study carried out in subsequent chapters serve as a complete validation of the CHARM model itself as its inclusion in the framework constitutes the first use of this model as a software assistance tool to the generation of knowledge.

Chapter 8: Cognitive Processes

In questions of science, the authority of a thousand is not worth the humble reasoning of a single individual. -Galileo Galilei

Introduction

The previous chapter described the conceptual support for the expression of subject aspects in the field of Cultural Heritage adopted by the framework-solution.

As was explained in Part II: Exploration of the Problem, one of the aspects detected over the course of this research as being fundamental to software-assisted knowledge generation in Cultural Heritage is the specific treatment within the framework of the cognitive processes which the Cultural Heritage specialist carries out on the previously defined subject model. Therefore, during the phase of exploring the problem, a characterisation of cognitive processes in Cultural Heritage was built up, allowing us to express which processes are more relevant when it comes to designing a possible system of software assistance to the generation of knowledge in the field. In the same way, a methodology was constructed which allowed for the integration of discourse analysis into Software Engineering processes in order to permit the extraction of cognitive processes from textual sources, a common source of information in the field of Cultural Heritage. It should be noted that, thanks to all this prior work, these cognitive processes were revised, studied and described in depth, as can be seen in Part I. Therefore, unlike the previous and following chapters of this thesis, which are dedicated to subject aspects and software presentation and interaction, this chapter directly presents the proposed solution for dealing with cognitive processes in the proposed framework, referring to Part I as the investigative context of this work.

Based on these tools, this chapter presents the final metamodel which has been built in order to express cognitive processes as part of the framework-solution.

The Proposed Solution

The metamodel consists of two main classes: *CoherenceRelation* and *InferenceType*. A coherence relation is a connection between two discourse elements characterised according to a functional criterion. In other words, the types of coherence relations attempt to characterise what relations exist between units of discourse, mainly between clauses and/or sentences [134] in the discourse and when each of them is used. On the other hand, an inference type is a set of coherence relations which maintain a common objective on the part of the Cultural Heritage specialist when carrying out the specific cognitive process.

As can be seen in Fig. 27, one or several coherence relations can contain one or several inference types, depending on the structure of the coherence relation in the discourse. In the metamodel, the coherence relations maintain the classification in linguistic relations and formal relations (on the basis of the degree of formalisation obtained) as has been described in Part II. The formalisation of the ten types of coherence relations identified by Hobbs, with each type of coherence relation constituting a sub-class of *LinguisticRelation* or *FormalRelation* in the metamodel, also maintains the structure described in Part II.
In the same way, each of the inference types identified in the characterisation of cognitive processes carried out in this thesis constitutes a specialised sub-class of *InferenceType*, in response to the definitions developed during Part II. Fig. **27** shows the full metamodel of cognitive processes which is used in the framework–solution. It should be noted that, unlike the models developed for the subject part of the framework, the cognitive processes metamodel works with classes which conceptualise "types". That is to say, the classes present in this metamodel conceptualise types of inferences and types of coherence relations and not specific inferences or coherence relations (with the latter being instances of these classes). We are, therefore, working on a higher level of abstraction than in the subject part. This is due to the fact that the framework-solution must specify the subject part on the level of the discipline so it needs to go down to a more specific level of abstraction in order to achieve this while working on the level of inference types (without taking into account more specific concepts) when it conceptualises cognitive processes. This allows this model to be used in order to relate the discourse analysis carried out with the inference types which have been characterised, using our abstract characterisation for Cultural Heritage for other disciplines, or even adding more inference types which could be identified in the future.

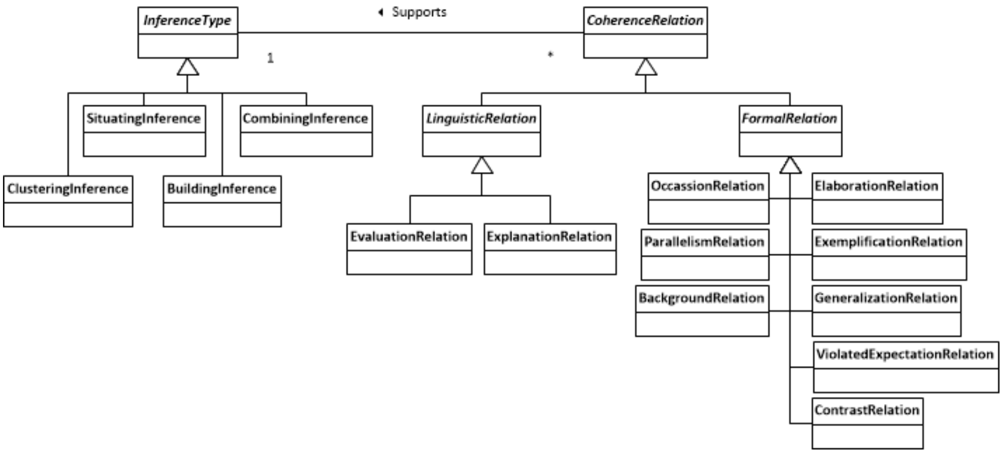

Fig. 27. Metamodel expressed in UML representing the cognitive processes in the framework-solution.

Conclusions

This chapter presents the metamodel of cognitive processes developed for the framework-solution and characterises within it the inference types which have been identified as most common and necessary in order to assist to the generation of knowledge in Cultural Heritage and its connection with the coherence relations which are present during discourse analysis. This model allows us to work with the cognitive processes which the Cultural Heritage specialist habitually carries out. Furthermore, if the methodology presented in Part II for discourse analysis has been previously applied, it allows us to state in the framework which coherence relations identified during the discourse analysis support which inference type, thus enriching our knowledge regarding the cognitive processes to be assisted which arise in each case of application of the framework and allowing the framework to respond according to this information.

As has been emphasised throughout the course of this thesis, the explicit incorporation of software models which include cognitive processes in the framework-solution in order to assist to the generation of knowledge is one of the main innovative contributions of this research. The connection in the metamodel of these processes with the results obtained from the application of the methodology for discourse analysis presented allows us to maintain traceability from the greatest source of information regarding how knowledge is generated in Cultural Heritage: textual sources.

The work carried out on the basis of the doctoral thesis in this area opens up future lines of research. The most immediate corresponds to the validation, via a wide range of cases of application, of the cognitive processes conceptualised in the metamodel and the coherence relations present in the associated discourse. This will enable us to know if more inference types exist which should be taken into account in the metamodel in order to include them in the framework-solution and provide software assistance for them. In addition, this research lays the foundation for future studies in the field of Cultural Heritage and other disciplines, basing software assistance on cognitive processes, as we believe that the characterisation of these processes, according to the field being assisted, can improve the assistance offered via software to specialists in other Humanities disciplines and even in other areas. Finally, the characterisation, conceptualisation and putting into practice of software models for cognitive processes in Cultural Heritage offers us a unique conceptual basis to study in depth how knowledge is generated in the field of Cultural Heritage, thus obtaining a greater degree of self-knowledge of the field on the part of the professionals themselves. The future lines of research will be dealt with in detail in Chapter 14.

Chapter 9: Presentation and Interaction Mechanisms

People think that the designers are handed this box and told, 'Make it look good!' That's not what we think design is. It's not just what it looks like and feels like. Design is how it works. –Steve Jobs

Introduction

In recent decades, the strategic importance of software data interaction and presentation techniques for the analysis of large volumes of data (Big Data), along with their use in decision making, has grown considerably with the appearance of emerging disciplines [165], professions [74] and techniques which assist human beings in the handling and interpretation of data. Decisions based on large volumes of data are taken on a daily basis in numerous disciplines, such as decision making in business (BPM- Business Process Management) [73, 273], qualitative research, market research, statistical reasoning, etc. Cultural Heritage and data related with Humanities disciplines are not an isolated case and also require data analysis techniques which provide assistance to the researcher as far as the interpretation of and decision making based on that data is concerned, in knowledge generation in Cultural Heritage, according to the definition employed throughout this research.

This need has emerged over the course of this research as can be seen, for example, in the empirical results regarding types of visualisations with specialists in the field, as well as in interviews and bed tests regarding interaction and presentation mechanisms, all of which are described in Chapter 5 and appendices. Due to this need, the framework-solution for assistance presented in this research project should deal conscientiously with the formal representation mechanisms of data presentation and interaction which exist, in order to later evaluate them and identify the specific needs in the field of Cultural Heritage and to propose a solution which is correctly integrated into the dynamics of the data and reasoning processes which have previously been defined.

With this aim, this chapter presents an analysis of formal interaction and presentation techniques which are currently in existence, in what applications they are used and which disciplines they represent. Furthermore, this chapter identifies a series of problems which are independent of the field of application being dealt with. Finally, based on the abstract problems identified, the chapter presents a proposal for a solution to these problems which will make up the interaction strategy of the framework-solution proposed in this research. The interaction solution, based on design patterns, will be explained in detail in an abstract way in order to then describe its application in the field of Cultural Heritage.

Formal Representation in Software Presentation and Interaction for Data Analysis

The growing demand for software systems which allow for the extraction of data and assistance to decision making processes based on that data has recently encouraged research into the creation of mechanisms which enable the formal representation of software presentation and interaction with data. One of the areas experiencing the biggest expansion at the present time is that of InfoVis or Information Visualisation [22, 46]. This emerging field draws together knowledge and skills from diverse disciplines (Psychology, Graphic Design, Data Analysis, Computation, Software Engineering, etc.) in order to create solutions for the visualisation of data which allow for greater understanding and assistance to the user in the analysis of the data. These visualisations are widely used for a wide variety of purposes, among which we can highlight Infographics [44] and the field of Education, which have been enhanced enormously by *MOOC* (*Massive Open Online Course*) and other types of online courses [1].

The majority of visualisations which arose when InfoVis first appeared as a discipline were generated on demand [14] in order to represent a specific dataset (a collection of related data) and to facilitate its understanding and use, or were based on specific visualisation techniques such as tree maps [271]. These ad hoc solutions could be immediately adjusted to the data which was to be visualised, providing the user with a satisfactory experience and fulfilling the task of providing decision making assistance. However, InfoVis researchers soon identified the fact that these visualisations did not allow for the reuse of the specific solutions for formal representation and interaction which they implemented [44].

Later, studies appeared regarding the definition, design and evaluation of specific visualisation techniques, as well as presentations according to the type of data being visualised or the audience at which the visualisation was aimed. Some of these approaches are at work in the present with abstract specifications of the visualisation techniques and the formal representation of the interaction, leading to abstract code libraries [37, 251, 260]. These libraries allow for the reuse of the solution with different datasets to be visualised but they deal with its formal specification and its specific implementation as a whole. This situation supposes the limitation of the capacity of reuse and formal representation of the components of the solution, due to the fact that the underlying conceptual model, which the adopted interaction solution represents, is excessively connected with the specific implementation chosen in the specific case.

Recently, new efforts have been made to create languages which facilitate the formal definition of software interfaces for the visualisation of data, in an attempt to uncouple the connection between implementation and the formal definition explained previously as [198, 199]. Another example is the language created by IBM [293] to define and specify interaction solutions in an abstract way, thus allowing for their reuse. In spite of the inherent advantages of the new approach, this solution still requires specific modelling skills on the part of the analyst, which reduces its degree of applicability, especially due to the significant learning curve which it presents. Specification languages are, therefore, an integral solution with numerous advantages in large software development teams and companies but are difficult to apply in other contexts.

Both approaches (abstract code libraries and specification languages) are currently being applied for the formal representation of presentation and interaction mechanisms with data [217], with the advantages and disadvantages explained above. However, the problems regarding the formal definition of presentation and interaction mechanisms have also been dealt with from another perspective by Software Engineering, highlighting the proposals focused on the use of interaction patterns.

The use of patterns consists of the repetition of a previously applied solution to similar problems to that which we wish to solve, independently of the field of application and the skills of the analyst or specialist in the field who designs the interface [10]. There is a broad corpus of research regarding the modelling of interaction based on patterns, from those based on the elements of the interface itself to approaches oriented towards objects or to the tasks carried out by the user. *OO-Method* [233], for example, is a design paradigm oriented towards objects for the development of software systems based on development settings directed by models (*Model-Driven Development*). In *OO-Method*, the interaction elements are defined using a set of interaction patterns expressed in the pattern language *Just-UI* [210]. Another solution based on pattern modelling on UML [157, 224] is *WISDOM* [219], a Software Engineering method for the construction and maintenance of interactive applications in the context of small and medium-sized enterprises (SME’s). These, along with other examples in Software Engineering, show the advantages of using the pattern concept for the formal representation of presentation and interaction mechanisms, with some limitations. OO-Method, for example, is limited to the sphere of application of interfaces based on forms, whereas the application of WISDOM is recommended by its authors in *Small Software Developing Companies* (SSDs), in order to represent interfaces which show small sets of data in the form of reports, and not large volumes of data for decision making. Furthermore, both *OO-Method* and *WISDOM* show a strong dependence between the formal representation of presentation and interaction and other models which illustrate other aspects of the system, such as function and persistence models. This dependence limits the capacity of application of the patterns identified to other cases, such as their direct integration to the framework-solution presented in this research or to any other solution designed to provide software assistance.

In addition, continuing with the revision of studies originating in the field of Software Engineering and based on the pattern concept, applications of patterns can be found for presentation and interaction in Web contexts, in which Valverde [291] has carried out an in-depth study emphasising the extension of *UsiXML* [182] to support the formal representation of interfaces. Solutions based on *UsiXML* present similar dependence problems to the previously described systems (OO-Method and WISDOM), requiring specific interaction modelling skills on the part of the analyst.

Finally, RIA (*Rich Internet Applications*) patterns are reusable solutions for common problems in the specification of presentation and interaction in interfaces [99]. RIA patterns present an approach which includes the advantages of the design based on patterns, as well as improving the reusability of the proposed solutions. However, their direct application as a solution for the representation of presentation and interaction in the proposed framework-solution in the case of this research is not possible, due to the fact that they are traditionally applied in the definition and formal representation of collaborative contexts of application or social networks [38]. RIA patterns can be found, for example, in user profiles and in search integration (the handling of active, inactive or recommended searches). For this reason, it is necessary to define new RIA patterns within the framework of this research, which are specific for software assistance to the analysis of data and decision making processes.

As all these works revealed, the specification of interaction based on patterns presents great advantages: an integral treatment of presentation and interaction mechanisms (thus avoiding ad hoc specifications), no excessive connection between the implementation and formal specification, allowing for the reuse of the solutions and avoiding the steep learning curve of specification languages.

Due to these advantages, the use of patterns, and particularly the approach of RIA patterns, fits into our purpose of offering a solution for the formal representation of software presentation and interaction in applications focused on providing assistance to the analysis of data and decision making and applying it specifically to our framework-solution in order to assist to the generation of knowledge in Cultural Heritage.

Challenges Identified

This section will analyse some current challenges as far as the specification of software presentation and interaction for assistance to data analysis and decision making is concerned, paying special attention to interaction with end users. These challenges have been identified following the prior analysis of applications [199] used by Cultural Heritage specialists for data analysis and decision making based on that data, as well as via interviews with specialists in the discipline. The systems studied share characteristics in terms of data, processes and visualisation, with the aim of assisting to the analysis of data in datasets. The challenges identified have been classified in two areas according to their origin: those related with the skills of the analyst and technological challenges.

As far as challenges related to the skills of the analyst are concerned, many analysts who design applications to provide software assistance have a great deal of experience in persistence or behavioural modelling but not so much expertise in interaction or design modelling [199]. However, there is not a notation widely used to represent interaction features, even though there are some standards, such as *Interaction Flow Modeling Language* [2]. Throughout the bibliographic revision of the chapter, we have seen how existing solutions require skills in interaction modelling with a steep learning curve for the analyst. Our challenge is to facilitate a repository of easily understandable solutions for the analyst which are defined with a context of application and one or several scenarios of use in which the advantages of using them can be illustrated. This can be done via the election of patterns as a mechanism for presentation and interaction representation. Thus, the analyst, although he/she may not be an expert in interaction modelling, will have at his/her disposal a repository of solutions which are fully adapted for software which provides assistance to data analysis and decision making processes.

As far as the technological challenges are concerned, we have identified six factors in the definition of interaction for contexts regarding assistance to data analysis:

- CHALLENGE 1: The need to model presentation solutions for large volumes of data, thus solving spatial limitations on the screen and interface.
- CHALLENGE 2: The need for dynamic modelling and interaction solutions which allow for the dynamic visualisation of data depending on the predominant (intentional) reasoning of the user at each moment.
- CHALLENGE 3: The need for modelling to deal with levels of importance: the same set of data can play different roles depending on the task being carried out by the user at each moment.
- CHALLENGE 4: The need for modelling of the use of different elements (colour, size, etc.) as interaction resources (solutions) in order to assist the user in data analysis tasks.
- CHALLENGE 5: The need for modelling of intrinsic characteristics of certain types of data, especially data of a geographic or temporal nature.
- CHALLENGE 6: The need for modelling schematic presentation solutions of data with sequential relationships between them, in such a way as to visually maintain the sequence.

The identification of these existing challenges allows for several different approaches, as they are identified independently of the field of application. Therefore, we require a solution based on design patterns with a sufficient degree of abstraction in order to deal with the challenges independently of the field of application, though always contextualising the solution within the objectives of providing software assistance to data analysis and decision making processes. Having established this, the following section shall outline the proposed solution in order to fully illustrate its applicability to our field of application. However, it will be necessary to put forward a specific implementation proposal in later sections in order to fully illustrate its applicability to our field of application.

The Proposed Solution

With the aim of setting out a proposal based on RIA patterns which may solve the problems identified above, it is necessary to point out that, although there have been attempts within the research community to reach agreements in the notation and definition of patterns, there is currently no standard which allows us to define in a single way a solution of these characteristics. We have, therefore, sets of patterns defined in different ways according to the purpose or the context of their application: for web contexts, social networks, etc. This situation leads to the lack of a single way to define the proposal of patterns we shall put forward below which constitutes our solution for the representation of presentation and interaction for software assistance (to be integrated later via a specific implementation into our framework-solution for Cultural Heritage). Due to the fact that RIA patterns are the basis selected in order to build the proposal which shall be described here, the decision has been taken to use the specification structure of patterns which is specific to RIA to describe the proposal, without prejudicing other models of pattern definition which could also be used. The most commonly used structure in the definition of RIA patterns consists of four parts [215]: a title, an identified problem to be resolved, an application context and a solution. Furthermore, we have included a fifth element in the specifications of our solution which describes scenarios of use for each one of the patterns, in an attempt to gain a better overall understanding of the solution proposed by the analyst.

The proposed solution outlined here attempts to resolve the challenges identified in the previous section thus building up a repository of solutions in formal representation of presentation and interaction for the development of systems providing assistance to the user in decision making based on data. Existing studies in this area have identified the need to work on this type of proposal with different levels of abstraction in order to define the solution [209]. The classification of the solutions from the most abstract to the most specific level allows behaviours to be encapsulated throughout the different levels, with the most simple patterns being able to be reused in order to specify more complex patterns [209]. Following this approach, three levels of patterns have been defined:

- LEVEL 1 Data-Analysis Assistance Unit: This consists of just one interaction unit which acts as a containing mechanism. Thus, the Data-Analysis Assistance Unit encapsulates the available units of interaction in order to assist users in decision making based on data. This pattern is an abstract representation of a navigational menu by way of interfaces. It should be noted that due to the fact that we only have one element in level 1 of the pattern hierarchy, this level will not be described in greater detail at a later point.
- LEVEL 2 Interaction Units: An Interaction Unit (hereinafter referred to as IU) is an abstract representation of a complete interface which will be used by end users in order to carry out data analysis and decision making tasks. Each IU can be seen as a set of presentation methods and simple behaviours identified in the third level for the support of a certain cognitive process or data analysis task.
- LEVEL 3 Individual Patterns: Each individual pattern identifies presentation representations and interaction behaviours which can be used within different Interaction Units. An individual pattern is an abstract representation of an interface widget with a predefined specific behaviour.

All of the patterns which make up the hierarchical suite which we propose as a solution can be seen in Fig. 28. Below, we shall describe each pattern following the base structure in order to define the previously mentioned RIA patterns.

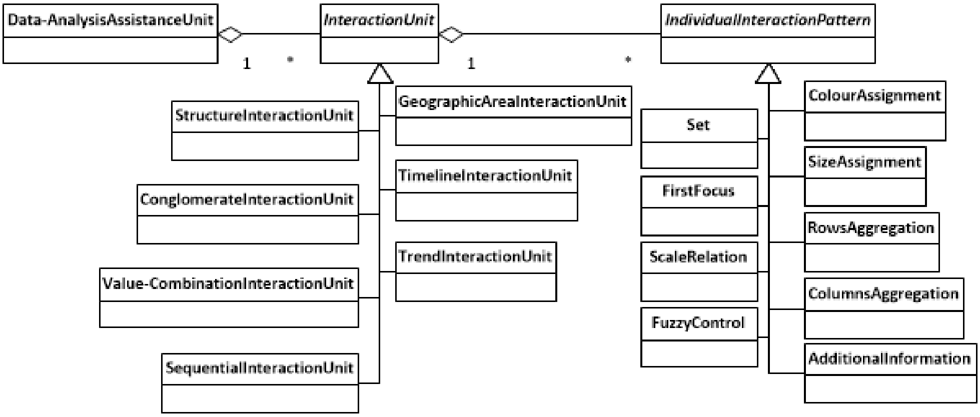

Fig. 28. Metamodel expressed in UML representing the proposed interaction and presentation patterns in the framework-solution.

LEVEL 1: Data-Analysis Interaction Unit

- Problem: The analyst or the end users themselves need to represent as a whole the presentation and interaction mechanisms aimed specifically at assisting end users in data analysis and decision making.
- Context of application: Situations identified as requests by the end users or decisions of the analyst in the pursuit of bringing together software assistance solutions for data analysis and decision making.
- Solution: Defining a first containing level which permits the grouping of the chosen solutions in each case to represent the software presentation and interaction, allowing for its reuse in other systems, architectures, configurations and designs of assistance applications. This level does not respond to any specific CHALLENGE but it attempts to provide the proposed solution with a grouping mechanism which allows for the reuse of solutions, as was previously identified in this chapter, as an objective of the solution to be proposed.
- Scenario of use: Having at his/her disposal a mechanism for grouping solutions, the analyst can reuse a set of solutions which have already been selected for similar applications or purposes, thus encapsulating them.

LEVEL 2: Structure IU

- Problem: The end users being assisted need a general view of the structure of data used to define the information contained in a certain dataset to be visualised, emphasizing the structure of the information and not the information itself.
- Context of application: Situations identified as requests by the end users or decisions of the analyst in the pursuit of improving understanding and self-awareness of the end user regarding the underlying structure to the information which is to be analysed, according to an OO (Object-Oriented) paradigm (): classes, attributes and associations.
- Solution: To organise the information in an interaction unit following OO (Object-Oriented) criteria (classes, attributes and associations) but also hiding technical aspects from the end user (types of data and technical specifications of the database). The interaction unit should be capable of representing the structure of the information, as well as maintaining a visual central theme with the specific instances, being able to visualise how that structure is reflected in a specific instance. This double view offers the user a clear view of the structure of the dataset, allowing him/her to play with the abstraction and to visualise the possible implications on the level of instances which any structural modification will have in the information. This solution is directly related with CHALLENGE 1.
- Scenario of use: An analysis based on the structure of information is a common practice in applications aimed at providing software assistance to data analysis. For example, the end users can see the attributes of different classes in order to decide if it would be interesting to compare these classes, their common structure or to establish what criteria are most appropriate for a later classification on the level of instances.

LEVEL 2: Value-Combination IU

- Problem: The end users being assisted need interaction and presentation mechanisms for searches and the evaluation of instances depending on the values of their attributes.
- Context of application: Situations identified as requests by the end users or decisions of the analyst in the pursuit of offering interaction solutions which enable us to know the values of the different attributes, classifying the information according to those values.
- Solution: To organise the information contained in a dataset, allowing for the election of a main class (which acts as an objective class for the analysis) and

to classify the instances of that class depending on the values of its attributes. This solution is directly related with CHALLENGES 1, 2 and 4.
- Scenario of use: The analysis based on values of attributes allows the end user to reason about characteristics of a statistical nature present in the dataset, such as inferring averages, relevant percentages, etc.

LEVEL 2: Conglomerate IU

- Problem: The end users being assisted need interaction and presentation mechanisms which allow the data contained in the dataset to be classified in a dynamic and simple way.
- Context of application: Situations identified as requests by the end users or decisions of the analyst in the pursuit of offering greater dynamism in the rapid classification of the information contained in the dataset by a dynamic criterion.
- Solution: To organise the information contained in a dataset, permitting the selection of the classifying criterion and emphasising the speed of reconfiguration of the interface. This solution is directly related with CHALLENGES 2 and 4.
- Scenario of use: An analysis based on rapid classifications of a large volume of data by just one criterion helps the user to understand which main entities exist in the dataset being analysed, as well as deviations in the data. For example, a user can detect atypical groups with respect to a certain criterion or instances which do not belong to any group (extreme values, etc.).

LEVEL 2: Trend IU

- Problem: The end users being assisted need interaction and presentation mechanisms which allow tendencies in the data in quantitative terms to be observed, both within one dataset (for example, the number of entities or instances which form part of one group or another) and in other datasets which have the same structure of information (for example, the number of entities or instances present in two datasets from different sources or two versions of the same dataset taken at different moments).
- Context of application: Situations identified as requests by the end users or decisions of the analyst in the pursuit of offering interaction solutions for the detection of quantitative tendencies in medium and large volumes of data.
- Solution: To organise the information contained in a dataset in quantitative terms, allowing for the selection of a grouping criterion. The interface should be able to structurally recognise the information being presented in order to

be able to visualise two datasets at the same time in quantitative terms, providing that the structure of the information visualised in both datasets coincides. This solution is directly related with CHALLENGES 3 and 4.

- Scenario of use: An analysis based on the detection of quantitative tendencies present in a large volume of data helps the user to understand what factors intervene in the belonging of objects of the dataset to a certain group, to compare data with the same structure coming from different versions and to infer possible future behaviours in the data. For example, a user can detect the importance of a certain group of data (by its number of elements) due to the fact that, in successive versions of the same dataset, this group increases its number of objects or he/she can compare two datasets from different sources in order to know whether their groups behave in the same way or whether they present different tendencies (one rising and the other falling in number of elements, etc.).

LEVEL 2: Timeline IU

- Problem: The end users being assisted need interaction and presentation mechanisms which allow the temporal aspects of the data to be analysed, especially attributes of a temporal nature or classes with values in attributes which change over the course of time.
- Context of application: Situations identified as requests by the end users or decisions of the analyst in the pursuit of permitting the analysis of changes over the course of time in values of attributes or instances of classes with a temporal component.
- Solution: To organise the information in order to select, visualise and interact with values of variable attributes over time in an interface which is particularly aimed at visual reasoning. This solution is directly related with CHALLENGE 5.
- Scenario of use: The analysis of temporal data allows the user to infer temporal dependencies in the data. For example, the user can see how the values of two attributes change over the course of time in order to analyse possible relations between both changes.

LEVEL 2: Geographic Area IU

- Problem: The end users being assisted need interaction and presentation mechanisms which allow geographical aspects of the data to be analysed, especially the attributes of a geographical nature or classes with eminently geographic semantics (locations, places, etc.).

- Context of application: Situations identified as requests by the end users or decisions of the analyst in the pursuit of permitting the geographic analysis of values of attributes or instances of classes with a geographic component.
- Solution: To organise the information in order to select, visualise and interact with the information contained in an interface which is especially oriented towards geographic reasoning. This solution is directly related with CHALLENGE 5.
- Scenario of use: A geographic analysis allows the user to situate his/her data geographically. For example, the user can see the data according to its geographic location of origin, being aware of the geographic area which it covers, thus allowing for the analysis of this coverage and/or the detection of possible implications.

LEVEL 2: Sequential IU

- Problem: The end users being assisted need interaction and presentation mechanisms which allow data connected with sequential relations to be analysed, be it a sequence of data of the same nature or any information which must be visualised “by levels” in order to be understood.
- Context of application: Situations identified as requests by the end users or decisions of the analyst in the pursuit of offering interaction solutions for sequential or organised information visualisation in levels or layers.
- Solution: To organise the information in order to select, visualise and interact with the information contained in an interface which is especially oriented towards sequential reasoning “by levels”. This solution is directly related with CHALLENGES 3, 4 and 6.
- Scenario of use: A sequential analysis allows the user to situate his/her data in levels. For example, the user can see the data belonging to a sequence along with its relations, thus allowing him/her to analyse these relations and/or detect possible implications.

LEVEL 3: Row Aggregation Pattern

- Problem: The users need a general view of the information contained in a dataset organised into interfaces with a landscape orientation.
- Context of application: The user requests a general view of the information, for example, according to values, or their intervals, of an attribute or of classes belonging to different instances, but always maintaining the landscape orientation.

- Solution: To organise the information in rows, creating visual divisions in the interface which allow the rows to be identified clearly and intuitively, without overloading the interface. This allows an analysis to be carried out by the user in the direction of reading of the interface (horizontally) but without affecting the direction of the reading. In other words, the interface can be read from right to left and vice versa, maintaining the distinction between the categories and intervals of values represented in the rows. This solution is directed related with CHALLENGE 1.
- Scenario of use: A horizontal visual analysis, maintaining the organisation in rows, allows the presentation of a large amount of data to be adapted in an organised and convenient manner for human visual analysis.

LEVEL 3: Column Aggregation Pattern

- Problem: The users need a general view of the information contained in a dataset organised into interfaces with a vertical orientation.
- Context of application: The user requests the visualisation of a general view of the information, for example, according to values, or their intervals, of an attribute or of classes belonging to different instances, but always maintaining a vertical orientation.
- Solution: To organise the information into columns, creating visual divisions in the interface which allows the columns to be identified clearly and intuitively, without overloading the interface. This allows an analysis to be carried out vertically, maintaining the distinction between the categories or intervals of values represented in the columns. This solution is directly related with CHALLENGE 1.
- Scenario of use: A vertical visual analysis, maintaining the organisation in columns allows the presentation of a large amount of data to be adapted in an organised and convenient manner for human visual analysis.

LEVEL 3: Set Pattern

- Problem: The users need to visualise a dataset grouped according to a criterion, treating the resulting groups as elements of the interface with an entity of their own.
- Context of application: The user requests the visualisation of aggregate information, generally according to a criterion, requiring the interaction and treatment of the resulting groups.
- Solution: To organise the information creating an element of interface, generally a recognisable shape (a sphere, an ellipse, etc.) for each group

resulting from the aggregation. This solution is directly related with CHALLENGE 2.

- Scenario of use: An analysis based on categories requires the choice of an interface element as a graphic notation representing the groups of data of the different categories created.

LEVEL 3: Additional Information Pattern

- Problem: The users need to obtain additional information about data or datasets which are present in the interface.
- Context of application: The user requests the visualisation of contextual information of some specific data or a dataset of the interface in which it is found, albeit without any changes in the interface.
- Solution: To organise the information by showing specific information contextualised to the element which the user wishes to know more deeply. This information is shown with an additional element, which does not intrude in the interface and which is activated in response to an action carried out by the user (typically a *click* or a *mouse hover*). This solution is directly related with CHALLENGE 3.
- Scenario of use: An analysis of data in its context with small enquiries for contextual information is common in data analysis processes and allows the user not to lose the overall vision of the data being analysed, allowing for knowledge to be gained via interaction with the interface of more specific information of the elements of which it consists. This additional information, which is offered quickly and unobtrusively, allows the user, for example, to gain a deeper knowledge of data which is out of range or which has an abnormal behaviour and to infer possible causes.

LEVEL 3: First Focus Pattern

- Problem: The users need to filter visual noise in a complex interface showing a large amount of data.
- Context of application: The user requests the visualisation of several focuses or parts in an interface with a high density of presented data, thus avoiding the visual noise which can be caused by the other elements of the interface.
- Solution: To organise the information into two levels, so that through the use of shading or other highlighting or visual deactivation mechanisms, the user can focus on one part of the presented information. This solution is directly related with CHALLENGE 3.

- Scenario of use: Interfaces with a high density of data generally require focused visualisation in one or more places at the same time in order to establish comparisons or to highlight parts or aspects of the information. This pattern offers a solution to cover these analysis needs without structural changes in the main interface.

LEVEL 3: Colour Assignment Pattern

- Problem: The users need mechanisms in order to give different semantic content to each element of the interface.
- Context of application: The user requests the identification of different elements of the interface with semantic coherence regarding the data which it represents.
- Solution: To organise the information offering the user a mechanism to choose a colour as the differentiating and representative element of elements of the interface and, therefore, of aspects and datasets which are shown within it. If the user groups information according to a criterion, for example, he/she can use colour in order to associate each group to a semantic value of that criterion. This solution is directly related with CHALLENGE 4.
- Scenario of use: The selection of colour is an effective mechanism to provide meaning to the interface in an unobtrusive way, also allowing a visual logic to be maintained throughout various interfaces of data analysis.

LEVEL 3: Size Assignment Pattern

- Problem: The users need mechanisms to give semantic content to the relations between each element of the interface and their size within the interface.
- Context of application: The user requests the association of the size of the different elements of the interface with semantic coherence regarding the data which they represent.
- Solution: To organise the information offering the user a mechanism to choose what meaning the size of the interface's elements will have. If the user groups information according to a criterion, for example, he/she will be able to use size to associate each element of the interface (which represents each resulting group) with its size according to the number of elements which make up each group. This solution is directly related with CHALLENGE 4.

- Scenario of use: Using the size of elements of the interface is an effective mechanism to provide meaning in an unobtrusive manner, also allowing a visual logic to be maintained throughout various interfaces for data analysis.

LEVEL 3: Scale Relation Pattern

- Problem: The users need to visualise information, generally values of attributes, whose nature is temporal or varies over the course of time.
- Context of application: The user requests the visualisation of data with a strong temporal component, such as phases or events relating to instances in a temporal context. Occasionally, the user requests this visualisation separately, in such a way that various attributes or data of a temporal nature can be represented in the same interface.
- Solution: To organise the information offering a mechanism which relates various temporal datasets in the same interface. This solution is directly related with CHALLENGE 5.
- Scenario of use: The solutions for visualising several temporal datasets at the same time generally consist of visualising them separately and combining them in the interface. This pattern allows the implicit relations between several sets of temporal information to be taken into account and to visualise them in different timelines, whilst maintaining the visual relation between them.

LEVEL 3: Fuzzy Control Pattern

- Problem: The users need to visualise information, generally values of attributes, the precision of which varies greatly from one to another, showing intervals with a great degree of diffusion in their values.
- Context of application: The user requests the visualisation of data whose values present different degrees of diffusion (wide intervals compared with very specific values) and a certain degree of imprecision (diffuse values on their limits).
- Solution: To organise the information offering a mechanism which, given a value of an attribute, allows its degree of diffusion to be visualised. It is generally implemented by making the element of the interface which represents the value vibrate. If the element covers more space when vibrating, the extent of the interval in values is greater and vice versa. In addition, if the element presents a lower frequency of vibration, it is more diffuse (understanding by ‘diffuse’, less precise in its definition), whereas if

it vibrates with greater frequency, the diffusion is less. This solution is directly related with CHALLENGE 5.

- Scenario of use: Diffusion in the values is a common characteristic in certain types of data to be analysed, which should be represented in order to assist to data analysis and decision making. This pattern allows the extent of the values of an attribute to be taken into account, along with the degree of diffusion which that value presents.

Table 4 sums up the interaction units defined and the challenges addressed:

	CHALLENGE 1	CHALLENGE 2	CHALLENGE 3	CHALLENGE 4	CHALLENGE 5	CHALLENGE 6
2. Structure IU	•					
2.Value-Combination IU	•	•		•		
2. Conglomerate IU		•		•		
2. Trend IU			•	•		
2. Timeline IU					•	
2. Geographic Area IU					•	
2. Sequential IU			•	•		•
3.Row Aggregation	•					
3.Column Aggregation	•					
3. Set		•				
3.Additional Information			•			
3. First Focus			•			
3.ColourAssignment				•		
3. Size Assignment				•		
3. Scale Relation						

	CHALLENGE 1	CHALLENGE 2	CHALLENGE 3	CHALLENGE 4	CHALLENGE 5	CHALLENGE 6
3. Fuzzy Control					•	

Table 4. Matrix of Challenges vs. Units of interaction and individual patterns which each challenge deals with.

Applying Interaction Patterns in Cultural Heritage

As can be observed, the set of challenges identified and solutions proposed in the form of the RIA patterns described above is applied to the set of software assistance applications for data analysis. Due to the fact that our studies [114, 116, 195] have been carried out in the field of Cultural Heritage, we have defined specific problems in this discipline, using the same enumeration as the challenges defined abstractly and independently of the field.

In this section, we shall present the problems which have been identified, with each specific problem being related with the abstract challenge corresponding to its enumeration in the field of Cultural Heritage. These problems reveal the presence of the challenges identified in Cultural Heritage contexts.

PROBLEM 1: Specialists in Cultural Heritage often work in teams on one particular dataset [115, 199]. Therefore, they require a general view of the structure of the information with which they are working, which will be a determining factor in order to clarify its content, helping to decide the strategy for analysis and research to be followed regarding the heritage data. This general view should show both the structure of the information and its relation with the data itself, which supposes the visualisation of a large amount of data at the same time. One example would be the need for a general view of the structure of the information of a dataset from an archaeological project or from a set of anthropological interviews, etc. This general view should assist the user in understanding the structure and should also give him/her information on specific instances (a specific interview, an archaeological finding in that particular project, etc.).

PROBLEM 2: The process of categorisation or grouping is extremely common in Cultural Heritage, forming part of the working methodology in the different fields of which it consists. Some good examples of this include the construction of thesauri, agreements regarding terminology and the typology of objects and evidence. It is necessary, therefore, to have a presentation and interaction mechanism which enables the simple and agile grouping of the data present in the dataset according to a criterion, which the user may vary.

PROBLEM 3: Users in Cultural Heritage often work with a dataset in which they need to deal with different levels of importance of the information in question. Some good examples of this include datasets containing information about archaeological evidence, historical events, literary references, etc. In all of these cases, the need arises to obtain additional information about the evidence, event or reference or a subset of them, whilst maintaining the general view of all of them on the screen.

PROBLEM 4: Within the process of analysis in the field of Cultural Heritage, it is common to find the presence of several attributes which cut across the dataset which the users are analysing to detect similarities or differences between the data. Good examples of this include morphology or decoration in archaeological evidence, the cultural assignation of historical or literary instances, the materials of which objects are made, etc. These similarities and differences should be made clear by way of the use of interface mechanisms which allow them to be visible.

PROBLEM 5: In Cultural Heritage, temporal and geographic components of data are the main axes for analysis in order to be able to postulate scientific hypotheses and to make decisions based on the data which has been observed [199]. In this context, the interfaces which present this data should reflect each one of the facets in a way which is adapted to the type of analysis which experts in Cultural Heritage commonly carry out, each with their own problems, such as the dispersion of temporal data or the support for spatial reasoning. A good example of this could be the needs for the temporal visualisation of events or phases with differing degrees of dispersion in historical and/or archaeological contexts.

PROBLEM 6: Within the process of the categorisation of information reflected in the problems detected above, some datasets exist in Cultural Heritage with a strong sequential (or level-based) component. The sequential structure of this type of information could go unnoticed without an interface which explicitly includes this type of data and the relations between its instances. Some good examples of this include stratigraphic studies in Archaeology or Paleo-Environmental Studies, the spatial analysis of buildings and formations in Architecture or the History of Art, geological strata, etc. Indeed, sequential schematic visualisation could arise in any area of Cultural Heritage.

In conclusion, the abstract challenges identified arise as problems in Cultural Heritage in relation to presentation and interaction for software assistance to the analysis of data. Continuing with the cross-sectional case study for this research, we have applied the hierarchical solution of patterns of interaction proposed in order to illustrate software assistance to the generation of knowledge in Cultural Heritage. It should be remembered at this point that the framework-solution proposed as a software assistance solution in the field of Cultural Heritage consists of three complementary perspectives or aspects: Subject Matter, Cognitive Processes and Presentation and Interaction Mechanisms. This chapter presents the solution for this last aspect.

We shall now go on to describe each interaction unit which has been implemented and the individual patterns chosen for assistance in Cultural Heritage.

STRUCTURE IU

The interaction unit Structure IU responds to Problem A identified above in the field of Cultural Heritage (and related with the general challenge 1). It makes reference to the need to provide the Cultural Heritage specialist with a general view of the structure of the information, whilst maintaining a connection with the specific data. In order to achieve this, an interface has been designed which allows the whole underlying structure in a dataset to be visualised, thus avoiding methodological bias in its visualisation (diagrams corresponding to different disciplines or branches of information sciences, such as Entity-Relationship diagrams [68] or class diagrams [157] and the notations already used for them). This interface presents two ways of working: in Classes and Instances modes.

In Classes mode, the interface, given a dataset chosen by the Cultural Heritage specialist (the user of the interface at that moment) and a main class, shows the structural relationships of the selected class with the rest of the classes of the model. This allows the Cultural Heritage specialist to “position” him/herself in one part of the structure of the dataset’s information and to navigate through it. If the specialist wishes, he/she can also access the defined attributes for that class, thus accessing not only a general view of the dataset’s structure but also knowing what information he/she can store in it.

In Instances mode, the interface maintains the design of the previous mode but permits the Cultural Heritage specialist to select a specific instance of the dataset and to navigate through its relationships whilst maintaining information about the structure of the information. If, whilst navigating, he/she finds another instance, this will be accessible. If, on the other hand, no object is instanced, information regarding the corresponding class will be maintained but the object will not be accessible, thus permitting the Cultural Heritage specialist to maintain, at all times, an overall vision of what classes have associated instances. From this interface it is possible to access the values of each instance’s attributes.

Internal Components

Four individual patterns have been selected from level 3 in order to compose our Structure IU proposal:

- Colour assignment: This pattern has been selected to use the colour mechanism in the differentiation of the nature of the classes or instances within the structure of the information. More specifically, Fig. **29** shows how the colour will differentiate the classes of the reference model which is used throughout this research (CHARM [110], explained in detail in Chapter 7), its extended classes, the elements of the structure of the information with a temporal component and those which have a subjective component.
- Additional Information: This pattern has been selected to show additional information about the relations between classes and instances in the Structure IU interface, basically providing information about what type of relationship is present and whether it has a temporal and/or subjective aspect.
- First Focus: This pattern has been selected to offer visual clarity in the presentation of additional information about the relations between classes and instances in the Structure IU interface. When the Cultural Heritage specialist selects a relation, the interface changes its focus to that relation, fading the background in order to highlight the element.
- Row Aggregation: This pattern has been selected in the design of the interface in order to show the structure of the information. Due to the fact that complex and/or profound structure can be presented, requiring a lot of space on the screen, the decision was taken to promote horizontal visualisation, playing with the horizontal scroll in order to access the full hierarchy. This allows the classes of the same level to be maintained together on the screen. Furthermore, in the application of the Row Aggregation pattern, the visualisation of the limits of each row has been discarded, mainly due to reasons of clarity, minimalism in the design and minimisation of visual noise.

Aspects of Use and Interaction

The aim of this interaction unit is to provide the Cultural Heritage specialist with a flexible presentation and interaction mechanism, based on the specialist's reasoning about the structure of the information. Fig. 29, Fig. 30, Fig. 31 and Fig. 32 show a visual prototype. The nominal sequence of steps will consist of the Cultural Heritage specialist selecting a dataset and a main class within it. Then, he/she will have to decide what type of structural information is of interest: attributes, composition and/or association relations. Finally, he/she will be able to decide the colours he/she wants to differentiate the different aspects of the information explained above by using the colour control.

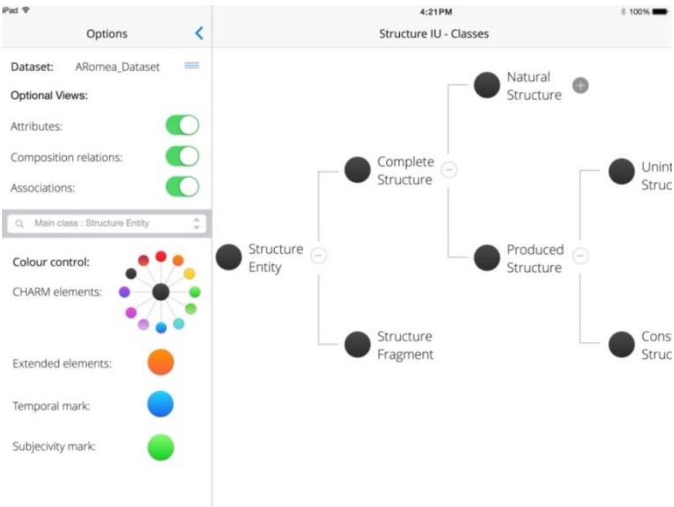

Fig. 29. Structure IU-Classes: the configuration options can be seen on the left.

Fig. 30. Structure IU-Classes: defined attributes for a selected class.

Fig. 31. Structure IU-Classes: an example of the behaviour of the Additional Information and First Focus patterns.

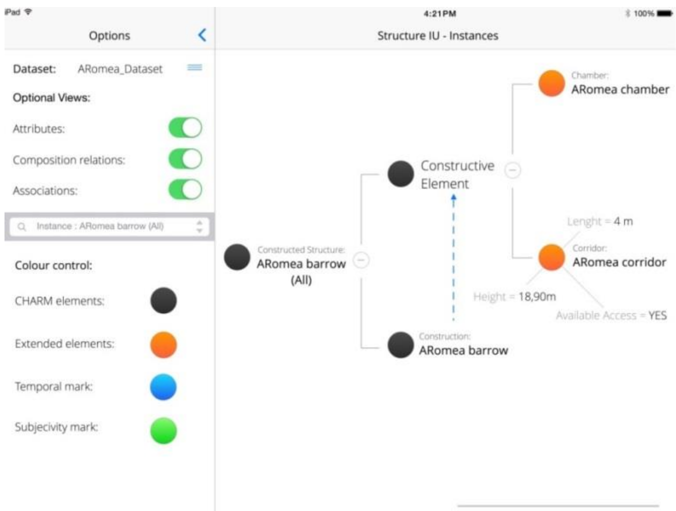

Fig. 32. Structure IU-Instances: the configuration options can be seen on the left.

Once the interface has been configured, the Cultural Heritage specialist can navigate through the underlying structure of the information in the dataset. If an association is selected, as can be seen in Fig. 31, the First Focus and Additional Information patterns will help to know the nature of the association. If a class is selected, access will be provided to its defined attributes. The class hierarchies can be expanded and contracted in order to avoid visual noise in very large and/or deep structures of information and, at any time, a different class can be selected as the main class and the user can resituate him/herself in the structure of the information.

This nominal sequence of steps is identical for instances. Generally, the natural option is to access Structure IU – Classes in order to then select in Structure IU – Instances a specific instance of interest for the Cultural Heritage specialist, once he/she knows the structure of the information in that part of the model. Once selected, he/she will navigate in a similar way to the Structure IU – Classes interface but, this time, accessing the specific values for that instance of the corresponding attributes. The interface in Structure IU – Instances mode can be seen in Fig. 32.

VALUE-COMBINATION IU

The interaction unit Value-Combination IU deals with problems A, B and mainly D (and related with the general challenges 1, 2 and 4) identified previously for the field of Cultural Heritage. In this implementation, we have focused on problem D, which makes reference to the need to detect similarities or differences between the present data, which are shown in values of attributes. In order to do this, an interface has been designed which allows one main class in a chosen dataset to be selected and the groups of instances which form to be visualised according to several values of attributes (up to three combined attributes at one time). This enables the user to search for similarities and differences in the data as it groups the data which have the same values into certain attributes.

Internal Components

Seven individual patterns from level 3 have been selected to compose our Value-Combination IU proposal.

- Size assignment: This pattern has been selected in order to use the size mechanism, associating the size of the elements of the interface to the perception of the size of the groups which the Cultural Heritage specialist forms in the interface by combining values of attributes.
- Colour assignment: This pattern has been selected in order to use the colour mechanism in the differentiation of a specific attribute within the combination of values of the interface. For example, Fig. **33** shows how the colour will differentiate the data present in the dataset by way of instances of Object Fragment according to the material of each fragment of object. This attribute has already been selected to be combined in the rows but it can be highlighted thanks to the colour. It would be possible to choose another attribute which has not been selected previously in order to illustrate it with the colour mechanism.

- Additional Information: This pattern has been selected in order to show additional information about the groups formed by the Cultural Heritage specialist in the interface by combining values of attributes.
- First Focus: This pattern has been selected in order to offer visual clarity in the presentation of additional information about the groups formed by the Cultural Heritage specialist in the interface when combining values of attributes. The specialist selects a group and the interface changes the focus of that element, fading the background in order to highlight the element.
- Row Aggregation: This pattern has been selected in the design of the interface in order to visually organise the categories or intervals of one of the attributes to be combined in the Value-Combination IU interface.
- Column Aggregation: This pattern has been selected in the design of the interface in order to visually organise the values (or their intervals) of an attribute or the classes to which the different instances to be combined belong in the Value-Combination IU interface.
- Set: This pattern has been selected in order to represent the groups formed by the Cultural Heritage specialist when combining values of attributes as interface elements with entities of their own. In this case, a bubble shape has been chosen for the implementation of the Set pattern.

Aspects of Use and Interaction

The aim of this interaction unit is to provide the Cultural Heritage specialist with a flexible presentation and interaction mechanism, based on the specialist combining values of attributes in order to find similarities and differences. Fig. 33 and Fig. 34 show a visual prototype. The nominal sequence of steps will consist of the Cultural Heritage specialist selecting a dataset and a main class within it. Then, he/she will have to decide what attributes are of interest and, by using the colour control, select the colours he/she wishes to use in order to differentiate another attribute or the values which the data presents according to a previously chosen attribute. Finally, he/she will be able to decide what semantics will be implicit in the size of the interface’s elements (a fixed size, according to the number of instances of information belonging to each group, etc.).

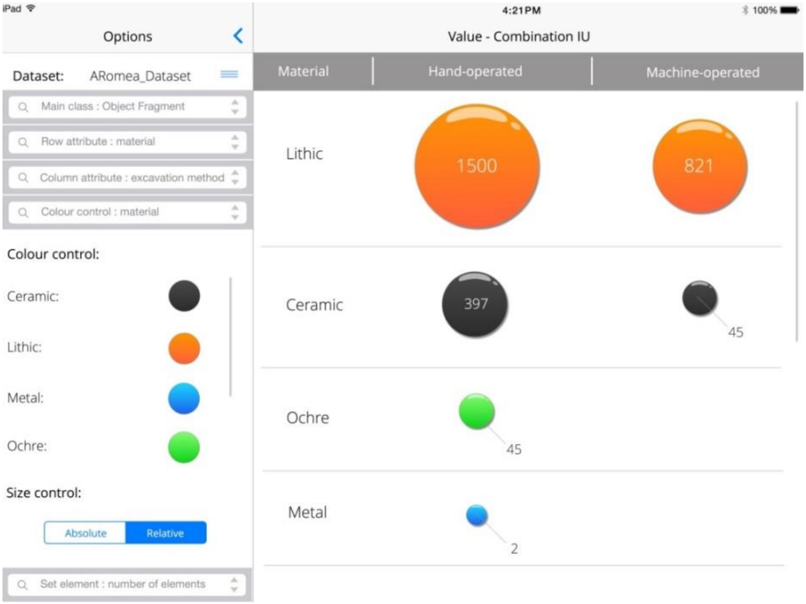

Fig. 33. Value-Combination IU: the configuration options can be seen on the left.

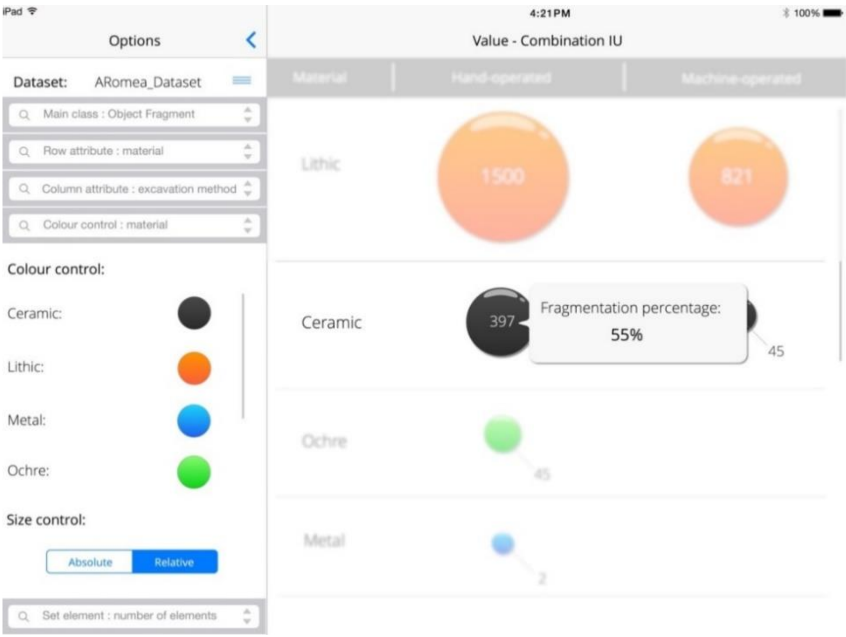

Fig. 34. Value-Combination IU: an example of the behaviour of the Additional Information and First Focus patterns.

CONGLOMERATE IU

The interaction unit Conglomerate IU deals with problems B and D (and related with the general challenges 2 and 4), previously identified for the field of Cultural Heritage. In this implementation, we have focused on problem B, which makes reference to the need for a presentation and interaction mechanism which allows for the simple and agile grouping of the data present in the dataset according to one criterion, which the Cultural Heritage specialist can vary. In order to do this, an interface has been designed which allows one main class in a chosen dataset to be selected and the groups of instances which are formed according to a selected criterion to be visualised. In this way, the dynamism in the action of grouping is maintained, due to the fact that the Cultural Heritage specialist can change the grouping criterion with a simple action (typically a click).

Internal Components

Five individual patterns from level 3 have been selected in order to compose our Conglomerate IU proposal:

- Size assignment: This pattern has been selected in order to use the size mechanism, associating the size of the elements of the interface to the perception of the size of the groups which the Cultural Heritage specialist forms in the interface according to the selected criterion.
- Colour assignment: This pattern has been selected in order to use the colour mechanism in the differentiation of the groups formed according to the main criterion or to another which is applicable to the same main class.
- Additional Information: This pattern has been selected in order to show additional information about the groups which the Cultural Heritage specialist forms in the interface according to the selected criterion.
- First Focus: This pattern has been selected in order to offer visual clarity in the presentation of additional information about the groups formed by the Cultural Heritage specialist in the interface according to the selected criterion. The specialist selects a group and the interface changes the focus of that element, fading the background in order to highlight the element.
- Set: This pattern has been selected in order to represent the groups formed by the Cultural Heritage specialist according to the selected criterion as interface elements with entities of their own. In this case, a bubble shape has been chosen for the implementation of the Set pattern.

Aspects of Use and Interaction

The aim of this interaction unit is to provide the Cultural Heritage specialist with a flexible presentation and interaction mechanism, based on the formation of groups of instances of a dataset in an agile and rapid manner. Fig. 35 and Fig. 36 show a visual prototype. The nominal sequence of steps will consist of the Cultural Heritage specialist selecting a dataset and a main class within it. Then, he/she will have to decide which grouping criterion is of interest and, by using the colour control, select the colours he/she wishes to use in order to differentiate the groups formed according to the main criterion of another attribute of the main class. Finally, he/she will be able to decide what semantics will be implicit in the size of the interface's elements (a fixed size, according to the number of instances of information belonging to each group, etc.).

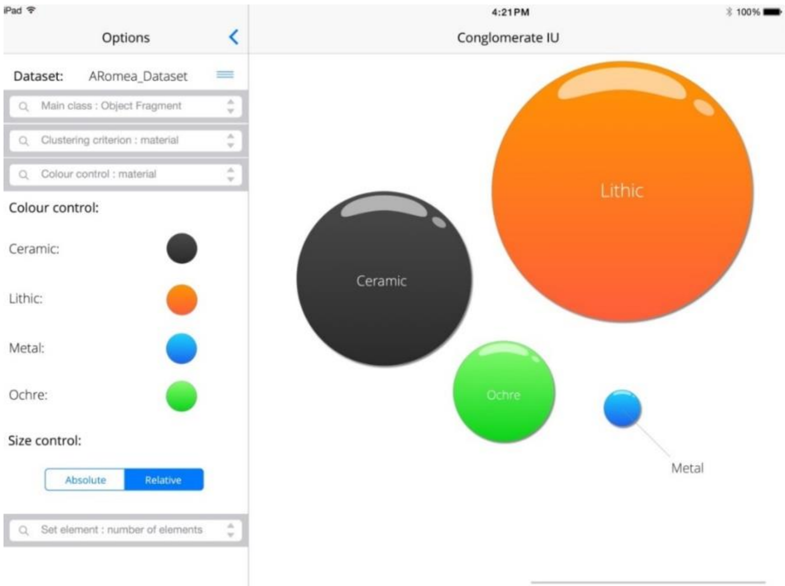

Fig. 35. Conglomerate IU: the configuration options can be seen on the left.

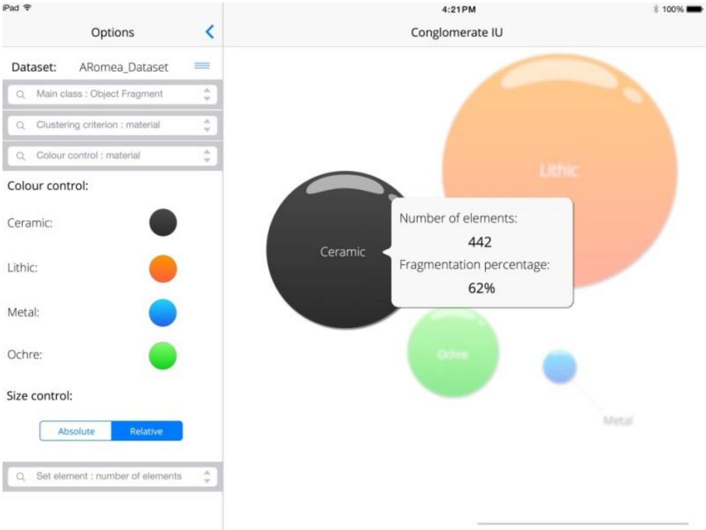

Fig. 36. Conglomerate IU: an example of the behaviour of the Additional Information and First Focus patterns.

TREND IU

The interaction unit Trend IU deals with problems C and D (and related with the general challenges 3 and 4), previously identified for the field of Cultural Heritage. In this implementation, we have focused on Problem C, which makes reference to the need for a presentation and interaction mechanism which allows different levels of importance in the information to be dealt with. Often, this importance is not possible to detect by studying the structure of the information or the groups of which it consists. Rather, we need a mechanism which allows us to observe tendencies in the datasets and subsets in order to then determine what roles each part of the information plays in a given dataset. Therefore, an interface has been designed which allows a main class in a chosen dataset to be selected and, optionally, a second dataset which maintains the structure corresponding to that main class and its relations. This secondary dataset is, typically, a previous or later version of the first one or a dataset which contains data belonging to another source which shares the same information structure as the main dataset. Once a dataset and a main class have been selected, the Cultural Heritage specialist can select the attributes about which he/she wishes to observe tendencies and visualise the groups of instances and their importance in the dataset.

Internal Components

Five individual patterns from level 3 have been selected in order to compose our Trend IU proposal:

- Size assignment: This pattern has been selected in order to use the size mechanism, associating the size of the elements of the interface to the perception of the size of the groups which the Cultural Heritage specialist forms in the interface according to the selected attributes.
- Colour assignment: This pattern has been selected in order to use the colour mechanism in the differentiation of the groups formed according to a third attribute belonging to the same main class.
- First Focus: This pattern has been selected in order to offer visual clarity in the presentation of additional information regarding the tendency in the data of a specific subgroup. The specialist selects an element and the interface changes the focus of that element, fading the background in order to highlight the specific element and its tendencies (lines which mark whether the data with that value of attribute have grown or decreased in number, along with the evolution if we are comparing with another, secondary, dataset).
- Column Aggregation: This pattern has been selected in the design of the interface in order to visually organize the data and its tendencies belonging to two different datasets (main and secondary).
- Set: This pattern has been selected in order to represent the groups formed by the Cultural Heritage specialist according to the attributes selected as interface elements with entities of their own. In this case, a bubble shape has been chosen for the implementation of the Set pattern. If it is not possible to view the bubble on the screen, it will vary, becoming an element in the shape of a drop in order to indicate that the position of the group corresponds to a value outside of the screen (by scrolling and accessing the data it will revert to the bubble shape).

Aspects of Use and Interaction

The aim of this interaction unit is to provide the Cultural Heritage specialist with a flexible presentation and interaction mechanism, based on the detection of tendencies in the data and on the comparison of two versions of the same dataset or of datasets which share the same structure as far as the level of importance of the data is concerned. Fig. 37, Fig. 38 and Fig. 39 show a visual prototype. The nominal sequence of steps will consist of the Cultural Heritage specialist selecting a dataset and a main class within it. If his/her aim is to compare two datasets, he/she can select the secondary dataset. Then, he/she will have to decide which attributes are to be used as information aggregates in order to observe the tendencies and, by using the colour control, select the colours he/she wishes to use in order to differentiate the groups formed according to the attributes chosen or to another attribute belonging to the main class. Finally, he/she will be able to decide what semantics will be implicit in the size of the interface's elements: a fixed size, according to the number of instances of information belonging to each group, etc. In this case, in Trend IU the decision has been made to enable the size control to be deactivated in an attempt to minimise visual noise in the interface.

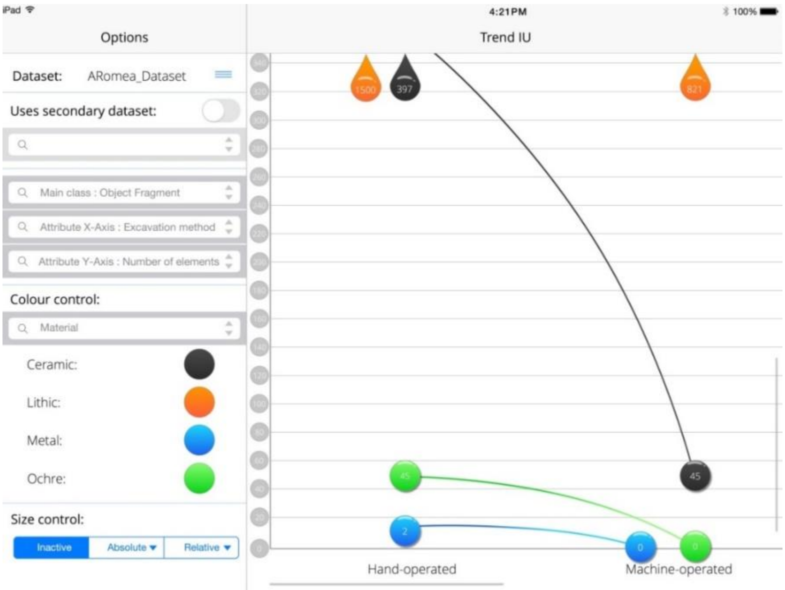

Fig. 37. Trend IU: the configuration options can be seen on the left.

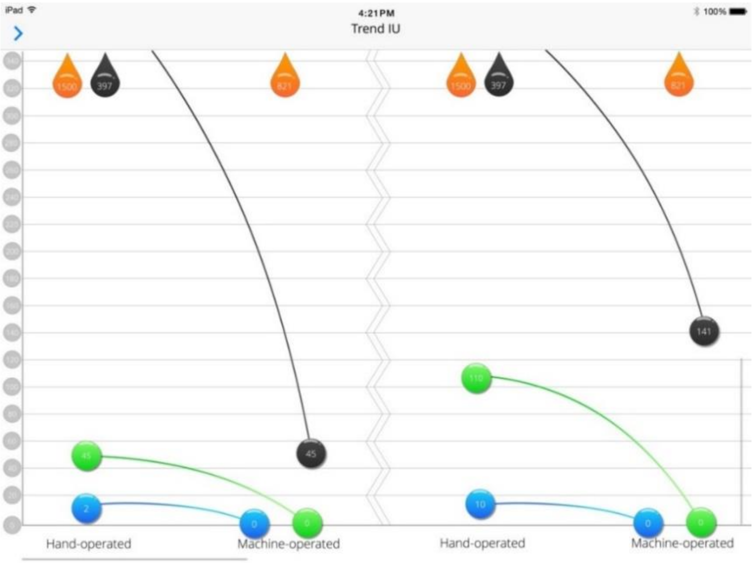

Fig. 38. Trend IU: an example of behaviour for two given datasets.

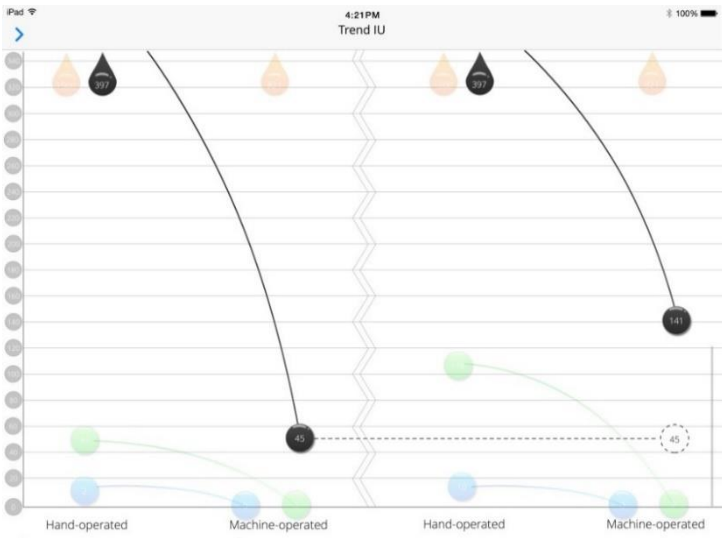

Fig. 39. Trend IU: an example of the behaviour of the First Focus pattern to assist in the detection of tendencies in two given datasets.

TIMELINE IU

The interaction unit Timeline IU deals with problem E (and related with the general challenge 5), previously identified for the field of Cultural Heritage, which makes reference to the need for a presentation and interaction mechanism which allows the temporal facet of the data to be reflected in a way which is adapted to that carried out in Cultural Heritage, with its own problems such as the dispersion of temporal data. In order to do this, an interface has been designed which allows a main class in a chosen dataset to be selected, along with one of its specific instances. Optionally, it is possible to select a second class and an instance belonging to it. From these classes and instances, the attributes defined as Time data type or temporal associations [144] according to the structure of the dataset's information will be uploaded into the interface. The Cultural Heritage specialist will be able to add the attributes which he/she wishes to visualise in the Timeline IU interface.

Internal Components

Four individual patterns from level 3 have been selected in order to compose our Timeline IU proposal:

- Colour assignment: This pattern has been selected in order to use the colour mechanism in the differentiation of the temporal attributes which are visualised in Timeline IU.
- Additional Information: This pattern has been selected in order to show additional information about each interface element present in Timeline IU.
- Scale Relation: This pattern has been selected in order to visually reflect the correspondence between the visual timeline of reference and the set of values of a temporal attribute. As many temporal attributes from the same main class or from the selected secondary class can be added as desired. The Scale Relation pattern will offer a timeline for each attribute, maintaining the vertical visual connection between the corresponding temporal periods in order to favour comparison and temporal reasoning.
- Fuzzy control: This pattern has been selected in order to represent how diffuse the time intervals are in which each value of each attribute is represented. The interface element which represents each value will vibrate horizontally more or less strongly depending on the degree of diffusion of the value: for more specific values, more vibration, for more diffuse values, less vibration. The strength of the vibration determines the extent of the temporal interval in which we are situated.

Aspects of Use and Interaction

The aim of this interaction unit is to provide the Cultural Heritage specialist with a flexible presentation and interaction mechanism, based on the temporal aspects of the data. Fig. 40, Fig. 41 and Fig. 42 show a visual prototype. The nominal sequence of steps will consist of the Cultural Heritage specialist selecting a dataset and a main class within it along with an instance to be represented. If he/she wishes, he/she can select a second class and an instance from it. Then, he/she will have to decide which temporal attributes are to be represented and, by using the colour control, select the colours he/she wishes to use in order to differentiate the values of those attributes.

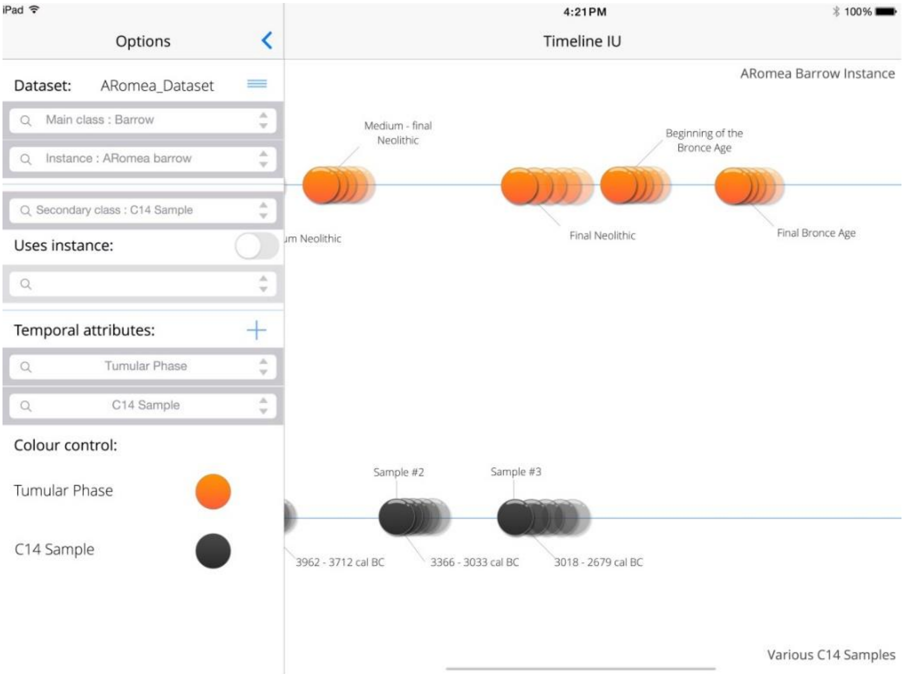

Fig. 40. Timeline IU: the configuration options can be seen on the left.

The sequence explained above gives rise to two sub-cases. Therefore, the difference in the visualisation of these two sub-cases contemplated by the interface should be noted:

- In sub-case 1, the Cultural Heritage specialist chooses the secondary class but not an instance from it: the Cultural Heritage specialist can select a main class and an instance upon which to visualise temporal information. However, he/she can select a secondary class without selecting an instance.

In this case, a timeline will be visualised with values of the attributes corresponding to the selected instance which belongs to the primary class and, if an attribute of the secondary class has been selected for visualisation, all the values associated to the primary instance will be shown without taking into account to which secondary instance they are associated. In Fig. 40, we can observe an example: "C14 Sample Valorization" has been selected as the secondary class but no instance is associated to it; The attribute "C14 Date result" belongs to the "C14 Sample Valorization" class. Therefore, the timeline shows all the samples which exist associated to the instance of the main class (associated to ARomea Barrow), without taking into account to which specific instance of "C14 Sample Valorization" they belong. In order to indicate that they belong to different instances (in this case to different instances of "C14 Sample Valorization") information is maintained regarding the name of the instance (Sample #1, Sample #2). There is the possibility of expanding the attribute's values via an icon under its name (see Fig. 42). By selecting this option, each one of its instances and their information is shown separately. This visualisation allows for a synthetic view of the attribute associated to the secondary class while maintaining structural coherence and providing the Cultural Heritage specialist with information regarding the number of existing instances belonging to the secondary class.

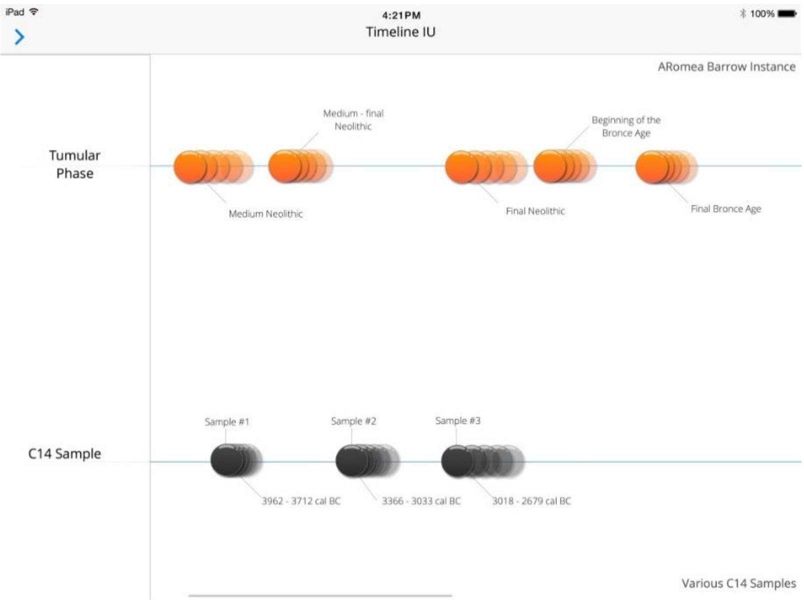

Fig. 41. Timeline IU: an example of behaviour with two timelines.

- In sub-case 2, the Cultural Heritage specialist chooses a secondary class and instance: a timeline is visualised with values of the attributes corresponding to the secondary instance selected, according to the model of the main class. Therefore, the names of the instances in the timeline shall not be shown and neither will there be an icon allowing the timeline to be expanded.

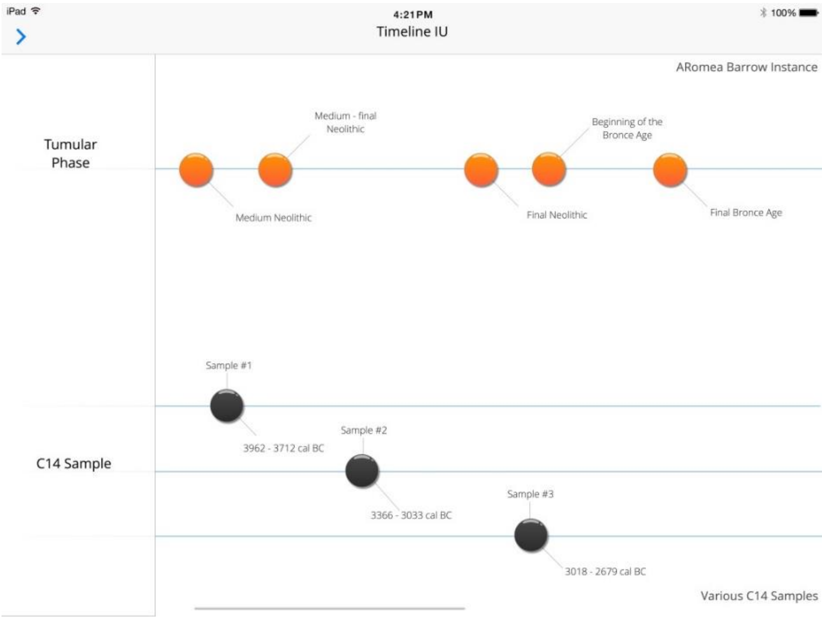

Fig. 42. Timeline IU: an example of behaviour with two timelines in sub-case 2.

GEOGRAPHIC AREA IU

The interaction unit Geographic Area IU deals with problem E (and related with the general challenge 5), identified previously for the field of Cultural Heritage and which makes reference to the need for a presentation and interaction mechanism which allows the geographic facet of the data to be reflected in a way which is adapted to that carried out in Cultural Heritage, with its own problems, such as the integration of different systems of geographic location. Therefore, an interface has been designed which allows a main class in a chosen dataset to be selected. This class must have absolute geographic locations associated to it. Optionally, it is possible to select a second class which also has absolute geographic locations associated to it. From these classes, the geographic locations of all the instances present in the dataset corresponding to the selected classes will be uploaded onto the interface. The Cultural Heritage specialist will be able to vary the system of coordinates, the centre of the map and the level of zoom in order to adapt the visualisation to his/her needs and the characteristics of the screen.

Internal Components

Three individual patterns from level 3 have been selected in order to compose our Geographic Area IU proposal:

- Colour assignment: This pattern has been selected in order to use the colour mechanism in the differentiation of the classes or sub-classes to which the instances visualised in Geographic Area IU belong, allowing the user to visualise instances of a different nature on the same map.
- Additional Information: This pattern has been selected in order to show additional information about each instance represented, such as the name or the precise geographic coordinates.
- First Focus: This pattern has been selected in order to offer visual clarity in the presentation of additional information about the instance or a set of instances. The Cultural Heritage specialist selects an instance and the interface changes the focus to that element, fading the background in order to highlight the specific element.

Aspects of Use and Interaction

The aim of this interaction unit is to provide the Cultural Heritage specialist with a flexible presentation and interaction mechanism, based on the geographic aspect of the data. Fig. 43 shows a visual prototype. The nominal sequence of steps will consist of the Cultural Heritage specialist selecting a dataset and a main class within it. If he/she wishes, a second class can be selected. Then, he/she will have to adjust the characteristics of the map visualisation and, by using the colour control, select the colours he/she wishes to use in order to differentiate the values of those attributes. It should be noted that the ultimate aim of this interaction unit is not to serve as an interface for calculation in geographic matters but rather to assist the Cultural Heritage specialist in spatial reasoning. For this reason, the common functions of geographic information systems or similar applications have not been included. Rather, only the functions which allow us to represent the data present in the dataset in its absolute locations and to identify them by their nature have been included. These two components, according to our interviews presented in Chapter 5, are the first questions which the Cultural Heritage researcher needs to ask of the data in order to outline his/her analysis of the data, to test research hypotheses and to make decisions based on that data. Later, the complex calculations on geographic matters can be carried out in applications which are more specifically oriented towards geographic calculations.

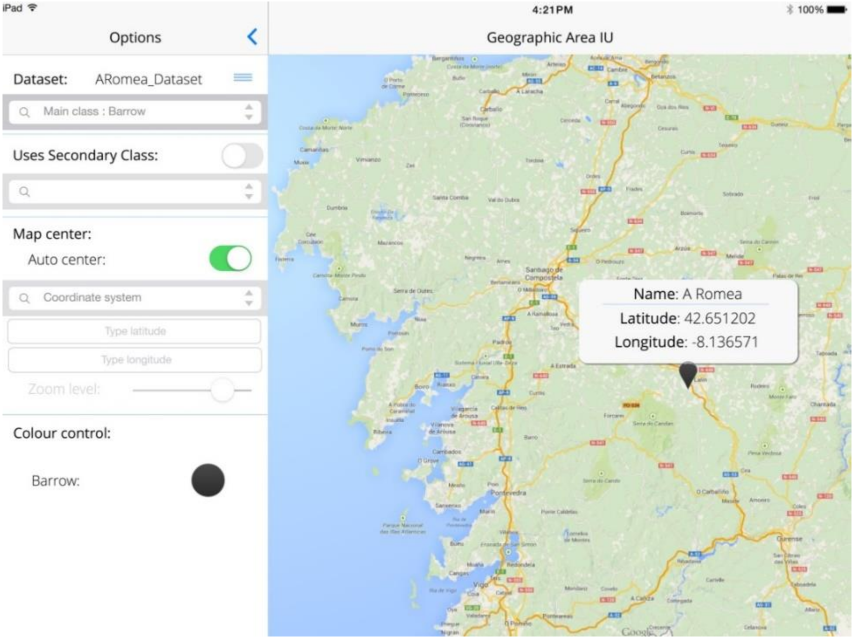

Fig. 43. Geographic Area IU: the configuration option can be seen on the left.

SEQUENTIAL IU

The interaction unit Sequential IU deals with problem F (and related with the general challenge 6), identified previously for the field of Cultural Heritage and which makes reference to the need for a presentation and interaction mechanism which allows sequential data or data organised "by levels" to be explicitly included. Therefore, an interface has been designed which allows a main class in a chosen dataset to be selected which will constitute the central element organised by sequential layers. In other words, all the instances belonging to the chosen main class will be visualised in the form of a sequence. Furthermore, the interface will allow the Cultural Heritage specialist to select a second class which must have a direct association with the chosen main class and show additional information about it. Optionally, it will also be possible to visualise in the interaction unit specific aspects such as typologies of the main class or associated temporal phases. The Cultural Heritage specialist will be able to select colour options in order to adapt the visualisation offered, due to the fact that it is possible that the sequences presented with several instances will need differentiating elements.

Internal Components

Four individual patterns from level 3 have been selected in order to compose our Sequential IU proposal:

- Colour assignment: This pattern has been selected in order to use the colour mechanism in the differentiation of the temporal phases to which the instances visualised in Sequential IU belong, as well as the valorization groups which the Cultural Heritage specialist forms of the sequential elements.
- Row aggregation: This pattern has been selected in the design of the interface in order to visually organise the sequential levels of the instances presented. Each sequential level is organised into a row, although its limits are not marked on the interface so as not to create visual noise in interfaces with a high number of instances to represent.
- First Focus: This pattern has been selected in order to offer visual clarity in the presentation of additional information about an instance or a set of instances. The Cultural Heritage specialist selects an instance and the interface changes the focus to that element, fading the background in order to highlight the specific element. This is also applicable to sets of instances which function as such in the sequential representation.
- Set: This pattern has been selected in order to represent the groups formed by the Cultural Heritage specialist, which are already stored in the dataset, as elements of the interface with their own entities. In this case, a way of grouping instances (they may be instances belonging to the same or to different sequential levels) has been chosen which superimposes a transparent rectangular element, thus grouping together the instances which fulfil the criterion chosen by the Cultural Heritage specialist.

Aspects of Use and Interaction

The aim of this interaction unit is to provide the Cultural Heritage specialist with a flexible presentation and interaction mechanism, based on the sequential aspect of the data. Due to the fact that the nature of the data to be shown sequentially by layers may be extremely different, the decision was taken to define the interaction unit in an abstract way, though illustrating the aspects of its use and interaction with a specific case of application (inserted into the full proposal defined in this doctoral thesis). The case of application is situated in the field of stratigraphic information in Archaeology. It deals with information relating to the study of archaeological layers or levels of occupation of an archaeological site. These layers are a fundamental source to establish the context of the site and its relative chronology, from which, in turn, the sequence of cultural and temporal evolution is obtained [203]. The selection of this case of application to illustrate Sequential IU can be put down to two fundamental reasons:

- The visualisation of stratigraphic information in Archaeology presents as yet unsolved challenges, which were necessary to deal with from the point of view of interaction and presentation solutions [198].
- The case study presented as the central validating theme of this doctoral thesis showed necessities regarding the sequential visualisation of specific stratigraphic information, which links the scenario of application with the interaction unit selected in order to resolve the problems detected.

Figures from Fig. 44 to Fig. 48 show a visual prototype of the use of Sequential IU for the case of stratigraphic visualisation in Archaeology. The nominal sequence of steps will consist of the specialist selecting a dataset and a main class within it. The instances of this main class will be those represented sequentially. Therefore, they must contain associated sequential information. In this case of application, it will be a class which conceptually represents the strata of the stratigraphic sequence. If he/she wishes, the user will be able to select a second class with related information. Then, he/she will have to decide if it is of interest to visualise specific aspects of the main sequenced class, which must be defined ad hoc for each application of Sequential IU, but which abstractly respond to typologies within the sequenced elements and to temporal phases associated to them, among other additional information. In this specific case, the Cultural Heritage specialist will be able to select if he/she wishes to visualise typologies of relations between the strata defined within the stratigraphic sequence, temporal phases or evaluations made by experts on those strata or their sequence. These evaluations correspond to groupings of some strata of the sequence carried out by the expert in Cultural Heritage. These groupings of strata generally correspond to a scientific interpretation of the function, age, or other aspects of these strata. Furthermore, the colour control allows the user to select the colours he/she wishes in order to differentiate the associated temporal phases.

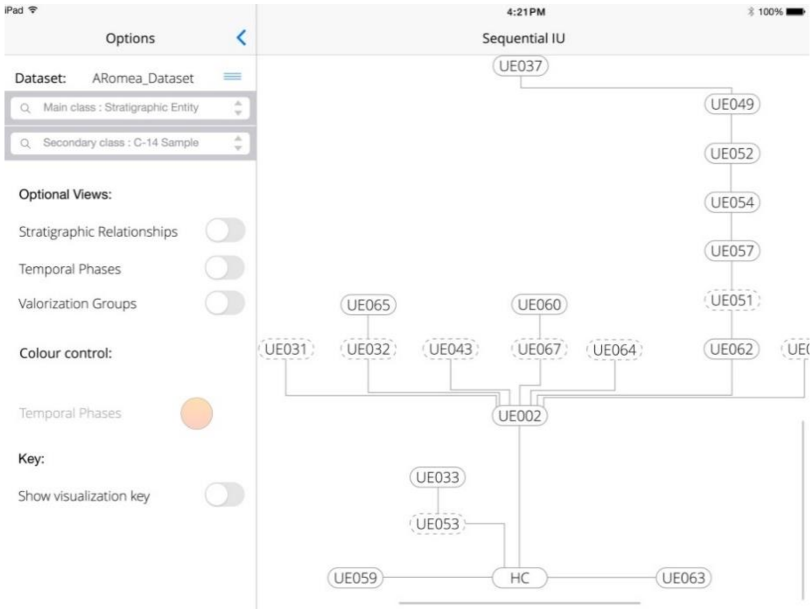

Fig. 44. Sequential IU for the visualisation of stratigraphic sequences: the configuration options can be seen on the left.

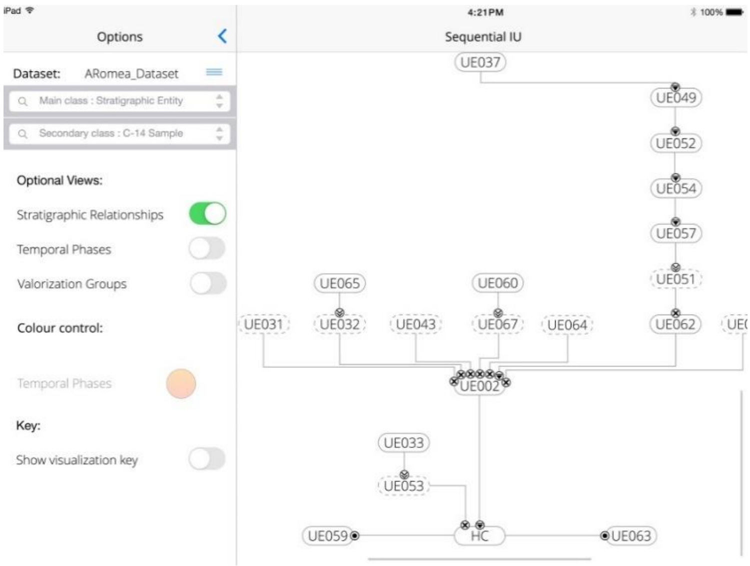

Fig. 45. Sequential IU for the visualisation of stratigraphic sequences with relations between visualised strata.

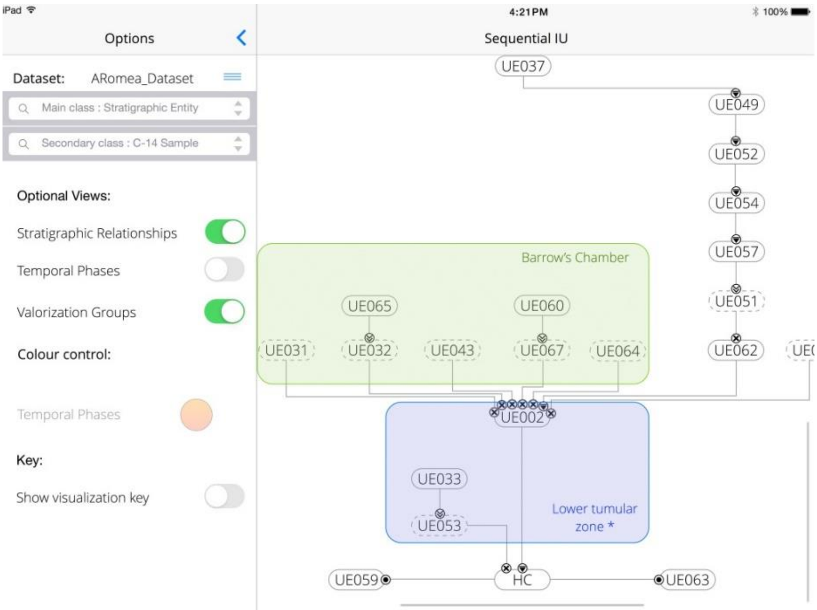

Fig. 46. Sequential IU for the visualisation of stratigraphic sequences with relations between strata and the evaluations of experts visualised.

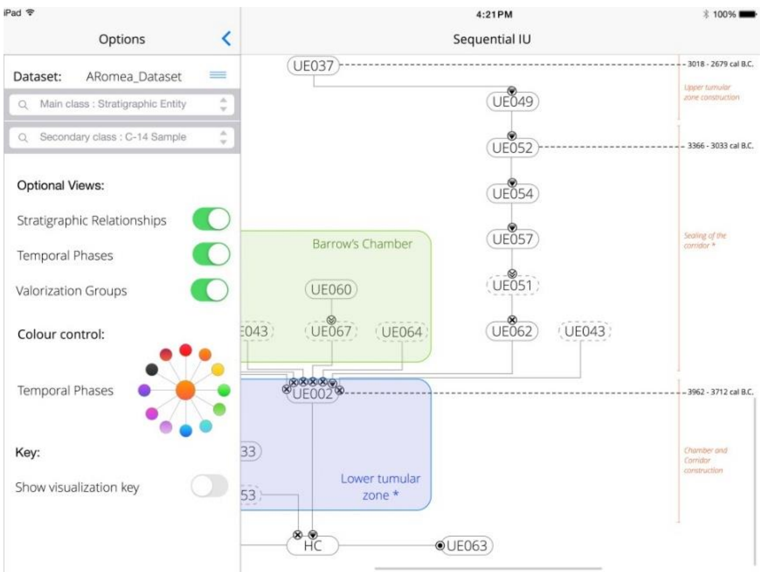

Fig. 47. Sequential IU for the visualisation of stratigraphic sequences with relations between strata, as well as the associated temporal phases and the evaluations (both made by experts) visualised.

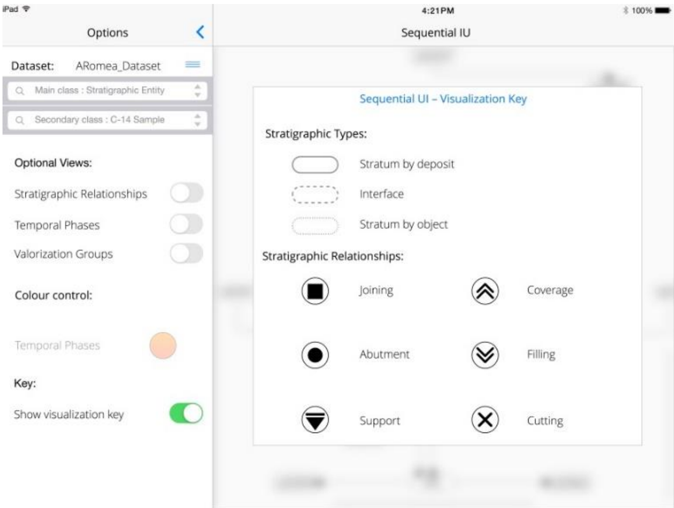

Fig. 48. Sequential IU for the visualisation of stratigraphic sequences: a view of the key explaining the semantics contained in the different symbols of the diagram.

Over the course of this section, the different interaction units present in the hierarchy of interaction patterns have been described, along with the individual patterns from level 3 selected for the specific implementation of each interaction unit. The implementation of the hierarchy of patterns proposed as a solution throughout this chapter allows a complete interaction solution to be drawn up for the problems of presentation and interaction of data identified in software assistance in the field of Cultural Heritage. It should be noted, however, that the organisation of the proposed solution into levels and its possibility of reuse confer upon the proposal described in this chapter a high degree of flexibility, being able to develop alternative designs which deal with other problems (or the same ones with other implementation mechanisms) in Cultural Heritage in particular, as well as to redefine the problems and their spheres of application to other fields.

Conclusions

This chapter has presented an analysis of the formal representation techniques for software presentation and interaction which are currently in existence. This overview of existing studies, in addition to allowing us to detect the need (which arose in the context of this research) for formally representing presentation and interaction for software assistance in Cultural Heritage, led us to identify series of challenges which are independent of the field regarding the formal representation of presentation and interaction in software assistance contexts for data analysis and decision making.

In this context, a solution based on the pattern concept —more specifically on the definition of a hierarchy of RIA (Rich Internet Applications) patterns— has been proposed oriented towards software assistance to data analysis and decision making. The proposed solution is organised into a three-level hierarchy in order to facilitate its abstract handling and the reuse of the individual solutions proposed. The hierarchy of patterns has been defined in an abstract way, in order to, later describe its possible implementation to resolve problems identified in the field of Cultural Heritage.

The validation of this proposal is described in Chapter 11, which deals with the support of presentation and interaction for the case study of A Romea. This case study validates the complete conceptual framework presented in this research and allows an evaluation and validation of the conceptual framework to be carried out with real users (in our case specialists in Cultural Heritage). Therefore, Chapter 12 describes how a subset of the interaction solution presented in this chapter has been implemented as a software demonstrator, being empirically validated with users from the field of Cultural Heritage.

Finally, the scientific contributions presented in this chapter corresponding to the area of the formal representation of software presentation and interaction must be highlighted. On the one hand, a complete proposal, which is independent of the field of application, has been drawn up, based on RIA patterns for the representation of presentation and interaction in applications whose objective is the software analysis of data and decision making. Later, a proposal has been specified for the field of Cultural Heritage, a field in which software presentation and interaction still lacks a corpus of application in data analysis and decision making assistance. In addition, the specific proposal of implementation of the interaction unit Sequential IU in Cultural Heritage constitutes, as has been seen throughout the study of previous research [199] and during this chapter, a novel solution for stratigraphic visualisation, which is cognitively adapted to the needs of the specialist in Cultural Heritage. Thus highlighting the resolution of problems which emerge regarding the non-separation between the material dimension and the interpretative dimension of the stratigraphic information, a problem which was detected in our previous research [198].

The research carried out in the light of the doctoral thesis in this area opens up future lines of research. The most immediate one corresponds to the more in-depth validation of the interaction proposal made, with more case studies in different fields. As a complementary aspect, the development of libraries or interface components which implement the proposed patterns is suggested, for the better and simpler development of software applications based upon them. Therefore, we believe that it is possible to detect new RIA patterns for software assistance to data analysis and the definition of guidelines to show what combinations of patterns are appropriate for each type of user, from the field of application or from the tasks to be optimised. Finally, an interesting line of research is the connection between the defined patterns and the cognitive processes which they assist and which are dealt with throughout this research. An emerging line of research is the in-depth study of this relation and the use of metric detection in order to evaluate the interaction proposal for software assistance to data analysis. All of this will be dealt with in Chapter 14.

Chapter 10: Integration, Interoperability and Consistency between Framework Models

Good information architecture makes users less alienated and suppressed by technology. It simultaneously increases human satisfaction and your company's profits. Very few jobs allow you to do both at the same time, so enjoy. -Jakob Nielsen

Introduction

A software system is not a conceptually one-dimensional artefact. The development of any software system implies that its different aspects work in a horizontal space, a fact which must be taken into account. These aspects are parts of a common metamodel of the system, which requires specific models in order to define (or prescribe) how the system supports the proposed requirements, fulfilling the objectives defined for it. It should be remembered at this point that the main objective of this research is to prove the hypothesis that **it is possible to significantly improve knowledge-generation processes in Cultural Heritage by way of by way of providing software assistance to the user with knowledge extraction and information visualization techniques**. Therefore, a conceptual framework in three parts (subject matter, cognitive processes and presentation and interaction mechanisms) has been proposed as a solution. This proposal has given rise to three conceptual metamodels which reflect these three aspects of the framework in an independent manner. In order to achieve the established objective, the framework must have an internal consistency, allowing the relations which exist between the three parts identified to provide assistance in this way to the Cultural Heritage user to be expressed. This makes it necessary to formally define the connections between the models, as well as the possibilities for interoperability which exist between the three models defined. This chapter shall deal with how the necessary conceptual mechanisms have been defined and designed in order to formally express the internal connections in the framework, as well as the interoperability which exists between them.

Within the field of Software Engineering, there are several approaches for the modelling of the different perspectives (or their combinations) in a software system. For example, approaches based on requirements [16, 86, 303], related with the data or the field it concerns [166] or approaches oriented towards objects [219, 231, 233]. All of these approaches also imply different notations of modelling.

In this context, it is in the field of Model-Directed Engineering (MDE) where, over the course of recent years, the need to formally express relations between models (created during the process of the development of information systems) regarding different views of the same software system has been identified. There are different techniques to express this relation between models: *model weavings*, *model mappings*, pivot metamodels and pivot ontologies, among others. All of these techniques have been applied successfully, especially in the reduction of the conceptual distance between the definition of the business areas of large companies and their related software systems [266, 285] or in complex integrations of requirements and functional models [186, 317].

Considering the choice of specific modelling approaches in order to express the different perspective of the same software system, it is necessary to define an integration mechanism which enables interoperability to these perspectives in order to compose a unique conceptual model of the system. This mechanism will provide a specific reference to deal with software creation tasks directed by models (MDE), such as automatic compilation, the verification of models, the evolution of models, the execution of metrics and model analysis operations, etc.

In particular, the proposal outlined here deals with the specific field concerning this doctoral thesis from this perspective: software systems created in order to assist users to the generation of knowledge. More specifically, our framework focuses this assistance on offering and applying adapted visualisation techniques according to the model defined by Chen [67] (see Chapter 2) and our later proposal (see chapters of Part III), and taking into account the implications on knowledge extraction techniques which this assistance may have. Due to the growth in the application of software-assisted knowledge generation systems in scientific disciplines, it is necessary to deal with the formal expression of the different modelling perspectives which are present in these systems. The expression of the relations between models allows the generation of scientific knowledge to be managed at a high level of abstraction, which implies fully dealing with the software-assisted knowledge generation process. For example, it is possible to capture the relation between available scientific data, the information or results produced and the cognitive processes involved in producing them. If we do not take into account these relations, it is extremely difficult to obtain data regarding traceability in this process or to replicate each research in order to validate or reuse the work done.

With this objective in mind, this chapter analyses the necessities as far as internal consistency and interoperability of software assistance systems for the generation of knowledge are concerned. Later in the chapter, an interoperability framework (Pastor et al. 2013) will be taken into account in order to propose a specific metamodel permitting the integration of different modelling perspectives which intervene in software assistance systems for the generation of knowledge. It should be noted that the integration metamodel defined will later be used in a real scenario: the specification of relations between models of the three different perspectives of the proposed framework in this doctoral research, being validated by their implementation and application in a case study in chapters 11 and 12.

Expressing Connections between Models

As was defined in Chapter 2, knowledge generation has been defined by many authors as a model formed by levels or layers from the raw data to levels of higher abstraction (knowledge, wisdom, etc.). In all of these models, the transition from one level to the next passes through the application of cognitive processes. Over the course of previous chapters, we have defined how the field which concerns us and the subject matter to which the data we have belongs can be conceptually expressed (Chapter 7), how to deal with and characterise the cognitive processes which take place in the generation of knowledge (Chapter 8) and, finally, how to formally express the data presentation and interaction patterns which favour and assist to the generation of knowledge in the field of Cultural Heritage (Chapter 9).

The three modelling perspectives mentioned above constitute the three parts of our framework-solution and must be correctly integrated with the aim of offering assistance to users in the generation of knowledge, independently of the chosen field of application (in our case that of Cultural Heritage). Thus, we can formally express the relations between the subject matter in which knowledge will be generated and cognitive processes, being able to integrate scientific data with the reasoning processes involved in the generation of knowledge. In the same way, we can formally express the relations between the aforementioned subject matter, the cognitive processes and the recommended mechanisms for presentation and interaction. Thus, it is possible to recognise, for example, that certain scientific results have been obtained by comparing (having carried out the cognitive process) two sets of data and/or specific values and to offer adapted visualisation patterns.

This need to formally express the relations between the models involved has previously been identified, particularly in areas associated with *Model-Driven Engineering* (MDE) [11, 32, 76], as well as in software development for software-assisted knowledge generation [102]. However, the providing of software assistance to knowledge generation has not been dealt with from an interoperability perspective based on models (*model-driven interoperability*). The formal expression of the relations between the models which take part in the process of software systems development is one of the main objectives of existing interoperability techniques. Therefore, we believe that this perspective allows the relations between models in the specific case of software-assisted knowledge generation to be expressed.

In this context, we have adopted the definition of "interoperability" as "the ability of two or more systems or components to exchange information and to use the information that has been exchanged" [248]. When the information exchanged is represented by models, we refer to interoperability based on models (*model-driven interoperability*). Thus, the exchanged information contains the relations between the different perspectives involved in a specification of the software system. In other words, models are used to represent the different points of view and their connections via interoperability techniques. There are numerous different techniques and approaches to formally express bidirectional relations between models.

Taking the existing literature on *model-driven interoperability* as a basis, we have identified some studies of special relevance which deal with the expression of relations between models representing different perspectives:

The approach taken by El Hamlaoui [82], for example, expresses the connections between models with a metamodel of correspondences. However, this approach presents a multi-user definition. In other words, different users interact with different perspectives of the same software system. In our case, though, the same user profile interacts with all the perspectives defined in the system. For example, several researchers (though always with a single user profile) interact with all the perspectives of the software assistance system in order to carry out knowledge generation tasks. Other solutions in existence, such as the Capella tool [242] —based on the Arcadia method [89]—, express the connections between models from an interoperability point of view directed by models. However, this approach is designed to provide support for industrial processes and not for assistance to the generation of knowledge. More examples of studies on interoperability can be found in the detailed review carried out by Pastor [232].

Furthermore, a significant number of authors have highlighted the need for a combination of techniques with the aim of improving results or confronting the different needs which arise. Some good examples include the uses of UML profiles for modelling specific perspectives of a system [266], the use of ad hoc processes based on diagrams of characteristics in order to find and represent the relations between models [312] and examples of the application of combined interoperability techniques with the aim of transforming one model to another [75, 285]. We can also find similar examples applied to the field of knowledge management, expressing interoperability between databases [254].

As can be seen in all these studies, there are many techniques to express the relations between models of different perspectives from an approach based on model-directed interoperability. However, they have not been applied to the field of software-assisted knowledge generation. Due to the existence of an abstract framework [232], which allows us to evaluate the different techniques and artefacts of interoperability (independently of the specific techniques and technology applied), our proposal consists of taking this framework as a reference point in order to design a mechanism which allows relations between models in software-assisted knowledge generation systems to be formally expressed. In our proposal, Chen's proposal [67] is adopted as the method of software assistance, offering adapted visualisation patterns.

The following sections of this chapter describe the work carried out in this respect, presenting the different parts of the framework in terms of interoperability. This gives rise to a double contribution: (1) a general solution by way of an integration metamodel in order to formally express the relations between the models present in software-assisted knowledge generation systems and (2) a full application and implementation of the proposal in the framework presented for the field of Cultural Heritage, which will be developed in the Chapter 11 entitled "Analytical Validation".

Our Approach Based on Interoperability

As has been seen in previous chapters and following Chen's foundation work [67], the assistance given to users in the generation of knowledge is materialised in our framework-solution in recommendations through adapted presentation and interaction patterns. According to the framework described by Chen and our own later proposal, there are three important aspects in any software-assisted knowledge generation system: the subject matter upon which the users will generate knowledge, the cognitive processes carried out by these users and the adapted presentation and interaction proposals which the system must offer. In order to express these three aspects, different modelling solutions can be found. As we have seen over the course of Part III, three metamodels have been created to represent these aspects: the subject model (named SM in this chapter), the cognitive processes model (named PCM in this chapter) and the interaction model (named IntM in this chapter).

As has been mentioned in previous chapters, the subject model of the framework corresponds to the ConML metamodel [144], a metamodel which, despite not having limitations in definition about the field of application, was specifically conceived in order to express conceptual structure in matters of Humanities and Social Sciences. The reasons for this choice are defined by the field in which the framework proposed in this doctoral thesis is set and are explained in detail in the Chapter 7 entitled “Subject Matter”. However, it should be noted that it would be possible for the subject metamodel of the framework to be any other metamodel oriented towards objects (UML for example) in the terms of interoperability which concern us here. Metamodels of cognitive processes and of interaction do not have limitations as far as the field is concerned. In other words, they capture the semantics necessary for the expression of aspects regarding cognitive processes and the possibilities for presentation and interaction at a high level of abstraction, which allows them to be applied to any software-assisted knowledge generation system which we may need to design.

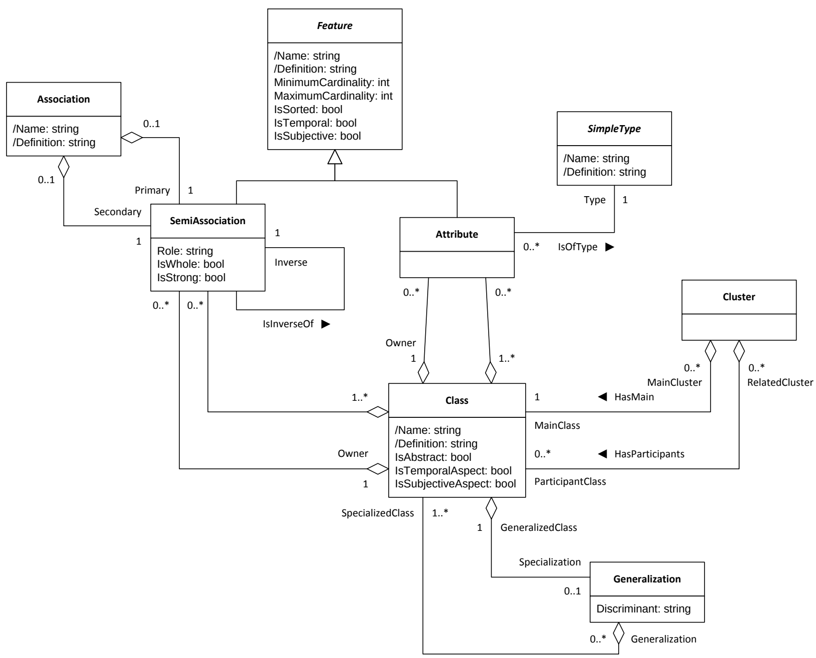

Fig. 49. ConML Metamodel, playing the role of Subject Model (SM throughout this chapter).

In order to obtain an integrated model which considers the different perspectives proposed in this research (subject matter, cognitive processes and presentation and interaction mechanisms), we have applied the MDD interoperability model defined by Pastor [232]. This model establishes interoperability based on models in three dimensions: semantic, syntactic and technical interoperability.

Semantic interoperability refers to the semantics belonging to the modelling approaches which we wish to interoperate with and is normally specified in textual representations (such as in UML [224] or i*specifications [4, 314]). In Pastor's MDD approach, it is considered that the semantics are implicit in the connections defined between the conceptual constructs which the different modelling perspectives to interoperate with represent. In addition, there is a warning regarding the lack of a standard for the definition of this semantic interoperability. Taking this into account, we describe the semantic interoperability by way of the models corresponding to the three dimensions being dealt with, as can be seen in Fig. 49, Fig. 50 and Fig. 51.

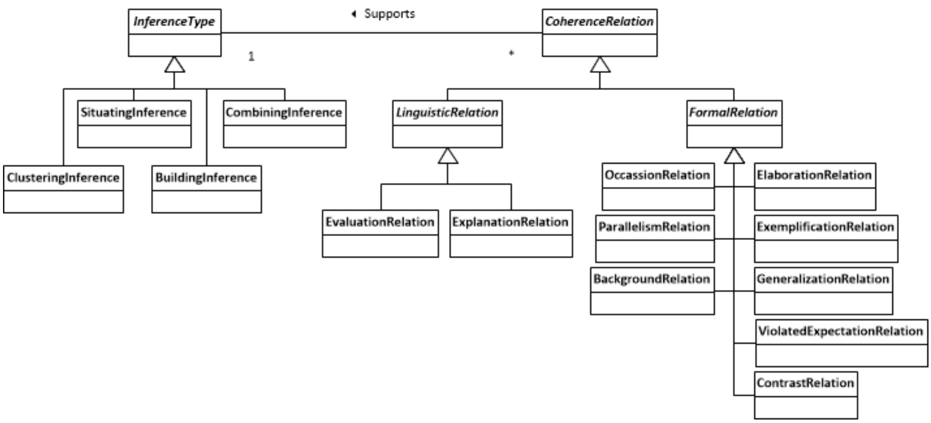

Fig. 50. Cognitive Processes Metamodel (PCM throughout this chapter).

Syntactic interoperability (abstract syntax) refers to the particular system of representation of the semantics described above. In this case, this syntax is obtained through the use of a common metamodeling language (Essential Meta-Object Facility, commonly abbreviated EMOF) [223] for all the modelling approaches involved. Technical interoperability refers to the format used for the exchange of information between dimensions being interoperated with and, in this case, is achieved via the XML specification provided by the Eclipse tools [97] used (UML2 y EMF).

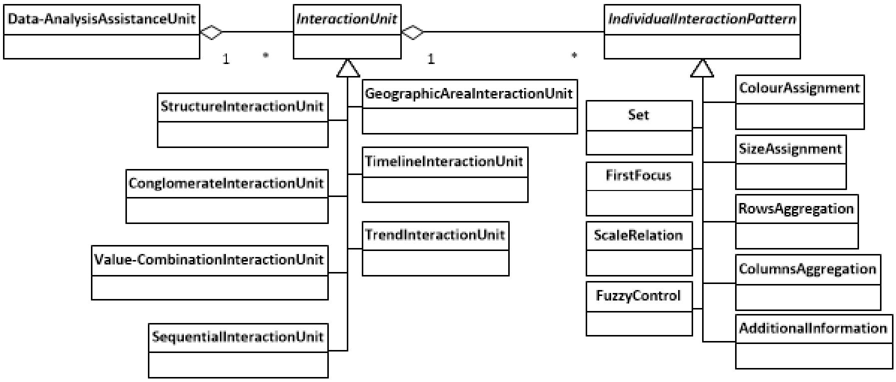

Fig. 51. Interaction Metamodel (IntM throughout this chapter).

On the other hand, Pastor's framework establishes that, for the implementation of any interoperability artefact or for the automatization of the operations based on the models involved, it is necessary to specify additional aspects, in terms of Procedure, Application, Infrastructure and Support for the representation of data.

The Procedure aspects make reference to the elements which must be defined, as well as to the steps which must be taken in order to achieve the sought-for interoperability. The procedure used in order to integrate the different perspectives involved in this case consists of three steps: 1) the definition of the metamodels; 2) the identification of equivalences and differences between them and 3) the definition of an integration metamodel which acts as a pivot solution for the representation of equivalences between metamodels, the new information generated necessary for the later application of the integration metamodel and the handling of heterogeneities on a modelling level between the three perspectives of data, cognitive processes and presentation and interaction mechanisms.

The Application aspect defines the utilities or tools used in order to achieve interoperability. In this case, the procedure described above has been implemented based on the utilities provided by Eclipse EMF (Foundation 2014), which are used for the generation of a model editor on the basis of a specification of an Eclipse UML2 metamodel.

These applications also provide the definition for aspects corresponding to Infrastructure and Support for the representation of data. The Infrastructure aspect corresponds to the definition of the mechanisms of communication between the applications in order to ensure the correct exchange of information and in order to avoid the loss of modelling information when this exchange process is carried out. In our case, the defined infrastructure has been the use of XML as the exchange format.

Finally, the aspect corresponding to the Support for the representation of data deals with the format in which the modelling artefacts are found and must be specified in a standard format, which can be interpreted by different modelling tools independently of application platforms and contexts of development. In our case, we have opted for an EMF representation for the resulting modelling artefacts.

The Integration Metamodel

Here, we shall describe the integration metamodel proposed for the formal expression of the relations between the models of the framework-solution in terms of model-driven interoperability. The full integration metamodel can be seen in Fig. 52:

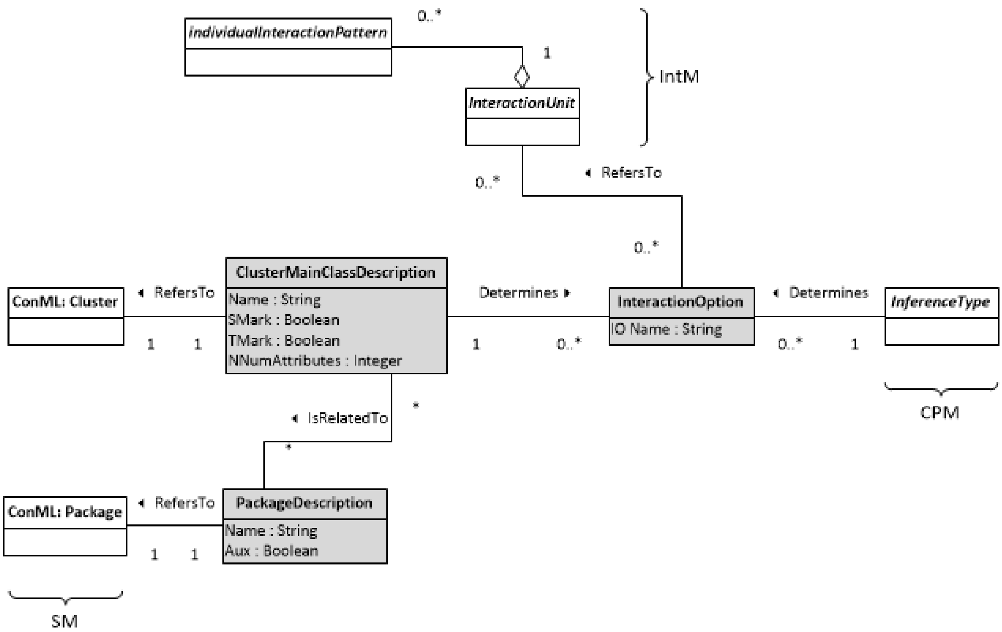

Fig. 52. The proposed Integration Metamodel. The classes in grey correspond to the integration model. The classes in White are part of the metamodels shown in the three previous figures.

The integration metamodel presents three classes: *ClusterMainClassDescription*, *PackageDescription* and *InteractionOption*.

The *PackageDescription* and *ClusterMainClassDescription* classes encapsulate all the necessary semantics which the metamodel of data establishes as far as the structure and meaning of the data involved is concerned. *PackageDescription* consists of two attributes:

- *Name*: Attribute of a text/chain type. Its value corresponds to the name of the class which plays the role of the main class of the package.
- *Aux*: Attribute of a Boolean type. It will present a True value if the package selected forms part of/plays the role of auxiliary for the rest of the packages within the subject extension with which we are working and False in the opposite case.

The *ClusterMainClassDescription* class consists of 4 attributes:

- *Name*: Attribute of a text/chain type. Its value corresponds to the name of the class which plays the role of the main class of the cluster.
- *SMark*: Attribute of a Boolean type. Its value indicates if the main class of the cluster is associated by way of associations with a subjective mark with other classes in the cluster.
- *TMark*: Attribute of a Boolean type. Its value indicates if the main class of the cluster is associated by way of associations with a temporal mark with other classes in the cluster
- *NNumAttributes*: Attribute of a number data type. Its value corresponds to the number of numerical attributes (enumerated or Boolean) which are present in the main class of the cluster. This information will allow us to then make decisions with regard to these attributes.

Furthermore, the relation *IsRelatedTo* between both classes allows it to be known which classes act within which package. This information is already indirectly present in the ConML metamodel since we know which classes form part of which packages and which classes form part of which clusters. However, this relation in the integration metamodel allows the relation to be made explicit. By evaluating the information contained in the instances of *PackageDescription* and *ClusterMainClassDescription* and the structure of instances arising in each case for *SM*, *CPM* and *IntM*, the integration metamodel allows us to determine which interaction options (via instances of the *InteractionOption* class) are appropriate in each case. The *InteractionOption* class consists of a sole attribute, *IOName*, of a text/chain type, which gives a name to each interaction option instanced. This last part shows software assistance by way of recommendations of presentation and interaction patterns modelled in our framework.

Interoperability Guidelines

As can be seen in Fig. **52**, the integration metamodel captures the three perspectives which participate in any software-assisted knowledge generation system, with the aim of offering the end user more appropriate visualisation techniques to assist him/her in his/her tasks [67]. The decision regarding which specific interaction unit is most appropriate according to the cluster of data being dealt with and the cognitive process being assisted is a choice which the analyst should make when it comes to implementing the framework presented here. However, we believe that there may be some universal guidelines which we have observed in the scenarios tested with our interoperability model [196]:

- Each cluster defined and each inference of a Building Inference type can determine an interaction option which refers to a Structure IU interaction unit. This interaction unit enables assistance to problems, such as Problem 1 (which is defined on an interaction level), related with the necessity of exploring the internal structure of the dataset of the case study.

- Each cluster defined and each inference of a Clustering Inference type can determine two interaction options:

  1) An interaction unit of a Conglomerate IU type, which allows the values associated to instances belonging to the cluster's main class to be explored. This interaction unit allows us to assist to problems such as Problem 2, (which is defined on an interaction level), which are related with the necessity for dynamism in the visualisation of datasets.
  2) An interaction unit of a Value-Combination IU type, which allows the values associated to attributes and to classes belonging to auxiliary packages which are associated to the cluster's main class to be explored. This interaction unit allows us to assist to problems such as Problem 2 (which is defined on an interaction level), which are related with the necessity for dealing with levels of importance throughout the visualisation, obtaining, if desired, additional information on a piece of evidence, an event or a reference or a subset, whilst maintaining on the screen the general view of the cluster being dealt with.

- Each cluster defined and each inference of a Combining Inference type can determine two interaction options:

  1) An interaction unit of a Value-Combination IU type, which allows the values associated to attributes and to classes belonging to auxiliary packages which are associated to the cluster's main class to be explored. This interaction unit allows us to assist to problems such as Problem 3 (which is defined on an interaction level), which are related with the necessity for dealing with levels of importance throughout the visualisation, obtaining, if desired, additional information on a piece of evidence, an event or a

reference or a subset, whilst maintaining on the screen the general view of the cluster being dealt with.

2) An interaction unit of a Trend IU type in cases in which the value of the NNumAttributes attribute of the CusterMainClassDescription class is higher than 2 (the more attributes of this type, the more appropriate the Trend IU interaction unit will be). This implies that the main class of the cluster dealt with presents various numerical, enumerated or Boolean attributes, which are potentially susceptible to varying considerably from one version of the dataset to another. This interaction unit allows us to assist to problems such as Problem 4 (which is defined on an interaction level), which are related with the necessity for carrying out analyses of similarities or differences between the data at different stages of the research.

It should be noted that these guidelines take on fundamentally structural aspects when it comes to deciding which interaction unit is more appropriate compared with others when presented with a data cluster and an inference to be assisted. Due to this fact, they are independent of the field of application of the framework and, therefore, it will be the analyst who takes the decision on whether they are appropriate for other fields (outside of the field of Cultural Heritage) which are not explored in this thesis.

Other application guidelines, of a semantic nature, do depend strongly on the field of application in which we wish to provide assistance. The guidelines extracted for the field of Cultural Heritage are described in Part IV, in which a complete implementation of the framework for assistance to the generation of knowledge in Cultural Heritage is carried out.

Finally, it must be highlighted that, in order to obtain a full representation of the relations implied in any software-assisted knowledge generation system, it is necessary to instance all of the metamodels, including the integration metamodel, which acts as a pivot. Over the course of following Chapter 11, a description is given of the application of the integration metamodel created for our real-life scenario: software-assisted knowledge generation systems in the field of Cultural Heritage. This application is carried out by way of a case study selected for the analytical validation of the complete framework and includes an implementation of the integration metamodel presented in this chapter.

The formal expression of the relations between the different perspectives of the framework, which are obtained thanks to the integration metamodel presented here, will allow us to guarantee the traceability, reuse and replication of studies carried out in the field of Cultural Heritage which use software-assisted knowledge generation systems

Conclusions

To sum up, this chapter presents a solution, by way of an integration metamodel, in order to formally express the relations between metamodels in software-assisted knowledge generation systems. In addition, some universal guidelines have been described which allow the analyst to approach software-assisted knowledge generation from the point of view of adapted presentation and interaction patterns. Although the interoperability techniques applied in the definition, design and later implementation and validation of the integration metamodel are not novel, their application in order to express the relations which exist between models in software-assisted knowledge generation systems does represent a scientific contribution. It is an application which, to our knowledge at the time of writing this doctoral thesis, has never before been employed. Furthermore, no studies have been found which, in matters related to knowledge generation systems, take into account the cognitive processes carried out by the users of a system as a perspective of the system which must be present in the integration metamodel.

The framework-solution presented in this doctoral thesis acts, in this real-life scenario, to carry out an initial analytical validation in the field of Cultural Heritage of the integration metamodel presented here and described in Chapter 11. The empirical validation of the proposal with specialists in Cultural Heritage allows us to discover the degree of added value which the formal integration of the framework's perspectives offers to the end users, as well as to obtain *feedback* in order to make improvements in the future. All of this is also described in Chapter 12.

In the future, the plan is to continue with a more in-depth validation of the proposed integration metamodel, modelling more complex real-life scenarios of software-assisted knowledge generation. This step is our immediate priority and is necessary in order to establish the degree of possible generalisation presented by the proposal. Due to the promising results obtained in both validations —and outlined in following chapters—, we believe that the greatest threats to the validity of the proposal are present in its application in software-assisted knowledge generation in other fields with different characteristics.

PART IV: Validation

Experience is the teacher of all things

- Julius Caesar

Chapter 11: Analytical Validation: A Romea as a Case Study

Ever tried. Ever failed. No matter. Try again. Fail again. Fail better.

-Samuel Beckett

Introduction

In using the hypothetico-deductive reasoning which constitutes the methodological framework of this doctoral research (as has been described in the Chapter 3 entitled "Research Methodology"), we take as our starting point the fact that **it is possible to significantly improve knowledge-generation processes in Cultural Heritage by way of by way of providing software assistance to the user with knowledge extraction and information visualization techniques**. Based on the resulted obtained from the use and validation of the techniques and tools created for the exploration of the problem (as described in Part II), a framework-solution was conceptualised and designed to provide software assistance to the generation of knowledge in Cultural Heritage. In this chapter, we shall present the analytical validation which has been carried out of this proposed framework-solution via a real Cultural Heritage case study: A Romea. This analytical validation responds to the following question: **Do the software metamodels of the defined framework-solution allow information regarding the three aspects necessary in order to provide assistance to the generation of knowledge (subject matter, cognitive processes and presentation and interaction mechanisms), and the degree of interoperability between them, to be used in a real case study and to define the software assistance offered in this case?**

Validation by Way of a Case Study

The validation of theoretical proposals by way of a real case study has been, and continues to be, a constant within the validation mechanisms employed according to hypothetico-deductive methodologies, such as Design Science Methodology [305] or other similar methods. Research projects validated by way of case studies can be found in many different fields [93], from Sociology [304] or Psychology [261] to Medicine [3], Education [204], etc. …In Software Engineering, this is a widely-used validation mechanism, with case studies being found in validations of requirements models, functional models, testing, empirical validations of business systems or processes [305, 306], etc.

Following the methodology described in Part I, we take into account the research framework defined by Wieringa [305]; Design Science Methodology applied to Software Engineering, in which the validation bases in Software Engineering by way of case studies are established. Therefore, we defined a case study, which shall be named “A Romea” hereinafter, for the validation of the framework-solution presented. This case study allows us to carry out an analytical validation of the proposed framework-solution, detecting possible problems in its application and possible lines for improvement, determining a specific context of application and allowing us to adopt an appropriate approach as far as the generalisation of the solution to other similar contexts is concerned.

A Romea as a Case Study: A General Overview

The case study selected for the validation of the proposed framework-solution presented over the course of this research forms part of a group of archaeological projects carried out with the aim of mitigating the impact on Cultural Heritage caused by the construction of the Santiago-Alto de Santo Domingo motorway in Galicia (North-West Spain) [62]. More specifically, during the work to assess the archaeological impact of the construction of this motorway carried out between December 1999 and February 2000, an underground spatial concentration of material remains of human activity (known as the Barrow of Monte da Romea) [189, 247] was documented on the plotted route of the motorway. This, in archaeological terminology, was identified as an unregistered site [203].

Traditionally, “barrow” is the name given to an artificial mount of earth and/or stones heaped up to cover one or more burials [72]. Barrows were common throughout the course of Prehistory in different cultural contexts [203]. The corrective measures proposed in order to mitigate the destruction of the barrow consisted of excavating the site before the construction of the motorway was carried out, in order to obtain as much information about it as possible. Archaeological excavation, as a fundamental method for obtaining archaeological data [72], consists of discovering and registering material remains of past human activity [203]. This research procedure uses appropriate methods to unearth these remains, which may include artefacts, organic remains and structures [203]. All of the elements found, with the obvious exception of structures (such as walls, etc.), are transferred to a laboratory in order to be analysed, thus generating more data. The excavation is carried out by extracting the earth which covers the remains, following natural or artificial layers (strata), which make up the stratigraphic sequence of the excavated site, of a thickness which is decided upon by the archaeologist [72, 203]. As excavation is an irreversible act, only those sites which can potentially provide new information or which are in danger of destruction [203] should be excavated, as was the case of A Romea [62].

The excavation work was carried out between January 2001 and January 2003, in parallel with the construction phase of the motorway, by an independent archaeological team. [62]

During the project, the existence of the barrow, its location and the evaluation of the impact suffered in the previous phase was confirmed. The barrow was located totally within the bounds of the construction work, thus making the work critical as the construction of the motorway would suppose the destruction of the site. Confronted with this situation, a zone of archaeological caution was established (a geographically delimited zone in which no movement of the earth, or of machinery, is permitted). In addition, some corrective measures were proposed:

- Graphic and cartographic documentation of the area.
- The intensive prospection of the area. By archaeological prospection, we understand the application of a set of methods in order to discover sites based on their superficial remains by visual inspection on the ground or from the air (aerial photography, teledetection, etc.), or from remains unearthed close to the surface by employing apparatus which measures chemical, electrical or magnetic variations in the soil (geophysical prospection) [72, 203].
- The marking out of the area during the work.
- The archaeological control of the clearing of the land.
- The mechanical digging of trenches/ditches within the limits of the barrow.
- The complete excavation of the site before the construction work was carried out at this geographic location.

The carrying out of these corrective measures gave rise to the project which is taken here as a case study and which is identified by the code CJ102A 2002/100-0, according to the appropriate authorisation of the Dirección Xeral de Patrimonio Cultural (DXPC) (General Directorate of Cultural Heritage) of the Xunta de Galicia (the regional parliament) (Resolution of 25th March 2002).

Description of the Site and the Associated Archaeological Research

The barrow of A Romea is situated in the council of Lalín in an area of inland valleys (see location in Fig. 53 and Fig. 54), in the district of Trasdeza, in the province of Pontevedra (Spain). Prior to the excavation, the visible barrow was covered by thick vegetation and by a variety of repopulated (pine) and autochthonous (oak) trees. It was 21 metres in diameter and one metre in height with an oval shape and steeper slopes on the south (S) and east (E) sides and more gradual slopes towards the west (W) and north (N). Once the vegetation had been cleared and the barrow cleaned, it measured 18.90 metres in length from north to south (N-S) and 18.50 metres from east to west (E-W), reaching a maximum height compared to its surroundings of 1.25 metres along its south-east edge and a minimum height of 0.60 metres along its northern (N) edge.

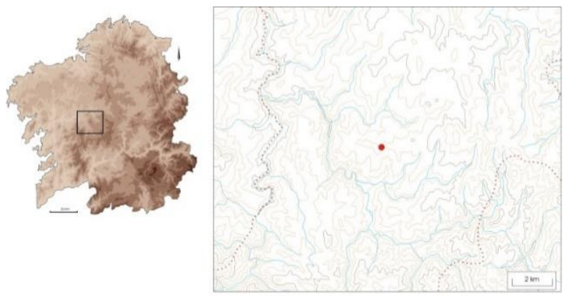

Fig. 53. The geographic location of the site of A Romea. Figure provided by Patricia Mañana-Borrazás (©Incipit, CSIC).

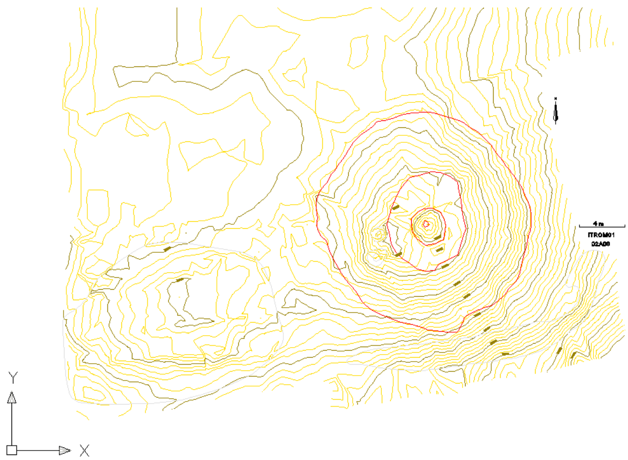

Fig. 54. A topographic plan of the A Romea site. The red lines indicate the contours at different levels of elevation of the barrow. Figure provided by Patricia Mañana-Borrazás (©Incipit, CSIC).

Taking into account these initial aspects of the project mentioned above, some archaeological and heritage objectives were proposed for the investigation of the A Romea site (which constitute the overall objectives which the framework-solution proposed in this thesis must achieve through software assistance). More specifically, the following objectives were proposed on an archaeological level [62]:

1. An approach towards a more exhaustive characterisation of the site and of the area in which it is located.
2. A verification of the existence or absence of associated archaeological remains in the surrounding area.
3. A definition of the morphology of the site and the remains found and the proposal of a hypothesis regarding its origin.
4. A full and detailed reading of the stratigraphic sequence paying attention to both formal and archaeological aspects. The relation between the characteristic material remains of the site and the different stratigraphic layers should be determined.
5. Samples should be obtained allowing for an analysis which will make it possible to clarify more exactly the chronology and configuration of the site and the structures excavated.

Therefore, we can assume that the research questions to be answered in the field of Archaeology will be:

- Do the archaeological findings confirm the existence of a barrow? What is the morphological structure of the mound? What is its oldest chronological adscription?
- What later phases can be attributed to the barrow (phases of occupation, abandonment, change of use, etc.)? Do the material findings correspond to the stratigraphic sequence of the site?
- Are there any nearby areas of activity generated by the presence of groups of humans linked to the barrow during its construction or even before?

To sum up, the fundamental objective on an archaeological and heritage level has two sides. On the one hand, there is a need to exhaustively document all the archaeological findings (be they objects, structures such as the stratigraphic sequence or the surrounding area), due to the site's imminent destruction for the construction of the planned motorway. On the other hand, there is the need to provide answers to the research questions mentioned above based on the data gathered during the excavation and which could be summarised by tracing the chronological phases and the activity of the barrow, based on data regarding the findings (objects, structures or the stratigraphic sequence). The answers to these questions regarding the specific case study are those which will be assisted in the proposed framework-solution of this doctoral thesis.

It should be remembered that, as has been emphasised throughout this research, during the phase of exploring the problem, no integral proposal for software-assisted knowledge generation in Cultural Heritage has been found in the current literature. What was found were isolated proposals for handling data or for the visualisation of subsets of information. The absence of a proposal and the revision of the proposed case study allowed us to ensure that the answers to these research questions at the time the project was carried out (years 2001-2003) were obtained without an integral software assistance system involved in the process of knowledge generation, although some assistance was provided in some cases in terms of spatial information. As will be discussed later in this chapter, a case study has been chosen in which the answers to the research questions and the knowledge generated from the data can be empirically evaluated in pre-software assistance and post-software assistance contexts with the framework-solution, thus allowing us to make comparisons between these two situations.

Therefore, the A Romea project serves well as a case study in the validation of the different solutions which make up the framework-solution presented in this thesis. The case study acts, therefore, as a central thread of this research and illustrates how software assistance can be achieved by applying the proposed framework-solution and what tangible results can be obtained thanks to its application within a real-life scenario in the field of Cultural Heritage. The following sections of this chapter go on to describe the specific applications of the three perspectives of the framework-solution as applied to the case study of A Romea.

A Romea: Subject Model

As has been mentioned in the general overview of our case study, in an archaeological excavation, a series of artefacts, biological remains and/or structures are extracted and documented and their associated information serves as a basis for the specialist in the field of Cultural Heritage (in this particular case for the archaeologist) to infer and generate knowledge regarding facts from the past. More specifically, the archaeologist can ascend through the DIWK hierarchy [7], advancing from the data to more complex forms of knowledge. In each case, the type of knowledge which is generated will depend on the research questions which the archaeologist, or a group of Cultural Heritage specialists, proposes. In this specific case, the knowledge generated from the data will be that which provides answers to the research questions mentioned above. This knowledge, therefore, can be summarised as:

- New knowledge regarding evidence which confirms the existence of the barrow, its internal morphological structure, its possible functional organisation and its oldest chronological adscription.
- New knowledge regarding the temporal phases associated to the barrow and its relation with the temporal phases associated to the materials found within it.
- New knowledge regarding the areas of activity which existed in the area surrounding the barrow.

In order to provide software assistance to this process of knowledge generation, it is necessary to possess the data extracted during the excavation process and during the laboratory analysis of the materials found. However, as is mentioned in the Chapter 7 entitled “Subject Matter”, the underlying conceptual model which we use for the conceptualisation and storage of this data plays an extremely relevant role in the generation of knowledge which can be accessed later and, of course, also in the type of software assistance which can be provided in this generation of knowledge. Bearing these aspects in mind, a conceptual model has been designed which reflects the subject matter dealt with in this case study as an extension of CHARM [110] (as a consequence of this it is expressed in ConML [144]).

In Fig. 55 the extension created for the case study of A Romea is shown. The classes and associations shown in orange represent classes and associations which are specific to the extension of CHARM created. The classes in green represent CHARM classes which have been redefined for the case study of A Romea.

The extension presented here covers the complete subject sphere of the case study: the structure and characteristics of the site in question, the types of findings and their specific characteristics, spatial and temporal information regarding the site and its findings, the stratigraphic sequence defined during the excavation process and data obtained in the laboratory. Furthermore, it includes the different evaluations made by the specialists in Cultural Heritage who participated in the A Romea project regarding the entities mentioned above.

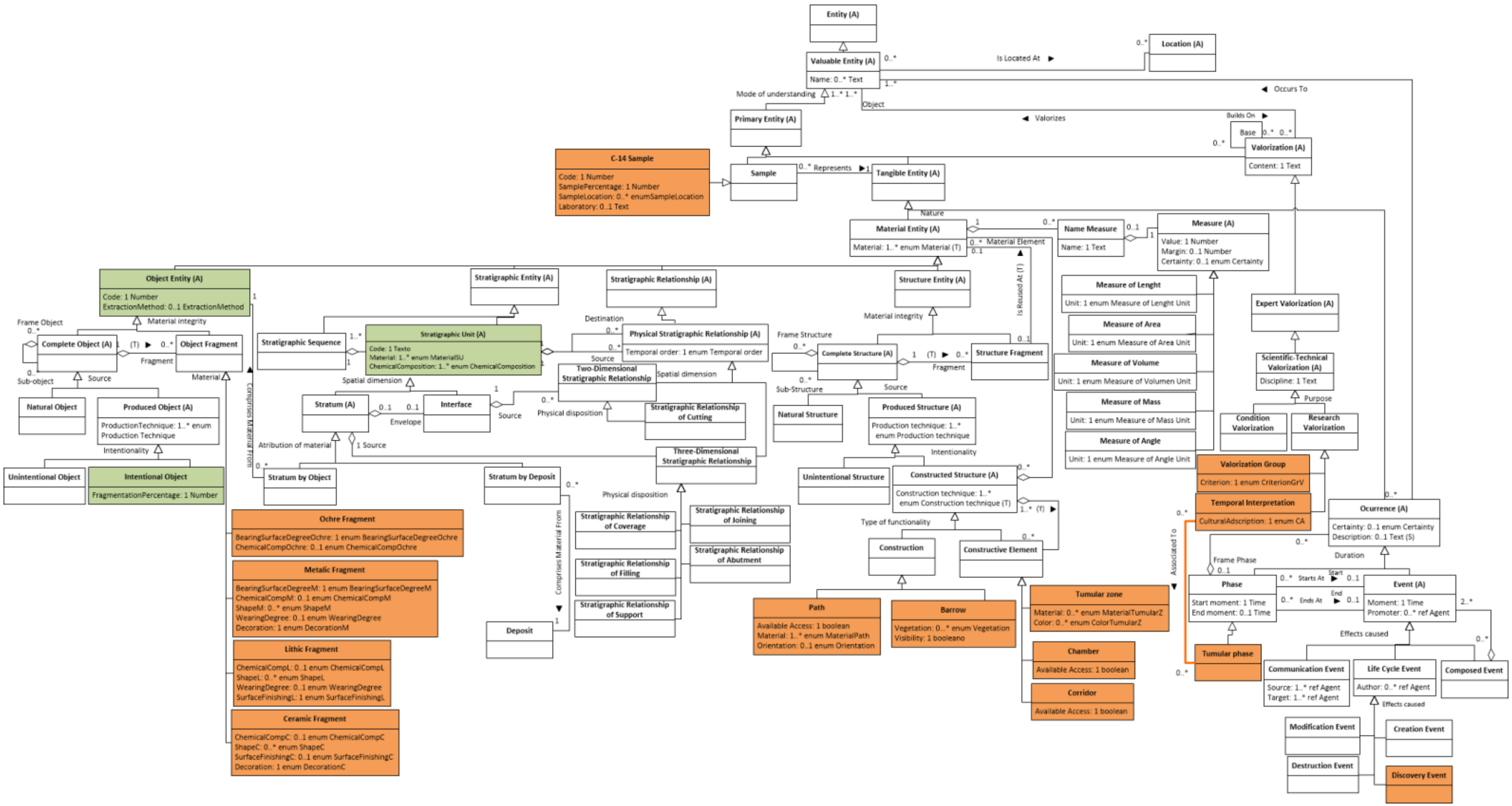

Fig. 55. The CHARM extension (based on version 0.8 of CHARM and expressed in ConML) made for the case of A Romea. The classes and associations in orange represent classes and associations which are particular to the CHARM extension created. The classes in green represent CHARM classes which have been redefined for the case study of A Romea

In its current version, ConML does not allow the in-place redefinition of classes. To achieve a similar effect, the mechanism shown in Fig. 56 is employed. A class is added as a specialization of a CHARM class, and used as a generalized class from the CHARM class that we want to redefine. Fig. 56 illustrates the redefinition technique used in the Stratigraphic Unit class redefinition. The same technique has been applied to all classes from CHARM redefined for A Romea extension —classes in green in all figures in this chapter—.

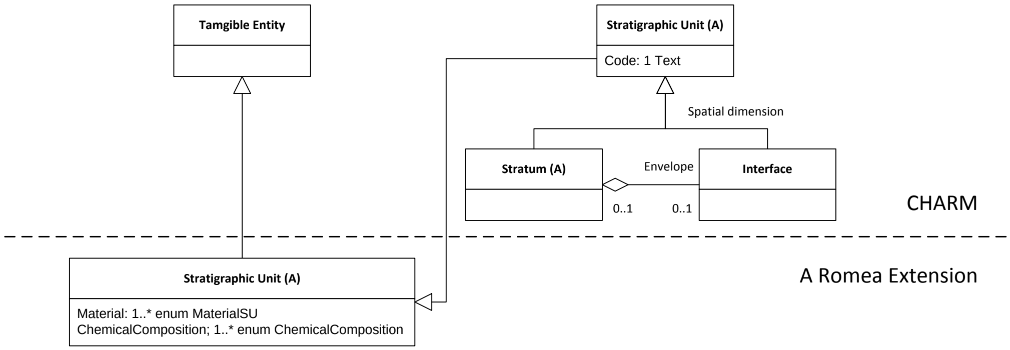

Fig. 56. Redefinition technique applied for green classes.

In addition, the framework-solution presented organises the defined extension of CHARM into subject sub-areas, by using the package mechanism. In this case study, the extension has been organized into 4 packages: Stratigraphic Unit, Object Entity, Structure Entity and Valuable Entity. In turn, the Valuable Entity package is divided into 5 sub-packages: Sample, Measure, Location, Occurrence and Valorization. It should be noted that, as was defined in the Chapter 7 entitled “Subject Matter”, each package takes the name of the class with the greatest semantic load within the package and which brings together its subject matter with a view to using the package mechanism as a subject aggregator in the integration model defined for the framework-solution (see Chapter 10).

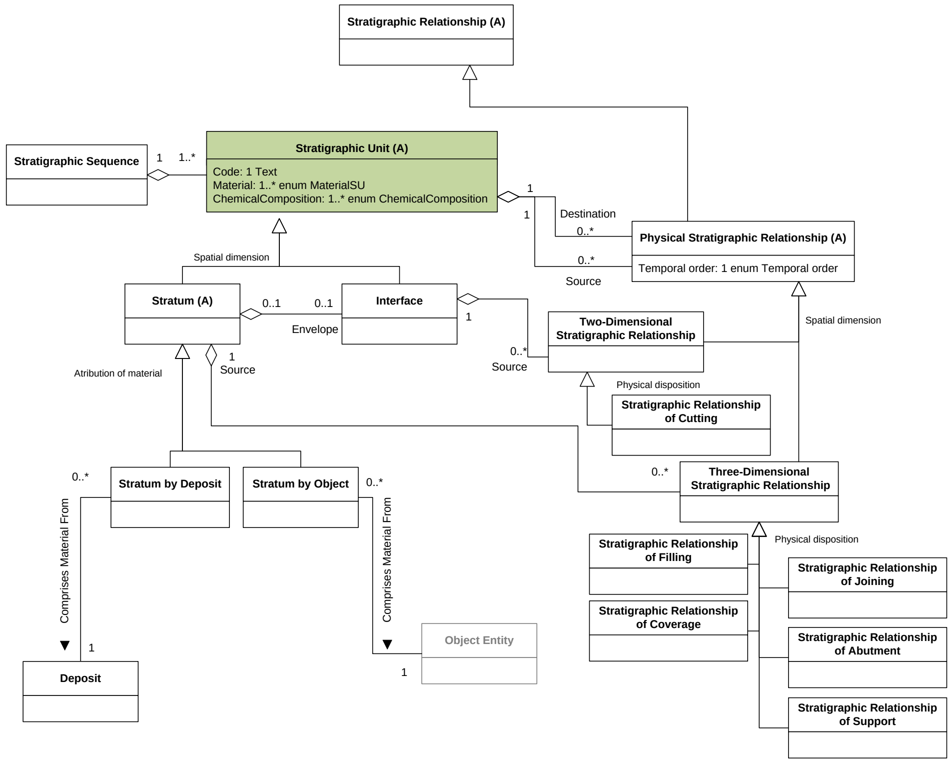

Fig. 57. The Stratigraphic Unit Package defined for the case study of A Romea. The Object Entity class is not part of the package but is shown in order to indicate its association with the classes of the Stratigraphic Unit Package.

The Stratigraphic Unit package includes the classes of the extension model for A Romea which conceptualise the stratigraphic units and the relations between them. Thus, the Stratigraphic Unit class, which gives its name to the defined package, represents the class with the greatest semantic load within it. The package also has a redefinition of the CHARM class *Stratigraphic Unit*, incorporating new attributes of use into it for the case study in question. The complete Stratigraphic Unit package can be seen in Fig. 57.

The Object Entity package includes the classes of the extension model for A Romea which conceptualise the objects found during the archaeological activity. Thus, the Object Entity class, which gives its name to the defined package, represents the class with the greatest semantic load within it. In this package, four specialised classes of Object Fragment are included as a result of the extension made: Ochre Fragment, Metallic Fragment, Lithic Fragment and Ceramic Fragment. The definitions of the extended classes are as follows:

- Ochre Fragment: An object entity corresponding to a separate portion of a complete object, having an altered material integrity, and whose material consists of a natural earth pigment containing hydrated iron oxide, which ranges in colour from yellow to deep orange or brown.
- Metallic Fragment: An object entity corresponding to a separate portion of a complete object, having an altered material integrity, and whose material consists of chemical elements that are typically hard, opaque, shiny, and has good electrical and thermal conductivity.
- Lithic Fragment: An object entity corresponding to a separate portion of a complete object, having an altered material integrity, and whose material is mainly composed of stone.
- Ceramic Fragment: An object entity corresponding to a separate portion of a complete object, having an altered material integrity, and whose material is inorganic, non-metallic solid comprising metal, non-metal or metalloid atoms primarily held in ionic and covalent bonds.

Therefore, it has been necessary to redefine the CHARM classes *Object Entity* and *Intentional Object* by incorporating new attributes of use for each case study dealt with. The complete Object Entity package can be seen in Fig. 58.

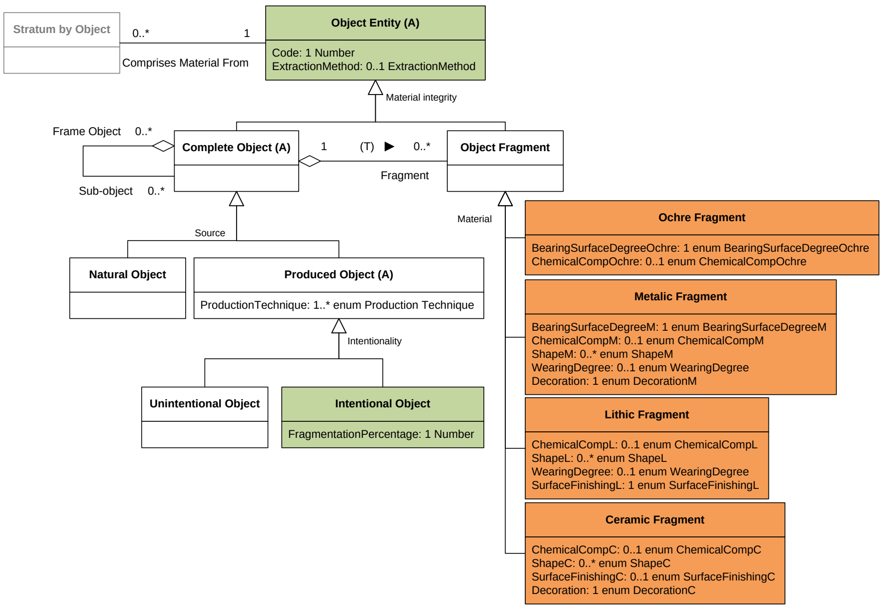

Fig. 58. The Object Entity package defined for the case study of A Romea. The Stratum by Object class does not form part of the package but is shown in order to indicate its association with classes of the Object Entity package.

The Structure Entity package includes the classes of the extension model for A Romea which conceptualise the structures found during the archaeological activity. Thus, the Structure Entity class, which gives its name to the defined package, represents the class with the greatest semantic load within it. In this package, specialised classes have been added in order to represent specific structures and their fragments: Path, Barrow, Tumular Zone, Chamber and Corridor. The definitions of the extended classes are as follows:

- Path: A constructed entity made to facilitate the movement of people, animals or vehicles, such as a road, way, or track.
- Barrow: An artificial accumulation of dirt and/or rocks forming an artificial mound, especially over a grave, frequent over the course of Prehistory in different cultural contexts.
- Tumular Zone: A constructed entity which, despite not providing direct functionality to its users, constitutes a material part of a barrow, to which it contributes structure and/or function.
- Chamber: A constructed entity which constitutes a material part of a barrow. It’s a room built from rock or sometimes wood, which could also serve as a place for storage of the dead from a family or social group and was often used over long periods for multiple burials.
- Corridor: A constructed entity which constitutes a material part of a barrow, to which it contributes structure and/or performs the function of an entrance.

The complete Structure Entity package can be seen in Fig. 59.

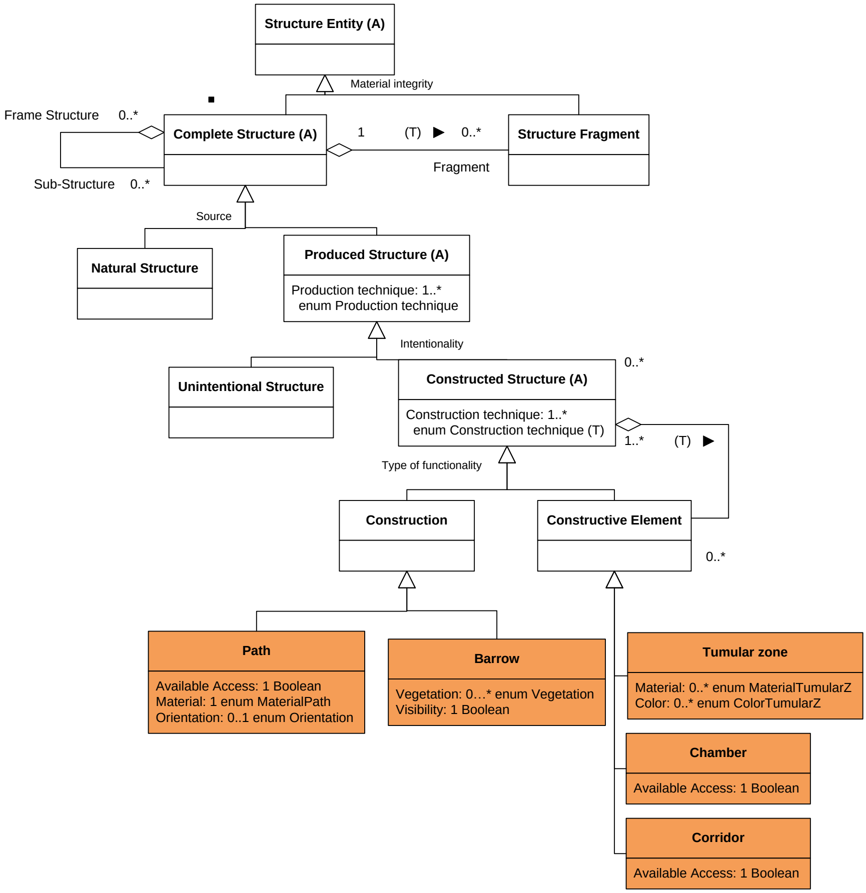

Fig. 59. The Structure Entity package defined for the case study of A Romea.

Last of all, the Valuable Entity package has been defined. This package includes subject sub-packages corresponding to cross-cutting uses of the model resulting from the A Romea extension. In other words, each sub-package within the Valuable Entity package has its own subject matter but with an application which is transversal to the previously defined packages. Fig. 60 shows the complete composition of the Valuable Entity package. Later, the composition of each sub-package will be described.

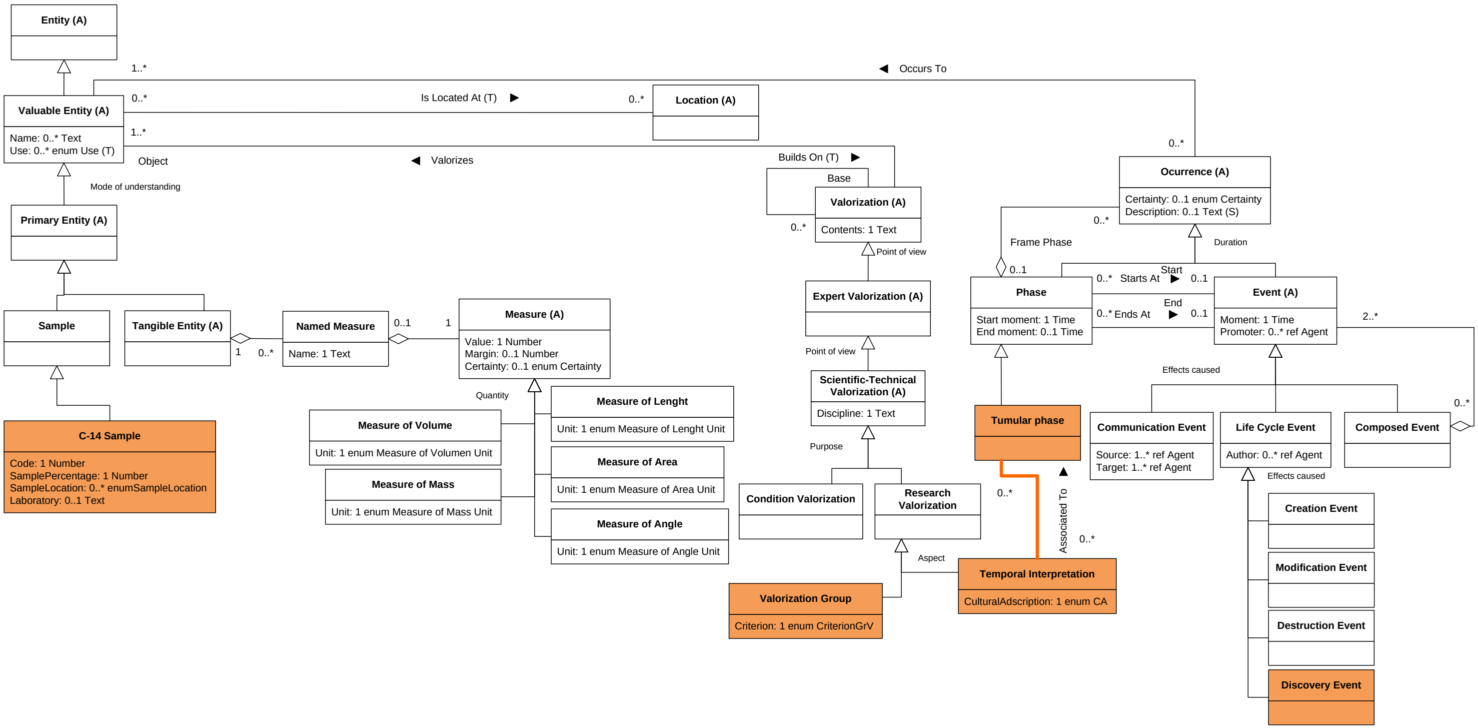

Fig. 60. The Valuable Entity package defined for the case study of A Romea. The classes and associations in orange represent classes and associations which are particular to the CHARM extension created.

The Sample sub-package includes classes which conceptualise representative portions taken from other Valuable Entities represented in the previous packages: objects, structures and stratigraphic units. It has been necessary to include C-14 Sample in the same extended class for our case study:

- C-14 Sample: A tangible entity corresponding to a fragment of another tangible entity, the properties of which it aims to represent. The fragment is specially picked for a C-14 radiocarbon analysis.

Fig. 61 shows the composition of classes of the Sample package.

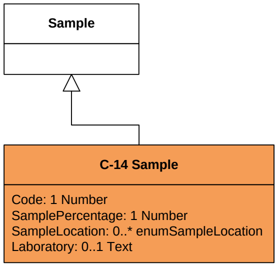

Fig. 61. The Sample package defined for the case study of A Romea.

The Measure sub-package includes classes of use in the conceptualisation of units of measurement which allow Valuable Entities present in other packages to be given a dimension. Fig. 62 shows the composition of classes of the Measure package.

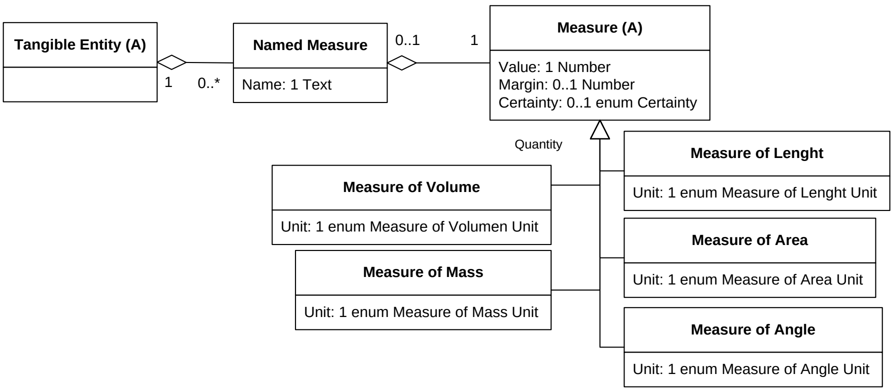

Fig. 62. The Measure package defined for the case study of A Romea.

The Location sub-package includes classes of use for the geographic and spatial location of the Valuable Entities which are present in other packages. Fig. 63 shows the composition of classes of the Location package, which has only one class (Location) present in CHARM and, therefore, maintains its original definition. Due to the fact that the case study of A Romea does not focus its information on spatial location, it has not been necessary to incorporate any extended classes into this package, in spite of the fact that CHARM () possesses location sub-classes which offer more detail in this area.

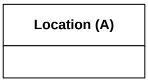

Fig. 63. The Location package defined for the case study of A Romea.

The Occurrence sub-package includes classes of use for the conceptualisation of temporal information about the Valuable Entities which are present in other packages. Two classes have been included in the extension for our case study:

- Tumular Phase: A circumstance which takes a relatively long time and corresponds to a stable period of a barrow studied.
- Discovery Event: A circumstance related to the life of an entity which takes a relatively short time and corresponds to the initial moment of a process of learning something that was not known before or of discovering someone or something which was missing or hidden about the entity studied.

Fig. 64 shows the composition of classes of the Occurrence package.

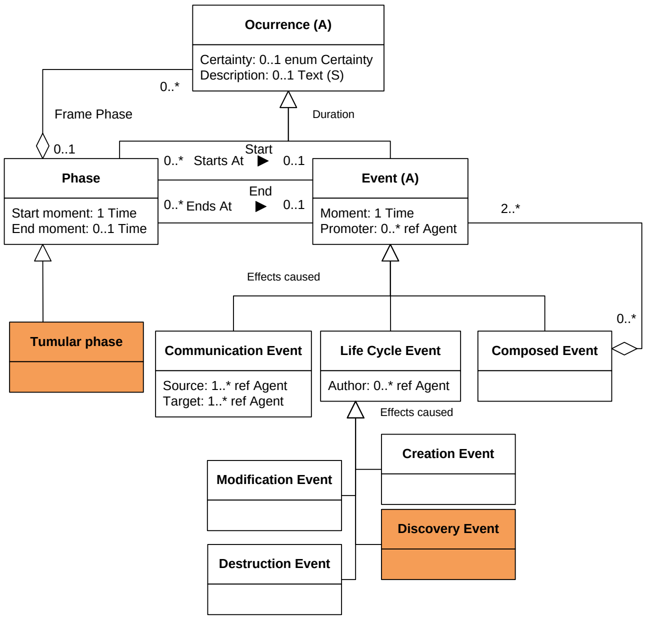

Fig. 64. The Ocurrence package defined for the case study of A Romea.

Lastly, the Valorization sub-package includes classes of use for the conceptualisation of valorizations made regarding the entities present in other packages. In this package, the classes *Valorization Group* and *Temporal Interpretation* have been added. The definitions of the extended classes are as follows:

- Valorization Group: a scientific-technical valorization produced with the purpose of generating new knowledge about the valorized object. The valorized object is a group of stratigraphic units which performs a unit in terms of a methodological, functional or other criterion selected.
- Temporal Interpretation: a scientific-technical valorization produced with the purpose of generating new knowledge about the valorized object. This valorized object could be any Valuable Entity. The new knowledge generated is always related with temporal assignments to the valorized object, interpreting it in temporal terms.

Fig. 65 shows the composition of classes of the Valorization package.

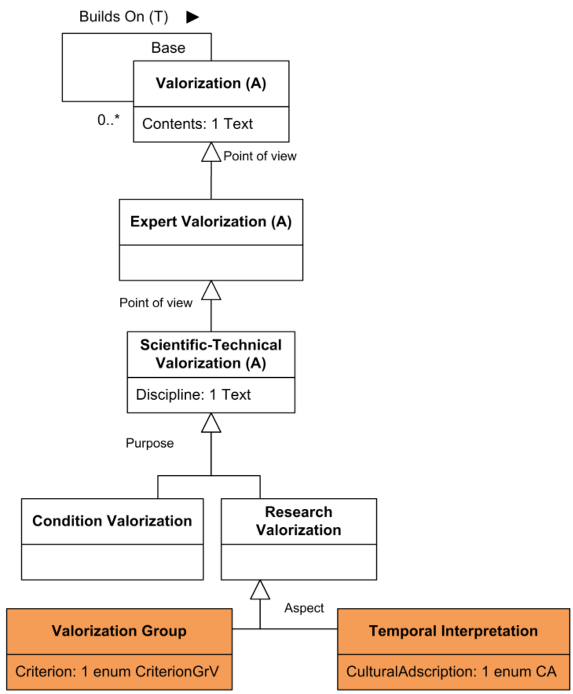

Fig. 65. The Valorization package defined for the case study of A Romea.

The packages defined allow us to structure the extension model for A Romea into subject areas with a fixed structure. In addition, the defined framework allows the use of the ConML clusters mechanism in order to identify both the classes with relevant semantics and those which play an auxiliary role in the subject model. The definition of clusters acts as a model view (TypeModelView in the ConML () specification) transversally to the packages. Therefore, a cluster may contain classes belonging to several packages, thus converting this mechanism into the appropriate way of conceptualising aspects which are transversal to the fixed package structure. Specifically, the model resulting from the A Romea extension consists of 11 clusters, expressed below in ConML notation [144]:

- **Stratum by Deposit - Deposit**: allows us to know which stratigraphic unit of a stratum by deposit type is defined according to which deposit among those found. Fig. 66 shows the classes belonging to the cluster.

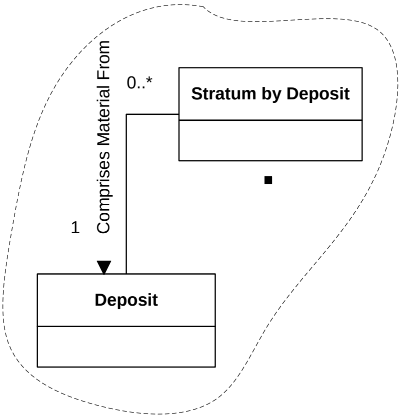

Fig. 66. Stratum by Deposit - Deposit cluster.

- **Stratum by Object - Object Entity**: allows us to know which stratigraphic unit of a stratum by object type is defined according to which object among those found. Fig. 67 shows the classes belonging to the cluster.

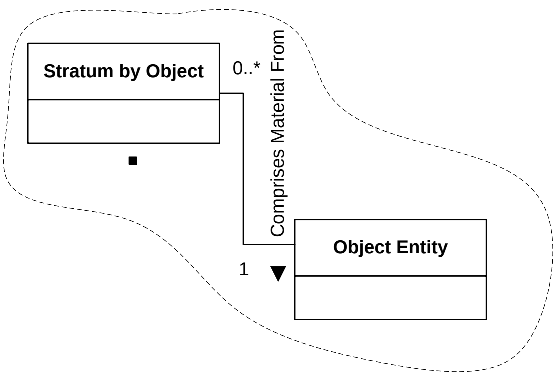

Fig. 67. Stratum by Object - Object Entity cluster.

- **Tangible Entity - Named Measure - Measure**: allows us to know all types of measurements taken from tangible entities. Fig. 68 shows the classes belonging to the cluster.

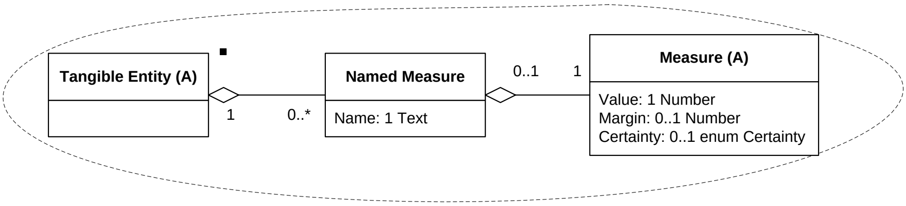

Fig. 68. Tangible Entity - Named Measure - Measure cluster.

- **Tangible Entity - Sample**: allows us to know to which tangible entity the sample taken corresponds. Fig. 69 shows the classes belonging to the cluster.

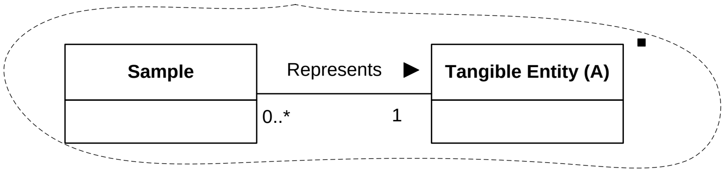

Fig. 69. Entity - Sample cluster.

- **Valuable Entity - Location:** allows us to know the locations associated to a defined Valuable Entity. Fig. 70 shows the classes belonging to the cluster.

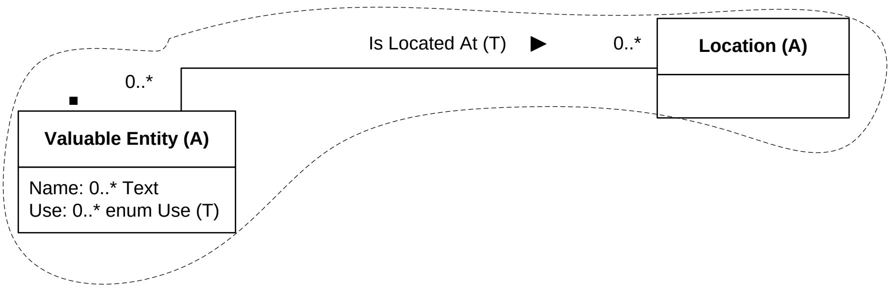

Fig. 70. Valuable Entity - Location cluster.

- **Valuable Entity - Valorization**: allows us to know the valorizations which any agent makes regarding a defined Valuable Entity. Fig. 71 shows the classes belonging to the cluster.

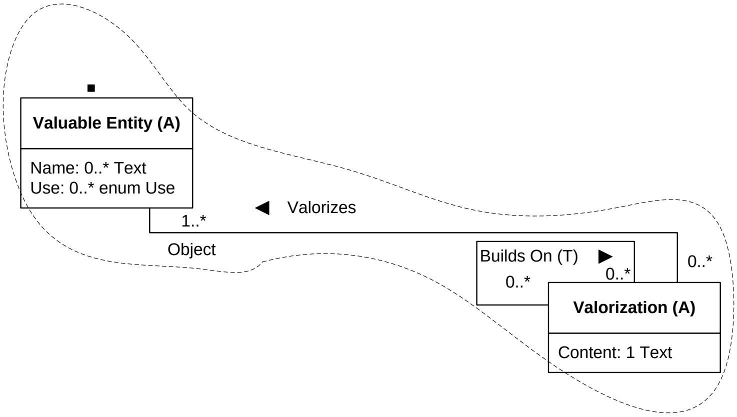

Fig. 71. Valuable Entity - Valorization cluster.

- **Complete Object - Object Fragment**: allows us to know which fragments correspond to which object among those found. Fig. 72 shows the classes belonging to the cluster.

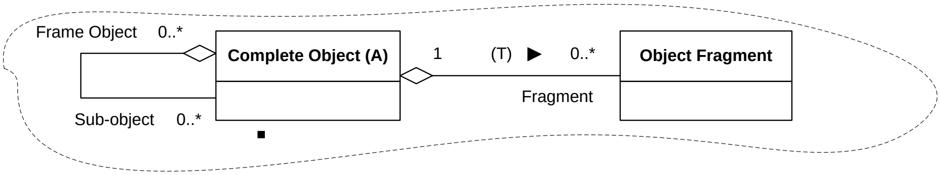

Fig. 72. Complete Object - Object Fragment cluster.

- **Complete Structure - Structure Fragment**: allows us to know which fragments correspond to which structure among those found. Fig. 73 shows the classes belonging to the cluster.

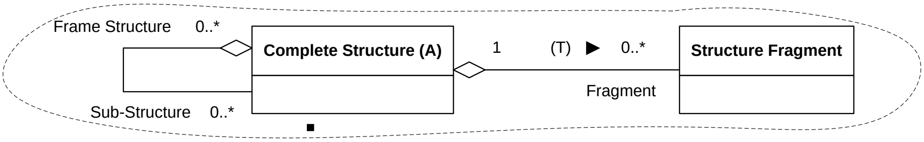

Fig. 73. Complete Structure - Structure Fragment cluster.

- **Composed Event - Event**: allows us to know which sub-events are included in a given event. Fig. 74 shows the classes belonging to the cluster.

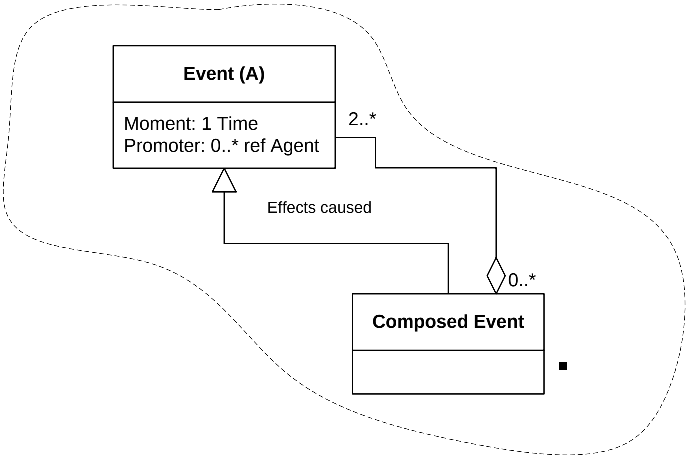

Fig. 74. Composed Event - Event cluster.

- **Construction - Constructive Element - Constructed Structure**: allows us to know which constructive elements and other constructions form part of each structure built. Fig. 75 shows the classes belonging to the cluster.

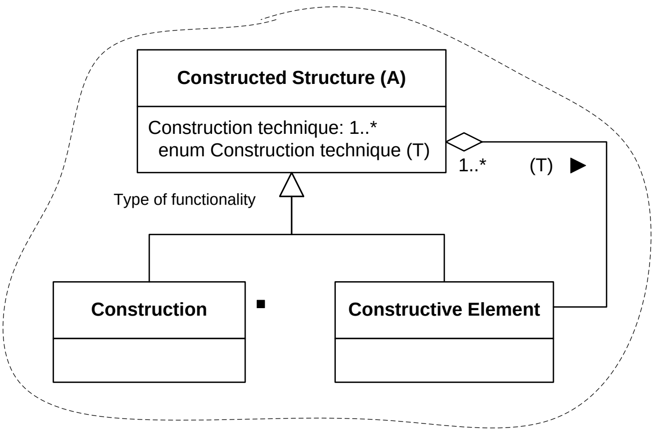

Fig. 75. Construction - Constructive Element - Constructed Structure cluster.

- **Stratigraphic Unit - Stratigraphic Sequence:** allows us to know to which stratigraphic sequence the defined stratigraphic units belong. Fig. 76 shows the classes belonging to the cluster.

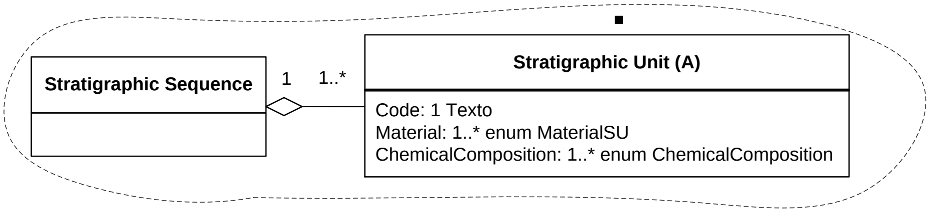

Fig. 76. Stratigraphic Unit - Stratigraphic Sequence cluster.

It should be noted that the main class of the cluster is referenced first in its name. The rest of the classes are participants of the cluster. In this point, it is necessary to remember that the cluster mechanism is used throughout the framework-solution in a hierarchical way. In other words, the cluster is defined at the highest possible level of abstraction, with this characteristic being inherited among the specialised classes which make up the cluster. In addition, it should be highlighted that the cluster mechanism will allow us to then identify the relevant semantics, having this information in the integration model defined for the framework-solution (see Chapter 10).

As part of the application process of the framework-solution proposed for the A Romea case study, this conceptual model has been implemented as a relational database and then instanced in the database itself. The model of instances for A Romea constitutes the implementation of the subject model for our case study. The complete outline of the model implemented can be seen in Appendix II.

A Romea: Cognitive Processes Model

The proposed framework-solution also has a second perspective to be dealt with, one which is particularly relevant for the design of a software assistance system for the generation of knowledge in Cultural Heritage: the cognitive processes which the specialist in the field carries out in order to ascend in the DIKW hierarchy [7] and, thus, generate new knowledge based on existing heritage data. In order to provide support for this dimension, a description was given in the chapter 8 entitled "Cognitive Processes" of the metamodel created, which conceptualises the types of inferences supported by the framework, their sub-classes and the coherence relations which may be present in each discourse and their relations with the most common types of inferences in Cultural Heritage. For the specific case of A Romea, the instance for Cognitive Processes has an instance for each type of inference which we wish to assist, as can be seen in Fig. 77.

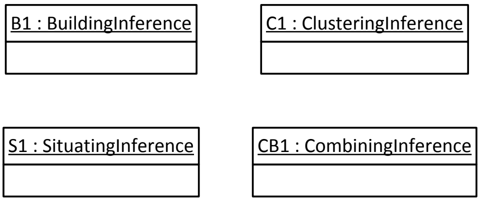

Fig. 77. Instances of each type of inference for the case study of A Romea in UML notation.

It should be noted that, as was described in the Chapter 8 entitled "Cognitive Processes", the types of inference dealt with by the framework-solution are always the same, so in each case of application there will be instances of the four identified types. The existence of instances regarding the coherence relations which are supporting the type of inference will depend on whether the discourse analysis has been carried out for each case of application dealt with and, therefore, this information can be incorporated into the cognitive processes model, providing additional information and information regarding traceability with the discourse of the case of application. In this case, the decision has been taken to maintain only instances for the types of inference due to reasons of simplicity as they are the minimum instances necessary in order to explain in detail the way of working of the proposed framework-solution.

The cognitive processes carried out by specialists in Cultural Heritage in order to provide answers to the research questions posed in A Romea (outlined in the previous section "A Romea as a case study: A general overview") are those which must be assisted by the framework-solution, corresponding in our model to the instances of types of inference.

Once we have the particular model of cognitive processes for our case study, with instances for each one of the four types of inference acting as primitives of cognitive processes, the framework can use this information in the integration model (see Chapter 10) and establish assistance in the form of visualisation and interaction mechanisms which will be provided in each case. The following section will describe the presentation and interaction mechanisms defined for the case of A Romea.

A Romea: Presentation and Interaction model

In addition to providing support for cognitive processes and analysing the subject matter of the case study, the proposed framework-solution should offer a formal representation solution for presentation and interaction in A Romea which allows for software assistance to the analysis of the data from the case study and the generation of knowledge in its context. In order to do this, the proposed solution, which was explained in detail in the chapter 9 entitled “Presentation and Interaction Mechanisms“, has been applied. This solution proposed a set of RIA patterns organised hierarchically as a reusable repository of solutions. The application of this solution to the specific case study which concerns us here (A Romea) has been carried out by characterising the problems identified in that chapter for Cultural Heritage and adjusting them to the particular case of A Romea, in such a way that there is a degree of traceability between the abstract challenges presented in that chapter, the specific problems in the field of Cultural Heritage and how those problems manifest themselves in this specific case study.

It should be remembered at this point that the problems identified in the Chapter 9 entitled “Presentation and Interaction Mechanisms “, in the field of Cultural Heritage are specific examples of the abstract challenges in the formal representation of interaction and presentation numbered from 1 to 6. In this point, A Romea specifies these problems in the following way:

PROBLEM ARomea_1: As we have seen in the section of this chapter entitled section “A Romea as a case study: A general overview”, the information obtained from the case study is organised into a single complete dataset which holds information of many different types related with the case study of A Romea, provided by many different researchers, treating this complete dataset as a group. Therefore, a general overview of the information with which we are working is needed, both on a structural level and regarding the relation between that structure and the specific data it holds, so that the different Cultural Heritage specialists can maintain a common idea about the structure of the information in this specific case, what terminology is used (for example, if the term barrow or megalith is employed), etc.

PROBLEM ARomea_2: The complete dataset from A Romea has an abundance of quantitative information, especially regarding the catalogued evidence found during the process of excavation of the barrow, which basically refers to structures and objects. It is necessary, therefore, to have a mechanism for presentation and interaction which enables simple and agile grouping of the evidence found during the excavation of the barrow according to a criterion which the user can vary. In this way, the specialists in Cultural Heritage will be able to group together and categorise the evidence present in A Romea in a rapid and agile manner.

PROBLEM ARomea_3: The information present in the complete dataset from A Romea has a great degree of detail in its description, being able to identify, for example, classes of the extension created which group together 8 or 10 attributes in total, due to the mechanism of inheritance in the hierarchies of specialisation defined. This situation requires, therefore, the handling of levels of importance throughout the visualisation in different interaction units of the information, obtaining, if desired, additional information about a piece of evidence, an event or reference, or a subset of them and maintaining a general view of all of them on the screen.

PROBLEM ARomea_4: The complete dataset from A Romea has an abundance of information about material entities, such as the evidence found during the excavation or the stratigraphic units. All of this information presents cross-cutting characteristics which allow an analysis of the similarities and differences between the data present to be carried out. It is necessary, therefore, to use interface mechanisms which allow the similarities and differences in these subsets of data to be shown.

PROBLEM ARomea_5: The research objectives proposed for the case study of A Romea present a significant temporal component. In fact, its main objective is the tracing of the temporal phases of the barrow of A Romea itself. In this context, it is necessary to present the data reflecting the temporal facet as a main aspect adapted to the case study, paying special attention to the dispersion and vagueness of the temporal data. The geographic aspect is also present in the case study of A Romea, although as it is a limited geographic area, no special needs for presentation and interaction have been identified beyond those already proposed as a general solution for Cultural Heritage in the Chapter 9 entitled "Presentation and Interaction Mechanisms ".

PROBLEM ARomea_6: As we are dealing with information extracted as the result of archaeological excavations, the complete dataset from A Romea has an abundance of information organised sequentially or by levels, in this case corresponding to the stratigraphic sequence of the site. As has already been mentioned, the sequential structure of this type of information could go unnoticed without an interface which explicitly takes in this type of data and the relations between its instances. It is necessary, therefore, to use interface mechanisms which allow the data of the case study related to the stratigraphic sequence of the site to be presented in an adapted way.

Having enumerated the problems to be dealt with in the formal representation of the presentation and interaction in our case study, the application of the proposed solution in A Romea has the following structure:

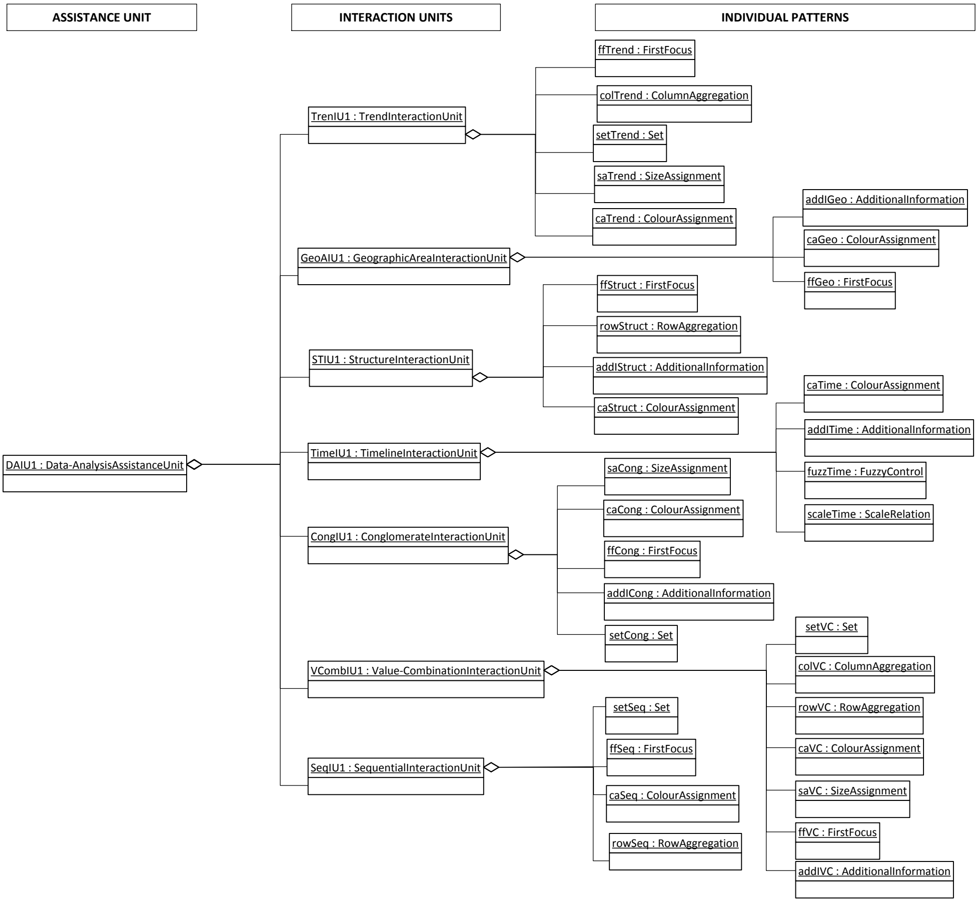

Fig. 78. Instances of interaction and presentation patterns for the case study of A Romea in UML notation.

As can be seen in Fig. 78, an analogous combination of individual patterns and interaction units to the one presented as a proposed framework-solution for the field of Cultural Heritage has been chosen, instancing one interaction unit per type and the individual patterns which correspond to each one, according to the specification and reasons explained in the Chapter 9 entitled "Presentation and Interaction Mechanisms ", with the aim of fully illustrating the proposal. In the case of dealing with other case studies or focusing on problems of knowledge generation of a different kind, the analyst could define configurations of different patterns, thus providing the framework in general, and the presentation and interaction model in particular, with a great degree of flexibility.

Over the course of the rest of the chapter, and in the later Chapter 12, the question of how these patterns have been adapted in order to assist to the problems of the specific case of A Romea will be dealt with.

A Romea: Integration, Interoperability and Consistency between Models

Lastly, the case study must be completed with the formal expression of the relations which exist between the subject model, the cognitive processes model and the model of presentation and interaction mechanisms defined and explained above for A Romea.

In order to achieve this, we shall apply the integration metamodel built with this in mind and described in the Chapter 10 entitled "Integration, interoperability and consistency between framework models". It should be remembered at this point that, according to this integration metamodel, it is necessary for the three models involved (the Subject Model, the Processes Model and the Interaction Model) to be instanced, in order to, then, express, via instances of the integration metamodel (which acts as a pivot), the relations between them.

Over the course of this chapter, we explain in detail how the information about the formal relations between the three parts of the framework are obtained, how this information is reflected in the instances of the integration metamodel proposed for the framework and how these instances allow the framework to carry out the software assistance to the generation of knowledge in the field of Cultural Heritage which we seek, offering adapted software presentation and interaction patterns.

Obtaining Information on Integration

As has been described in Part III of this doctoral thesis, the framework presented acquires the structure and content of the information upon which knowledge will be generated thanks to the subject model. From this subject model, the integration metamodel obtains information about which packages and clusters are defined, what are the main classes and characteristics for each cluster and in which packages the main class of each cluster is present (see the relations between instances of *ClusterMainClassDescription* and *PackageDescription* in Fig. 79). In addition, the framework has a cognitive processes model which allows us to define the most relevant cognitive processes in the field of Cultural Heritage, which we have instanced for A Romea (see Fig. 77).

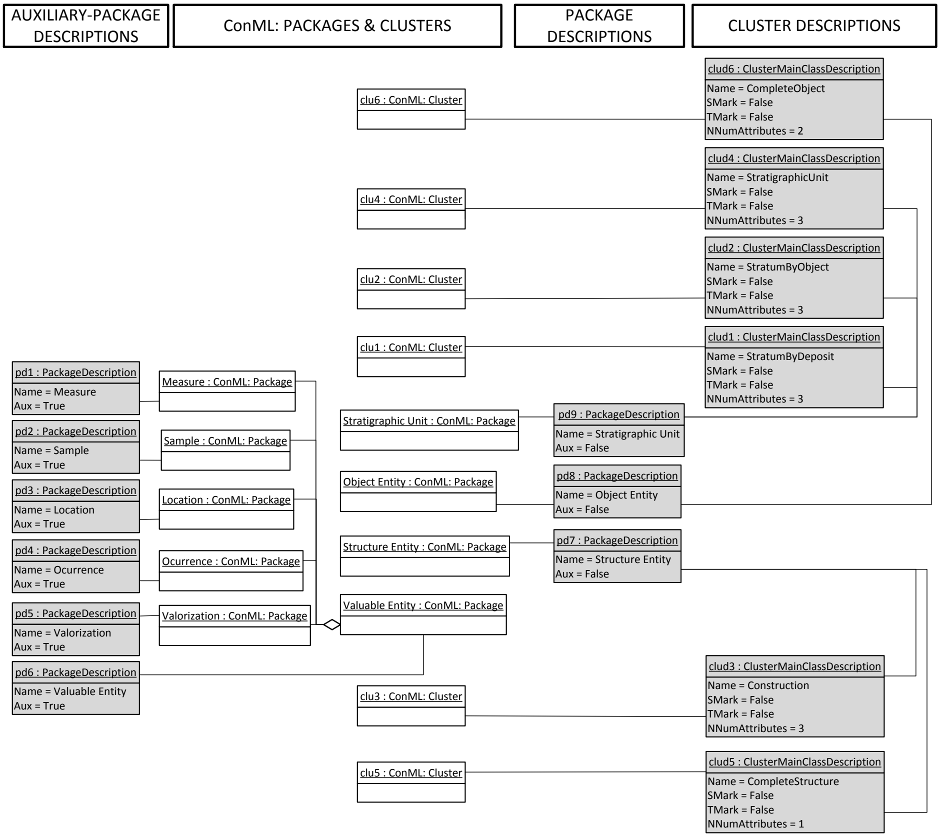

Fig. 79. Information extracted from the subject model of A Romea. The figure shows all the packages defined and the clusters with direct relation to them (6 clusters of the 11 defined in the complete model for A Romea).

It should be noted that the packages which interest us thematically in order to assist to the generation of knowledge are those which have the attribute *Aux* with a value of False, that is to say, the packages which are semantically main in the case study with which we are concerned. In this case, there are three: *Stratigraphic Unit*, *Object Entity* and *Structure Entity*. The clusters which have a direct relation with them, as seen in Fig. **79**, are those which we shall also deal with on the level of interoperability. For each one of the clusters with a direct relation with the packages of the model, four types of cognitive processes are evaluated, which we have defined for the field of Cultural Heritage, instancing one object for each type.

With this information, the case study of A Romea provides us with the following matrix of possibilities:

Package	Related cluster	Building Inference	Clustering Inference	Combining Inference	Situating Inference
Stratigraphic Unit	Stratigraphic Unit	- Structure IU	- Value-Combination IU - Conglomerate IU	- Value-Combination IU - Trend IU	- Geographic IU
	Stratum By Deposit	- Structure IU	- Value-Combination IU - Conglomerate IU	- Value-Combination IU - Trend IU	- Geographic IU
	Stratum By Object	- Structure IU	- Value-Combination IU - Conglomerate IU - Sequential IU	- Value-Combination IU - Trend IU	- Geographic IU
Object Entity	Complete Object	- Structure IU	- Value-Combination IU - Conglomerate IU	- Value-Combination IU - Trend IU	- Geographic IU
Structure Entity	Complete Structure	- Structure IU	- Value-Combination IU - Conglomerate IU	- Value-Combination IU	- Geographic IU
	Construction	- Structure IU	- Value-Combination IU - Conglomerate IU	-Value-Combination IU -Trend IU	- Geographic IU - Timeline IU

Table 5. Matrix of instance possibilities for package defined vs. cognitive processes assisted, and the corresponding interaction units defined in each case.

It should be noted that each cell formed by the cross between cluster-cognitive process evaluated from this matrix would correspond to an instance of the

InteractionOption class in the integration metamodel. In each cell of Table 5, the interaction units which the system can offer for assistance to the generation of knowledge in the field according to each case are defined. For the definition of one or another interaction unit within each cell, the universal guidelines defined in Chapter 10 on Interoperability have been applied, along with those for application to the field of Cultural Heritage. It should be remembered that the universal guidelines are:

- Each cluster defined and each inference of a Building Inference type can determine an interaction option which refers to a Structure IU interaction unit. This interaction unit enables assistance to problems, such as Problem 1 defined in A Romea, related with the necessity of exploring the internal structure of the dataset of the case study

- Each cluster defined and each inference of a Clustering Inference type can determine two interaction options:

  1) An interaction unit of a Conglomerate IU type, which allows the data to be grouped by the values associated to instances belonging to the cluster's main class. This interaction unit allows us to assist to problems such as Problem 2 defined for A Romea, which are related with the necessity for dynamism in the visualisation of datasets.
  2) An interaction unit of a Value-Combination IU type, which allows the data to be grouped by the values associated to attributes and to classes belonging to auxiliary packages which are associated to the cluster's main class. This interaction unit allows us to assist to problems such as Problem 3 defined for A Romea, which are related with the necessity for dealing with levels of importance throughout the visualisation, obtaining, if desired, additional information on subsets of evidence, events or other instances, whilst maintaining on the screen the general view of the cluster being dealt with.

- Each cluster defined and each inference of a Combining Inference type can determine two interaction options:

  1) An interaction unit of a Value-Combination IU type, which allows the values associated to attributes and to classes belonging to auxiliary packages which are associated to the cluster's main class to be explored. This interaction unit allows us to assist to problems such as Problem 3 defined for A Romea, which are related with the necessity for dealing with levels of importance throughout the visualisation, obtaining, if desired, additional information on a piece of evidence, an event or a reference or

a subset, whilst maintaining on the screen the general view of the cluster being dealt with.

2) An interaction unit of a Trend IU type in cases in which the value of the NNumAttributes attribute of the CusterMainClassDescription class is higher than 2. This implies that the main class of the cluster dealt with presents various numerical, enumerated or Boolean attributes, which are potentially susceptible to varying considerably from one version of the dataset to another. This interaction unit allows us to assist to problems such as Problem 4 defined for A Romea, which are related with the necessity for carrying out analyses of similarities or differences between the data at different stages of the research

In the field of Cultural Heritage, we have applied specific guidelines in order to decide the most appropriate interaction unit(s):

- If the main class of the package concerns stratigraphic information and the cognitive process to be evaluated regards Clustering, a Sequential IU unit is defined, which allows Problem 6 defined for A Romea to be assisted, which is related with the specific visualisation of sequential information, of a stratigraphic nature, and its specific analysis.

- Each cluster defined and each inference of a Situating Inference type can determine two interaction options:

1) An interaction unit of a Geographic Area IU type in cases in which the main class of the cluster presents relations with the auxiliary package Location. This interaction unit enables us to assist to problems such as Problem 5 defined for A Romea, which is related with the need for visualising geographic locations of the entities studied.
2) An interaction unit of a Timeline IU type in cases in which the main class of the cluster presents relations with the auxiliary package *Occurrence*. This interaction unit enables us to assist to problems such as Problem 5 defined for A Romea, which is related with the need for visualising information with a strong temporal aspect regarding the entities studied.

In summary, the information obtained thanks to the subject model of A Romea, along with the evaluation of the cognitive processes defined on the level of clusters applying these rules, allows the framework to offer the appropriate interaction units in order to provide assistance to the specialist in Cultural Heritage in these cognitive processes.

It should be noted that the instances of the cognitive processes evaluated, along with the interaction options and interaction units defined in Table 5, are objects in the integration model for the case of A Romea. Due to the complexity of the resulting model, the decision was taken to illustrate the integration model by selecting the instances corresponding to one non-auxiliary package of the three of which A Romea consists: Structure Entity. The complete integration model presents similar models of instances of integration for each one of the remaining non-auxiliary packages of the case study (Stratigraphic Unit and Object Entity). Fig. 80 shows the model of instances of the integration metamodel for the Structure Entity package:

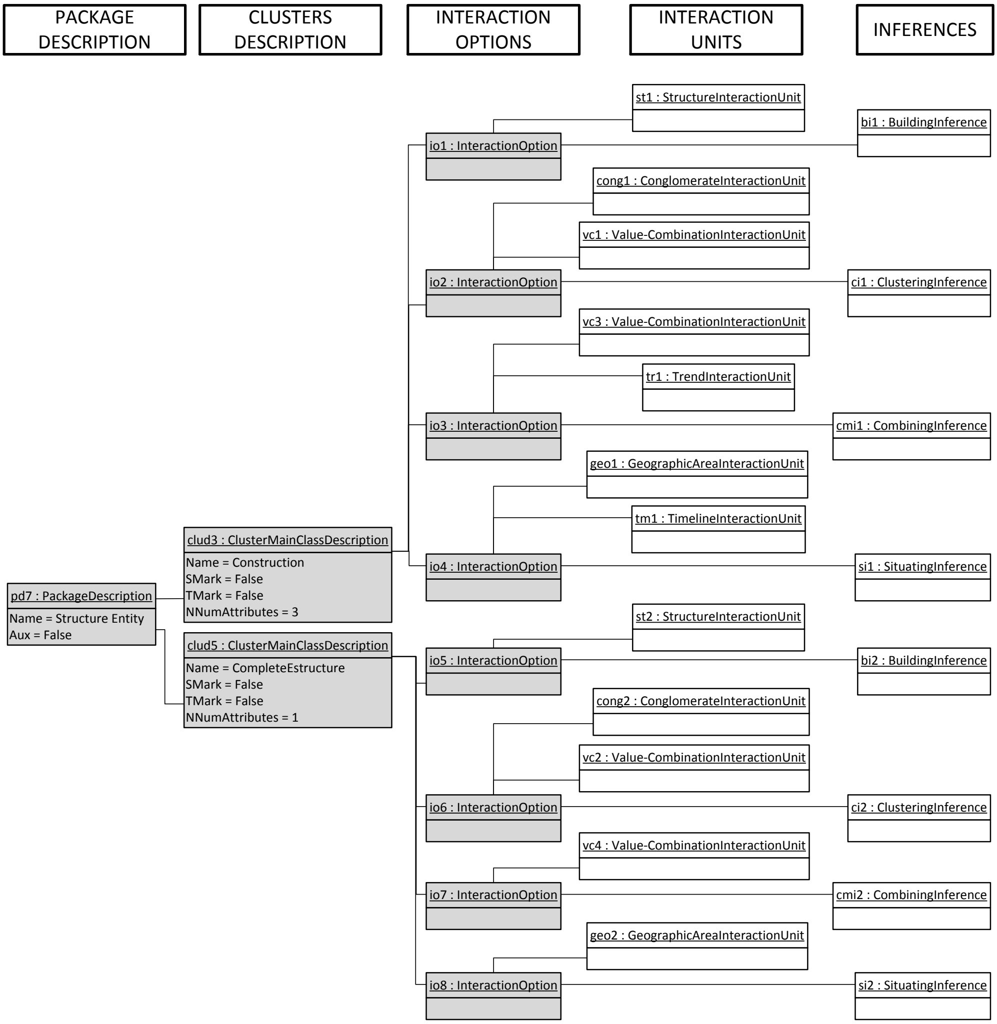

Fig. 80. model of instances of the integration metamodel for the Structure Entity package.

Implementing Interoperability

Up to this time, we have had the complete scenario of the case of A Romea at our disposal, described by specialists in the field via all the empirical data presented in Chapter 5 and appendices, and modelled according to the metamodels of the framework for the three perspectives which concern us: subject matter, cognitive processes and presentation and interaction mechanisms. In addition, we have the instance of the integration metamodel, which defines interoperability between the three perspectives for the case study, as well as which guidelines (both universal and those specific to the case being dealt with) will be applied for software assistance to the generation of knowledge in the case in question.

Both the models of the three perspectives and the integration model which acts as a pivot have been subjected to a first validation, being instanced for a specific case (not A Romea) with data from the field of Cultural Heritage [196, 199]. Its design and validation follow the interoperability framework defined by Pastor [232], which establishes the conditions which need to be fulfilled for an interoperability solution for models in order to guarantee interoperability on syntactic, semantic and technical levels. All of the validation was carried out using tools from the Eclipse EMF suite (*Eclipse Modeling Framework*) [97], and can be seen in detail in [196].

It should be taken into account that, during the validation in [196], the application scenario was narrated by specialists in Cultural Heritage, who had no prior knowledge of the structure of the metamodels involved or of the integration metamodel. In the same way as in this first validation, the specialists also narrated the case study of A Romea, its objectives, the structure of the information dealt with and the new knowledge which was generated in a free way. This separation of activities between the conception of the integration metamodel and the application scenario allows us to establish if the integration metamodel is capable of correctly expressing the relations detailed, avoiding the creation of an ad hoc integration metamodel for the proposed scenario.

As a result, and basing ourselves on the initial validation carried out, we can affirm that the proposed integration metamodel is capable of expressing the relations between the different aspects or perspectives which are involved in a software-assisted knowledge generation system (in terms of subject matter, cognitive processes and presentation and interaction mechanisms) to a high level of abstraction. This permits the materialisation of software assistance by way of adapted visualisations, showing acceptable behaviour in terms of structural cohesion and semantics in the context of EMF. For more information on the EMF implementation carried out, see [97]. Furthermore, the proposed metamodel has been capable of expressing the case study in Cultural Heritage.

Conclusions

This chapter presents the validation of the framework-solution proposed throughout this doctoral research via a case study in the field of Cultural Heritage. During the course of this chapter, the various solutions provided in terms of the subject model, cognitive processes and software presentation and interaction mechanisms for A Romea have been applied. The application of these different solutions have given rise to specific software models which materialise the proposal presented in order to assist specialists in the field in the generation of knowledge in the case study in question. In addition, this chapter shows that the integration of the different modelling perspectives in a common conceptual representation (the integration metamodel), is possible, implemented through open-source technology, such as [97], among others previously detailed.

It can, therefore, be stated that the framework-solution fulfils the desired objectives as far as the capacity for reflecting what kind of software-assisted knowledge generation in the form of information visualisation mechanisms are to be offered is concerned. Applying the proposed framework to any other case study in a similar context would give rise to specific models of application of similar characteristics to those presented throughout this analytical validation, allowing the characterisation of the structure of information which the specific case presents, identifying which of the defined processes we wish to assist (it is not necessary to assist them all) and which application of the pattern metamodel is to be carried out in each case. This lends the framework a great deal of flexibility in terms of specifying what type of software assistance based on information visualisation mechanisms we desire but adjusting it to the needs of the field of Cultural Heritage which we have identified throughout the course of the research. The possibilities of applying, supporting and using the framework presented in other contexts and/or fields, as well as providing other types of software assistance to the generation of knowledge will all be dealt with in detail in the Chapter 13 entitled “Discussion”.

Finally, the scientific contribution which the analytical validation presented in this chapter supposes should be highlighted. First of all, this validation serves as an application and validation scenario for already existing technology and methods, such as CHARM [110] and ConML [144], allowing their capabilities to be demonstrated and their limitations to be detected when it comes to testing them with real heritage information in knowledge generation processes.

Secondly, this validation is, as far as we know at the time of writing this thesis, the first case study in which software-assisted knowledge generation has been fully applied in the field of Cultural Heritage.

The work carried out in the light of this doctoral thesis in this area opens up future lines of research, mainly related with the analytical validation of this software assistance to the generation of knowledge in Cultural Heritage in other case studies which have different contexts of application. In addition, the conceptualisation and design of the case study of A Romea for the validation of the proposed framework-solution has enabled multidisciplinary work to be carried out between specialists in the field of Cultural Heritage and software engineers, increasing self-awareness in the process of knowledge generation in this field and its relationship with software. We believe, therefore, that this case study can open the door to more research which will allow for the application of the framework-solution presented here. These future lines of research and their implications will be commented on in Chapter 14.

Chapter 12: Empirical Validation

A man who carries a cat by the tail learns something he can learn in no other way. -Mark Twain

Introduction

The previous chapter, entitled "Analytical Validation" presented a formal validation of the software models which make up the framework-solution presented in this thesis, applied to the specific case study of A Romea. This validation demonstrates the capacity of the framework-solution to provide the kind of software-assisted knowledge generation in the field of Cultural Heritage which we aim to offer by way of interaction and presentation patterns adapted to the structure of heritage information and to the cognitive processes performed on this information during the knowledge generation process.

However, we were of the opinion that it was necessary to go one step further and create a prototype of the system resulting from the implementation of these framework models for the specific case of A Romea. This prototype has enabled us to carry out an empirical validation of the software assistance provided by the framework-solution. It should be remembered at this point that, as we explained in the presentation of the case study, A Romea is a real case of knowledge generation in the field of Heritage, which was carried out years before this research began. This enabled the software assistance offered by the framework-solution to be evaluated by comparing it to the method employed for knowledge generation in the original case.

This chapter describes the process of implementation and prototyping of the framework-solution, along with the empirical validation carried out in collaboration with Cultural Heritage specialists using the afore-mentioned prototype. This empirical validation complements the analytical validation, which has already been presented, in an attempt to verify the original hypothesis of this research. Furthermore, it allows us to determine the degree of software assistance achieved in the field and to detect problems and points to improve on in the future. This will enable us to provide an answer (with nuances which shall be dealt with throughout this chapter) to the question emerged from the main question *MQ* applying the proposed solution: Are knowledge generation processes in Cultural Heritage significantly improved via software assistance provided to the user by the proposed framework-solution?

Prototyping Process and Prototype Characteristics

The software models resulting from the application of the framework-solution, presented for the specific case of A Romea, provide us with a full structure in terms of the subject model, the assisted cognitive processes and the well-defined software presentation and interaction mechanisms. This structure has served as a reference point for prototyping the framework-solution.

We have developed a prototype which implements the full framework-solution using iOS technology [139], version 8.4 SDK (Software Development Kit) [140] for development in Apple iPad devices. The memory which the device temporarily dedicates to the application enables the subject model's implemented structure to be saved in the relational database (see Appendix II) thanks to the CoreData library [141] (which is integrated into the SDK). Our main motivation when choosing iOS as the basis for the prototype was born out of the prior expertise of the author of this thesis in mobile technologies. Furthermore, having the prototype in tablet format sped up the empirical validation with end users as it enabled us to carry out the empirical validation in different Heritage institutions without the need to install the framework on different devices and gave us greater logistical advantages.

Therefore, the prototype which was built consists of; a part of the subject model, in which the thematic structure of the case of A Romea has been implemented as a relational database (see Appendix II); software controllers, which, instancing the defined interoperability metamodel, enable us to interpret and decide what kind of software assistance is most suitable according to the cognitive process selected by the user and; the defined interaction and presentation mechanisms. Finally, these interaction and presentation mechanisms have been implemented as interfaces, following the mock-ups presented throughout this research.

We shall go on to describe how, during the design phase of the empirical validation, we identified the need for implementing not only the A Romea case study, which has been fully developed throughout this doctoral thesis, in the prototype, but also another heritage case study. This decision was taken in order to prevent the A Romea case study from interfering in the results of the empirical validation. Therefore, a second case study, named "Forno dos Mouros" was chosen and implemented in the same way that has already been described for A Romea.

The resulting prototype allows the user to select which case study he/she wishes to analyse (see in next pages Fig. 84). Then, the user selects which of the four types of cognitive processes instanced in the cognitive processes model he/she wants to perform. The user must also select which package is to be studied from among those defined in the extension of the case study. The structural information of the package and the data of the case study itself can be found in the relational database implemented for each case study.

After having selected these two options, the framework-solution instances the interoperability metamodel and offers the user the available interaction units, according to the instances which have been created from the defined interaction and presentation metamodel (all the possibilities for A Romea can be seen in the Chapter 11). Due to the need to develop another full case study, in addition to the characteristics of the selected cases themselves, the prototype implements a subset of the matrix of possibilities of each case study.

Package	Cluster	Building Inference	Clustering Inference	Combining Inference	Situating Inference
Stratigraphic Unit	Stratigraphic Unit	- **Structure IU**	- **Value-Combination IU** - Conglomerate IU	- **Value-Combination IU** - Trend IU	- Geographic IU
	Stratum By Deposit	- **Structure IU**	- **Value-Combination IU** - Conglomerate IU	- **Value-Combination IU** - Trend IU	- Geographic IU
	Stratum By Object	- **Structure IU**	- **Value-Combination IU** - Conglomerate IU - **Sequential IU**	- **Value-Combination IU** - Trend IU	- Geographic IU
Object Entity	Complete Object	- **Structure IU**	- **Value-Combination IU** - Conglomerate IU	- **Value-Combination IU** - Trend IU	- Geographic IU
Structure Entity	Complete Structure	- **Structure IU**	- **Value-Combination IU** - Conglomerate IU	- Value-Combination IU	- Geographic IU

		Building Inference	Clustering Inference	Combining Inference	Situating Inference
	Construction	**- Structure IU**	- **Value-Combination IU** - Conglomerate IU	-**Value-Combination IU** -Trend IU	- Geographic IU - **Timeline IU**

Table 6. Matrix of possibilities for assistance offered, bold interaction units are offered through the framework-solution prototype.

As far as the specific case of A Romea is concerned, the previous Table 6 shows the matrix of possibilities for assistance offered. The interaction units in bold are those which are implemented in the prototype. In order to illustrate this more clearly, Fig. 81 shows the instance of the presentation and interaction metamodel defined for the A Romea case study, with the classes implemented by the prototype shaded in blue.

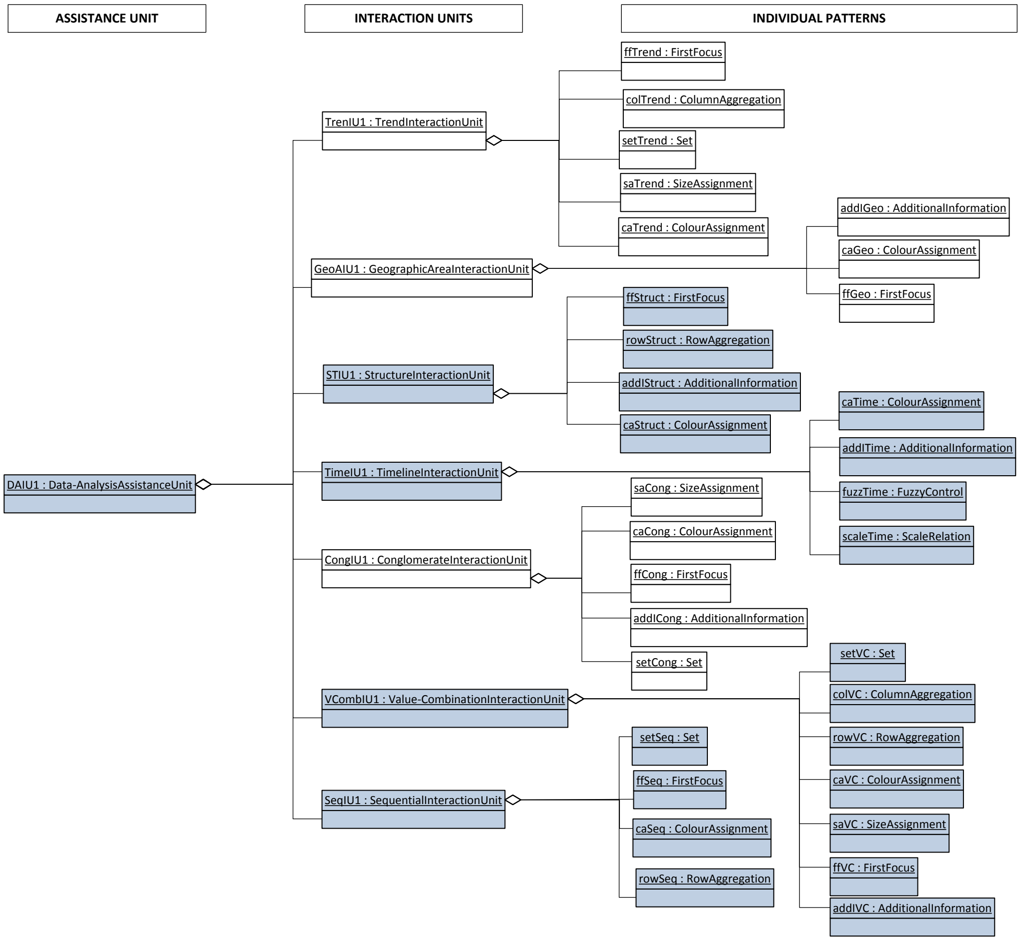

Fig. 81. An instance of the framework's presentation and interaction metamodel applied to the case study of A Romea. The elements implemented by the prototype are shaded in blue.

It should be noted that four of the six types of interaction units defined are implemented. The two exceptions are Trend IU (due to the fact that the case studies do not present much need to observe trends, as there is only one dataset for each case) and Geographic IU (due to the fact that, in both cases, the knowledge generation process being assisted does not present questions of a geographic nature, as both cases are archaeological sites with a clear geographic location without patterns of comparison with other geographic references). The case study of "Forno dos Mouros" follows a similar structure, implementing Structure IU in order to assist in Building inferences, Value-Combination IU for Clustering and Combining inferences and Timeline IU for Situating inferences. In figures from Fig. 82 to Fig. 90 some screenshots of the implemented prototype are shown:

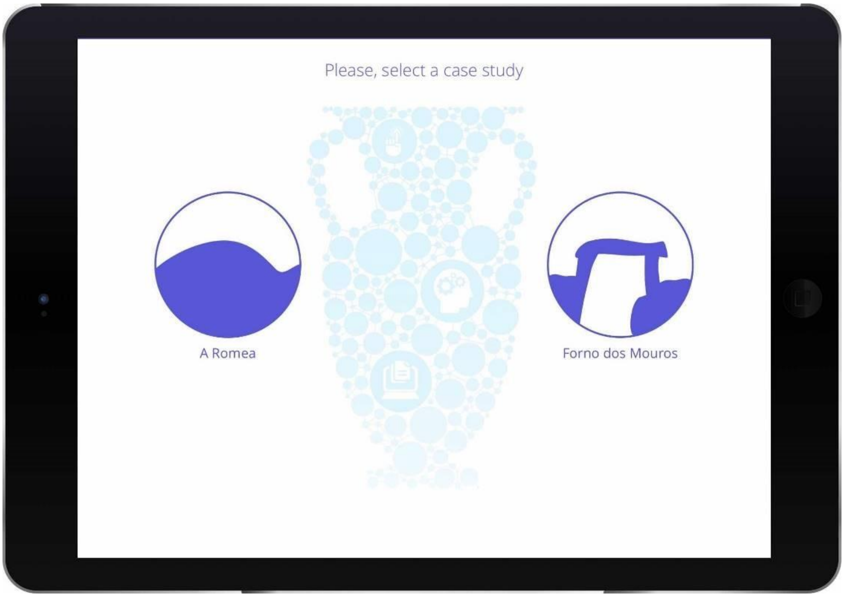

Fig. 82. The home screen of the implemented framework-solution's prototype: the selection of the case study.

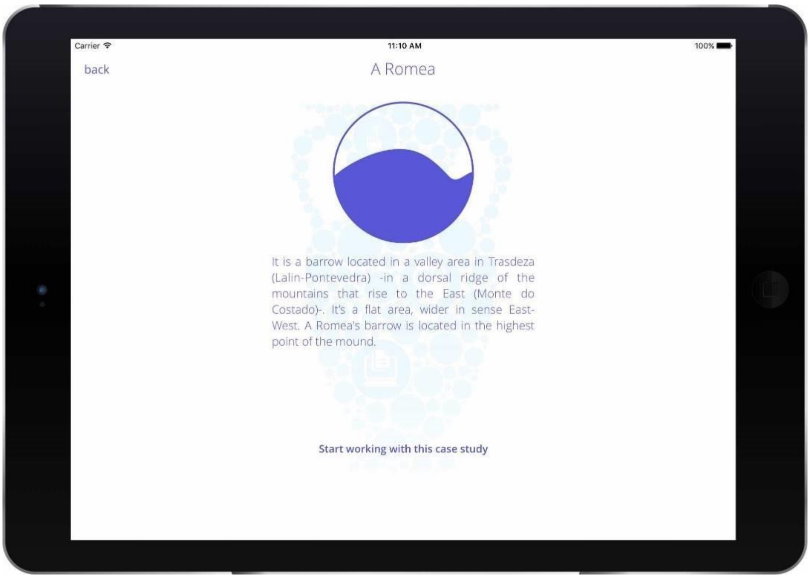

Fig. 83. Screen showing a summary of the selected case study.

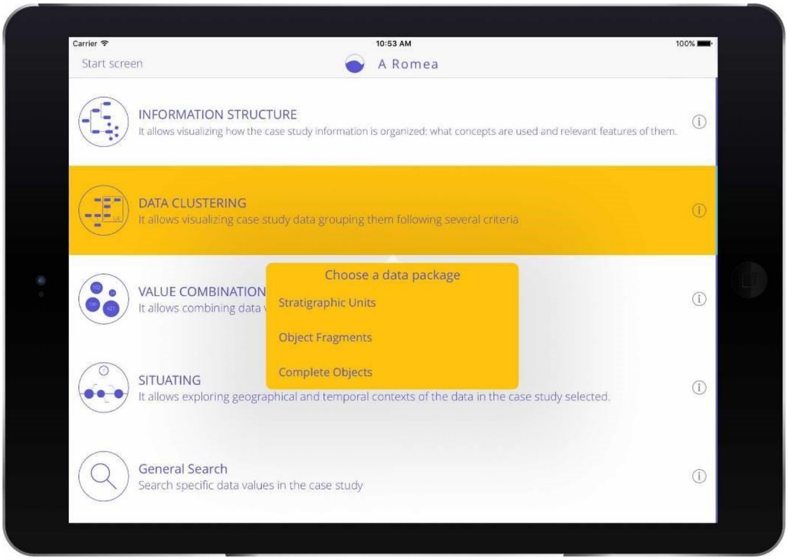

Fig. 84. The selection screen for the cognitive process to be assisted.

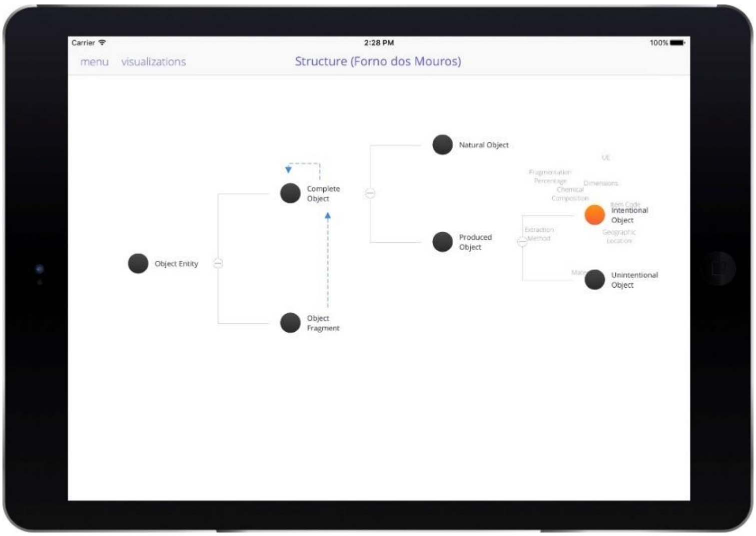

Fig. 85. A screenshot showing the final implementation of the Structure IU interaction unit for the Forno dos Mouros case study (Objects package).

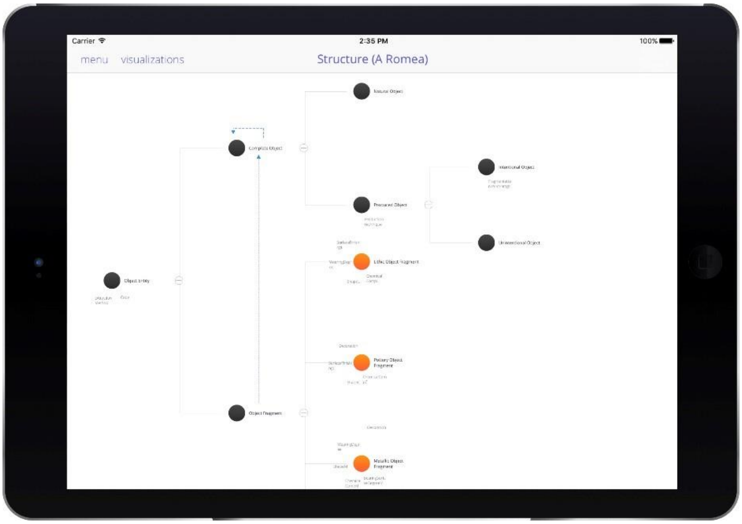

Fig. 86. A screenshot showing the final implementation of the Structure IU interaction unit for the A Romea case study (Objects package).

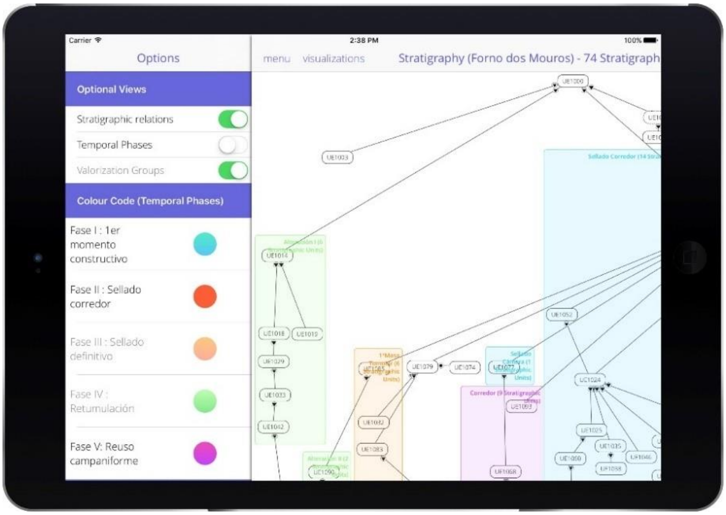

Fig. 87. A screenshot showing the final implementation of the Sequential IU interaction unit for the Forno dos Mouros case study.

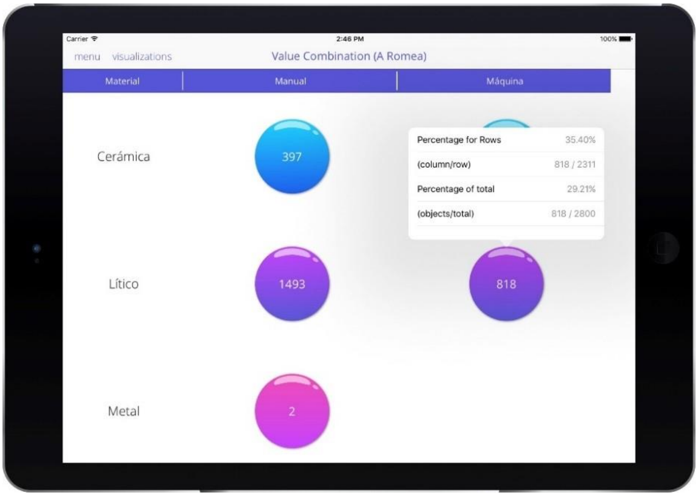

Fig. 88. A screenshot showing the final implementation of the Value-Combination IU interaction unit for the A Romea case study.

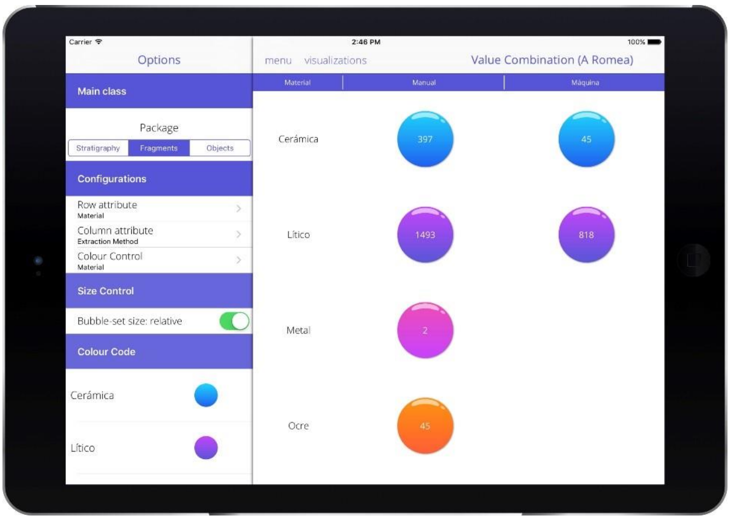

Fig. 89. A screenshot showing the final implementation of the Value-Combination IU interaction unit for the A Romea case study showing the configuration options.

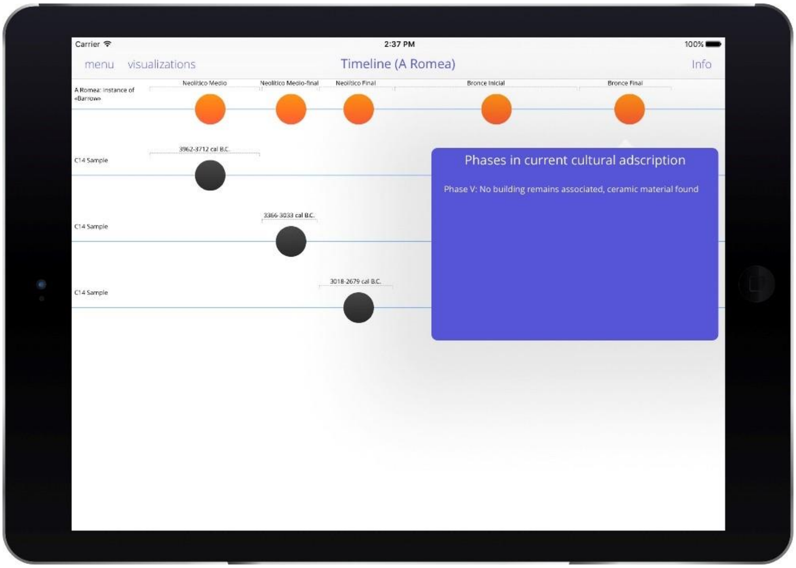

Fig. 90. A screenshot showing the final implementation of the Timeline IU interaction unit for the A Romea case study.

This prototype enables us to test the implementation of the defined framework-solution and to identify possible problems in its effective use. Furthermore, it has served as a tool for the proposed empirical validation. The following section describes the full design of the validation process and how it was carried out employing this prototype.

Validation Methodology

The experience gained during the work carried out for this doctoral thesis in designing, evaluating and monitoring empirical strategies in the field of Software Engineering in Cultural Heritage [192, 194, 198], along with the good results obtained in the prior empirical studies using Wohlin's reference framework (see Appendix I), led us to continue in the use of Wohlin's framework [309] for the empirical validation which concerns us here.

The Validation Process

According to Wohlin's reference framework [309], which was described in the Chapter 5, we shall define below each of the stages of the experimentation process followed for the empirical validation of the software models used in order to assist in the generation of knowledge. These models have been generated throughout this research and are referred to as the **framework-solution**. It should be remembered here that the framework-solution consists of software models affecting three dimensions: the subject model, the cognitive processes model and the software interaction and presentation model. Furthermore, it has an interoperability model which describes the relations between the three aforementioned models, enabling us to express how the software assistance we wish to provide is carried out. The empirical validation of the framework-solution created is described below.

Definition of the Empirical Study Range and Objectives —Scoping—

The objective of the empirical validation in Wohlin's terms [309] can be defined as follows:

"To compare the proposed framework-solution with the traditional method employed in the process of generating knowledge from raw data in Cultural Heritage, with the aim of evaluating the quality of the software assistance provided to the process of knowledge generation from the point of view of Cultural Heritage researchers in the context of public and private institutions in the field of Cultural Heritage in Spain."

Planning

Context

The validation empirical study is set in a specific, though broad, context as the subjects are all Cultural Heritage specialists belonging to public and private institutions on a national scale. The context, therefore, is considered to be the professional environment of the subjects. The objects used are created ad hoc for the empirical study, although they use real data from the field of Cultural Heritage.

The Formulation of Hypotheses

There are many characteristics which can be compared between the traditional method of generating knowledge from raw data and the proposed framework-solution. These include aspects of usability, the study of processes carried out during the analysis itself, the study of decision-making and the role played by the use of one specific method or another, the degree of comprehension and handling, as well as aspects relating to integrity, flexibility and portability of both methods and their related technology. However, because the ultimate aim of the framework-solution is to provide software assistance to the generation of knowledge in Cultural Heritage, we have only selected characteristics of interest in this field. More specifically, we deal with **accuracy**, **efficiency** and **productivity**, which are achieved with both methods when carrying out data analysis tasks for the generation of knowledge. Furthermore, we believe it is relevant, given the assistance nature of the framework-solution, to study aspects of the user's (in our case the Cultural Heritage specialist) **satisfaction**. Finally, the **quality of the knowledge generated** with both methods must be considered, with the aim of fully evaluating the assistance function of the proposed framework-solution. The research questions which aim to deal with each of these characteristics and the hypotheses which arise from them in this empirical validation are as follows:

- **RQ1**: Does the framework-solution affect **accuracy** in tasks relating to knowledge generation in Cultural Heritage? We define accuracy as a "quantitative measure of the magnitude of error" [151]. We shall measure accuracy as the percentage of correct answers that the subjects give once the defined knowledge generation tasks have been carried out. Therefore, the null hypothesis shall be:
  H_{01}: The accuracy in tasks relating to the generation of knowledge in Cultural Heritage using the framework-solution is similar to the accuracy obtained when carrying out the same tasks with the traditional method of data analysis.
- **RQ2**: Does the framework-solution affect **efficiency** in tasks relating to knowledge generation in Cultural Heritage? We define efficiency as "the ability to produce a result with a minimum of extraneous or redundant effort" [150]. We shall measure efficiency as the response time employed by the subjects in carrying out the defined knowledge generation tasks. Therefore, the null hypothesis shall be:
  H_{02}: The efficiency in tasks relating to the generation of knowledge in Cultural Heritage using the framework-solution is similar to the efficiency obtained when carrying out the same tasks with the traditional method of data analysis.

- **RQ3**: Does the framework-solution affect the **productivity** of Cultural Heritage specialists when generating knowledge in Cultural Heritage? We define productivity as "the ratio of work product to work effort" [150]. We shall measure productivity as the ratio between the accuracy achieved and the response time employed in carrying out the indicated data analysis tasks. Therefore, the null hypothesis shall be:
  H_{03}: The productivity in tasks relating to the generation of knowledge in Cultural Heritage using the framework-solution is similar to the productivity obtained when carrying out the same tasks with the traditional method of data analysis.
- **RQ4**: Does the framework-solution affect the Cultural Heritage specialist's **satisfaction** when generating knowledge in Cultural Heritage? We define satisfaction as the degree of "positive attitudes towards the use of the product" [152]. We shall measure satisfaction as the degree of ease of use

expressed by the subjects when carrying out the tasks, via the use of a Likert questionnaire with a 5-point scale. Therefore, the null hypothesis shall be:

H_{04}: The satisfaction expressed by subjects when carrying out tasks relating to the generation of knowledge in Cultural Heritage using the framework-solution is similar to the satisfaction they express when carrying out the same tasks with the traditional method of data analysis.

RQ5: Does the framework-solution affect the **quality of the knowledge generated** by the Cultural Heritage specialists? We define quality as "the degree to which a product meets specified and implicit requirements [152] when it is used in specific conditions" [153]. As we are interested in specifically measuring the quality of the generated knowledge, we must know whether this knowledge meets the needs of the Cultural Heritage specialists. This generated knowledge generally takes the form of text (heritage reports, monographs or similar documents). Thus, a written report in Cultural Heritage shall be evaluated as an end product. We shall measure this internal quality of the generated knowledge by analysing the correctness and satisfaction of the Cultural Heritage specialists when evaluating the written report produced, using the data analysis methods being compared. Correctness shall be measured as the number of errors reported by the Cultural Heritage specialists when evaluating the end product by evaluating a report made during the analysis of each of the data analysis methods. Satisfaction shall be measured as the degree of general perception expressed by the Cultural Heritage specialists when evaluating the end product, using a Likert questionnaire [181] with a 5-point scale. Therefore, the null hypothesis shall be:

H_{05}: The degree of correctness and satisfaction expressed by subjects evaluating the generated knowledge as a product (a written report) of the data analysis process in Cultural Heritage using the framework-solution is similar to the degree of correctness and satisfaction they express when carrying out the same evaluation with the traditional method of data analysis.

The Selection of Variables

RESPONSE VARIABLES

The selected response variables emerge from the five characteristics listed above as being especially relevant when comparing the traditional method of data analysis and the proposed framework-solution. We can define these variables as follows:

- **Accuracy**: the subject's magnitude of error when carrying out data analysis tasks using both methods is measured. The metric selected shall be the percentage of correct answers that the subjects give once they have carried out the defined knowledge generation tasks. The tasks are divided into several items so it is possible to obtain the percentage of accuracy by measuring the percentage of items which have been successfully completed in all the tasks. The total accuracy obtained can be aggregated in two ways: Firstly, by only taking into account the percentage corresponding to the tasks which have been carried out, paying correct attention to all their sub-items (in other words, the tasks which have been carried out fully and correctly). Secondly, accuracy can also be aggregated by calculating the average accuracy obtained for each task, thus avoiding the interference of aspects relating to the type of task at that moment, although this data may be of interest in future analyses.

- **Efficiency**: measuring the subject's ability to carry out tasks relating to the generation of knowledge from raw data, thus providing answers to relevant questions in the generation of new knowledge in the proposed heritage problems by using as few resources as possible. In this case, the selected metric is the response time the subject takes to carry out the tasks. The total accuracy obtained is aggregated by calculating the average accuracy obtained for each tasks, thus avoiding interference from aspects relating to the type of task at that moment, although this data may be of interest in future analyses.
- **Productivity**: the ratio between work and resources achieved by the subject using both methods to carry out data analysis tasks is measured. Therefore, the metric will be that ratio.
- **Satisfaction**: the degree of ease of use for both methods is measured. As we are working in assistance contexts, we believe it is relevant to evaluate this variable, as assistance can be obstructed due to an inappropriate degree of ease of use. The metric used will be the ease of use expressed according to a 5-point Likert scale. The instrument employed is a questionnaire based on Moody's framework [211], which evaluates satisfaction based on three concepts: Perceived Usefulness (PU), Perceived Ease of Use (PEOU) and Intention to Use (ITU). In accordance with Moody's framework, a questionnaire regarding ease of use for each treatment with 22 sentences for evaluation, of which eight evaluate perceived usefulness (PU), nine evaluate ease of use (PEOU) and five evaluate intention to use (ITU). Each questionnaire on treatment refers integrally to all the tasks carried out with the same treatment, following the same structure as the rest of the response variables.
- **The quality of the generated knowledge**: the degree of quality which the generated knowledge presents using both methods is measured. In order to do so, we have selected two relevant sub-aspects in this generated

knowledge: 1) the degree of correctness and 2) the degree of satisfaction of the subjects as far as the new knowledge generated is concerned.

The correctness metric consists of the number of errors reported by the specialists in the field, analysing the generated knowledge by way of the analysis of the written report, according to the method used to produce it. The majority of knowledge generated in the field of Cultural Heritage is found in written texts, as several published studies have already pointed out (see Chapter 4). Therefore, it is important to use this format in order to evaluate the degree of correctness of the knowledge which is generated. After finishing the data analysis tasks with the selected treatment, the Cultural Heritage specialists produced a written report of between 300 and 500 words, in which they summarised the case study analysed and drew conclusions about it. Later, they evaluated the written text of another subject, reporting errors following a script provided which tackles four types of errors:

- Errors, in the opinion of the specialist, in references found in the written report regarding the raw data of the case study analysed.
- Errors, in the opinion of the specialist, in phrases alluding to the processes which the author carried out in order to draw conclusions from the data. For example, the use of verbs such as to compare, to classify, to identify, to categorise, to differentiate, to be the cause or consequence of, etc. or exemplifications and/or generalisations.
- Errors, in the opinion of the specialist, due to redundancies in the written report regarding an aspect which has already been dealt with in another part of the same report, such as the repetition of arguments, references to raw data and examples.
- Errors, in the opinion of the specialist, in phrases alluding to the conclusions which the author comes to regarding the case study.

The satisfaction metric consists of the degree of positive attitude expressed by the Cultural Heritage specialists when evaluating this knowledge by way of the written reports produced by other subjects. This has been measured using a questionnaire with sentences regarding the written reports and evaluated via a 5-point Likert scale.

FACTOR

For each of the variables identified, we shall apply the factor (variable controlled by the responsible of each empirical study, which is applied on different levels in order to discover its impact on the model). We shall call our factor "the data analysis method". It should be noted that this term possesses specific semantics at the heart of this validation: the data analysis method consists of a set of tasks which are performed in order to examine raw data with the aim of extracting conclusions and thus generate new knowledge. Generally, these conclusions will then support the decision-making process in the field in question and will verify or refute existing models or theories within that field. Therefore, we are not dealing with tasks relating to data extraction (which are commonly related to the categorisation of data) but with tasks which focus on the inferences which emerge from the data. The “data analysis method” is made up of two levels:

M_1: The control level. This is the traditional method of data analysis employed to generate knowledge from raw data in Cultural Heritage, based on the direct observation of data obtained from the heritage case being studied. The data is generally organised in a table format and basic software with limited graphic capacity, such as spreadsheets, is used. In this case, we shall use Excel [205], as it is one of the most widespread tools and is commonly used in the institutions to which the subjects in the validation process belong.

M_2: The treatment level. This is the data analysis method to generate knowledge from raw data in Cultural Heritage in which the framework-solution is used to perform the analysis. In this method, the data of the heritage case being studied is described using a CHARM extension [143] and is selected in the form of subsets by the Cultural Heritage specialist. Depending on the subset selected, the framework-solution presents this data organised into interaction patterns, according to the cognitive process being assisted. In order to increase the legibility of the statistical results of this validation, we shall use the acronym **SAKG** (Software Assisted Knowledge Generation) to refer to the proposed framework-solution.

The following Table 7 shows a summary of the research and hypotheses questions dealt with, the variables and the metrics which will be used in order to define them:

Research Question	Hypothesis	Response Variables	Metric
RQ1	**H_{01}**	Accuracy	Percentage of correct answers
RQ2	**H_{02}**	Efficiency	Response time
RQ3	**H_{03}**	Productivity	Accuracy/Efficiency
RQ4	**H_{04}**	Satisfaction	Perceived Usefulness (PU), Perceived Ease of Use (PEOU), Intention to Use (ITU)

Research Question	Hypothesis	Response Variables	Metric
RQ5	H_{05}	Quality of generated knowledge: correctness and satisfaction	Number of errors (Correctness) Likert scale (Satisfaction with the generated knowledge)

Table 7. Research questions dealt with in the validation, the defined variables and their corresponding metrics.

BLOCKING VARIABLES

The heritage problem being dealt with in the validation has been detected as a blocking variable and shall be called P from this point on. In order to prevent the heritage problem from affecting the results of the validation, its value has been balanced, thus blocking the possible effect. In order to do this, P takes two values, P1 and P2. Therefore, the subjects will carry out the data analysis tasks on two different heritage case studies. Another advantage of using two problems is that the threat of the learning effect is avoided, as what is learnt with the problem of the first treatment is not applied in the second treatment. In the section entitled "Design Principles of the Validation", more details are given about how the P variable has been balanced.

The Selection of Subjects

The subjects are all specialists in Cultural Heritage, mainly from heritage sub-disciplines such as History, Archaeology, the History of Art and Architecture. An open call for participation was made via an e-mail list of heritage professionals in Spain or of Spanish nationality. In turn, these professionals were encouraged to share this call with other colleagues. The validation process was carried out with 16 specialists in Cultural Heritage belonging to 7 public (such as the University of Santiago de Compostela, the Institute of Heritage Sciences and the University of Minho) and private (different archaeological companies, the Campo Lameiro Archaeological Park) institutions. The specialists were selected randomly from among all those who expressed an interest in collaborating in the validation process. Later, the implications of the size and characteristics of the sample taken will be dealt with along with the discussion of the results. In order to characterise the sample in a better way, the subjects completed a demographic questionnaire before starting the process of validation, which they did individually. The demographic distribution of the subjects selected is described below.

GENERAL DEMOGRAPHIC DATA

In this section, we shall examine the demographic characteristics of the sample selected to carry out the empirical validation.

As far as gender is concerned, Fig. 91 shows that 56% of the subjects were male and 44% were female. This distribution reflects the proportion by gender in the field of Cultural Heritage. For example, the INE's (Spanish Statistical Office) 2011 report on University teaching in Spain [147] established that, of 170 university teachers in the area of "Archaeology", 73 were women, thus reflecting a female percentage of 42%, which is similar to the distribution of our sample. Another complementary study was carried out on Human Resources in Science and Technology [146] and examined the system of Science in Spain, analysing its different areas. The latter report dates from 2009 and shows that 14.70% of doctors work in areas of the Humanities. Of this 14.70%, 6.56% were women, representing a relative percentage of 44%, similar to our own sample. We believe, therefore, that this balanced and representative distribution as far as gender is concerned allows us to interpret the data obtained without offering views differentiated by gender.

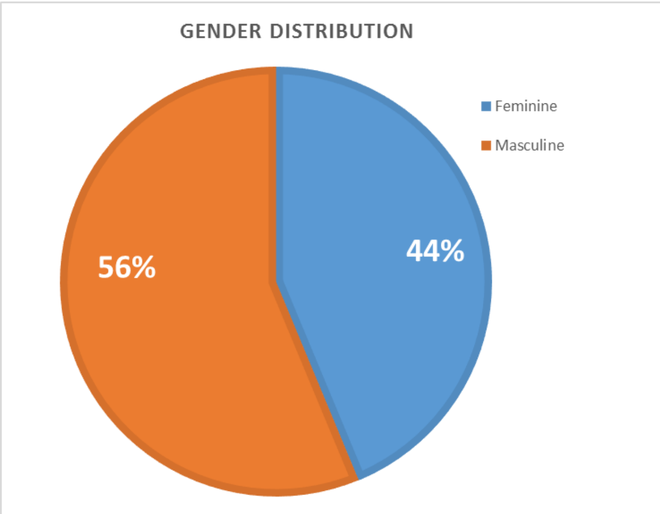

Fig. 91. Percentages of the sample according to distribution by gender.

As far as the subjects' age is concerned, we considered it necessary to carry out the validation with a heterogeneous group, in order to avoid any bias in the sample. Thus, Fig. 92 shows that the oldest group, with 38% of the subjects, corresponds to subjects older than 37 years of age. On the other hand, there is significant representation of the other two groups involved, with subjects ranging from 33 to 45 years of age. The lowest percentage, although it is still representative, corresponds to the age range of 26-32 years of age, which generally corresponds to professionals with less work experience. The age ranges indicated have been defined according to the age ranges commonly used in research, in which the first ranges generally consist of staff in training and the older ranges to research staff with a greater level of experience. It should be noted that age is not an indicator of the level of training of the participating subject in all cases. Therefore, this aspect has been dealt with as a variable separated from age. However, the ranges defined are useful given that, in most cases, they also indicate the stage of the subject's research career.

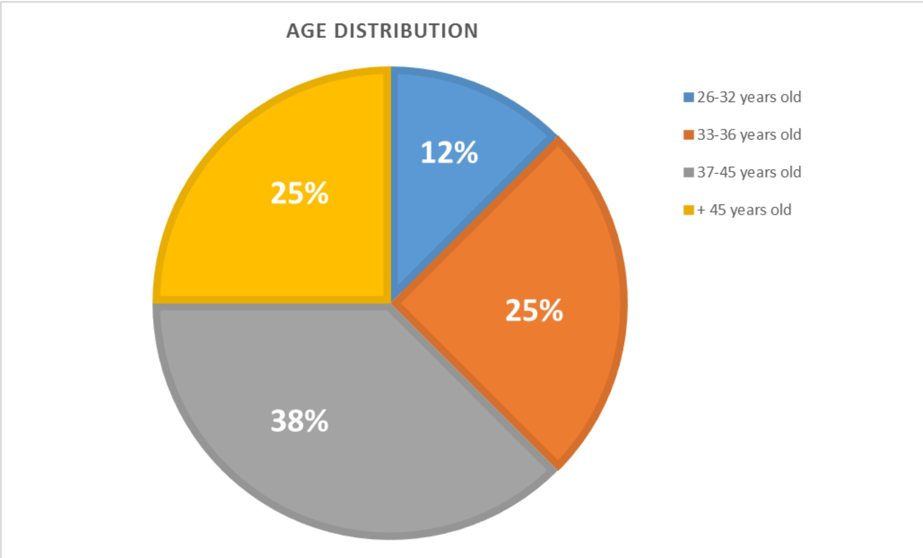

Fig. 92. Percentages of the sample according to age distribution.

Finally, we carried out a profile study regarding the subjects' level of studies. It should be noted that the level of studies of any subject in the sample will be high compared to a random sample of the general population, due to the characteristics of the end users at whom the study is aimed. A professional in the field of Cultural Heritage will generally have a high level of studies so we do not believe that this determines any of the variables being measured in the validation. However, we believe it is interesting to characterise the sample according to the level of studies in order to illustrate that, given a random sample of our end users, almost half of them are doctors (see Fig. 93). This allows us to gain an idea of what type of people generate knowledge in the field of Cultural Heritage and the importance of dealing with reasoning processes, not only defined processes, when it comes to building software assistance in this field.

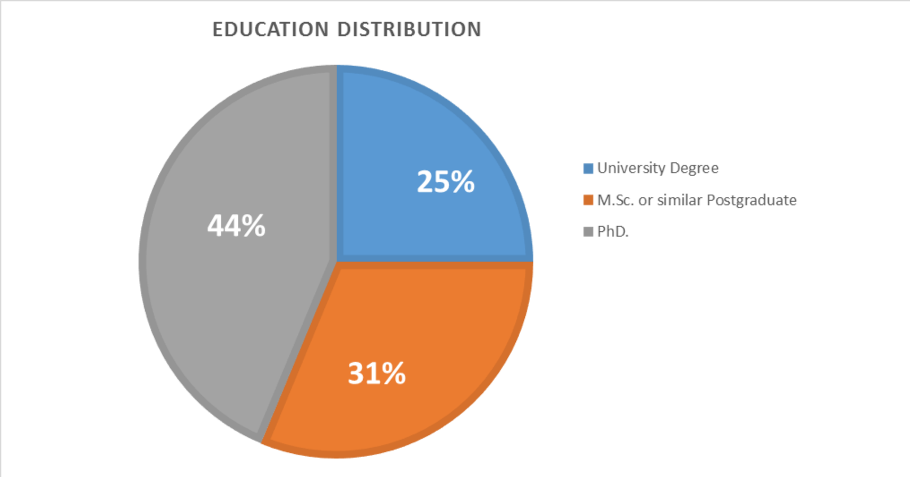

Fig. 93. Percentages of the sample corresponding to level of education.

Therefore, along general lines, we have a sample which is balanced as far as gender is concerned, well-distributed in terms of age and polarized when it comes to the level of education. This last aspect is due to the characteristics of our typical end users: professionals in Cultural Heritage who generate knowledge in the field.

DISCIPLINARY PROFILE

Firstly, we wanted to characterise the sample according to the professional sector to which the subjects belong. In a similar way to the level of education, this variable is illustrated in Fig. 94 and has only been used in order to give a more detailed idea of the type of professionals of which the sample consists. Therefore, 56% of the subjects work in the public sector, 25% in private companies and the remaining 19% are self-employed. This information allows us to gain an idea of the enormous importance of publicly funded research in the field of Heritage in Spain. An in-depth study of the specific field of Archaeology was carried out in 2011 [228], studying the proliferation and subsequent debacle after 2007 of the private sector connected with heritage research in Spain, the area known as “commercial Archaeology”. This study showed that the majority of knowledge generation produced in Cultural Heritage in Spain took place within the public research sector, with the support of small companies or individuals forming a structure based on KIBS (Knowledge Intensive Business Services) [227].

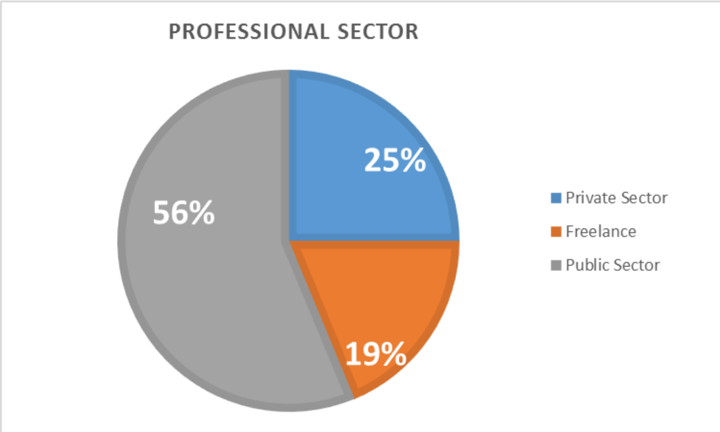

Fig. 94. Percentages of the sample corresponding to the subjects' professional sector.

In the following section, we shall characterise the sample according to the disciplines represented. As has been repeated over the course of this thesis, the area of Cultural Heritage takes in many disciplines, making it complicated to select a sample which is representative of all of them. Taking into account the fact that the objective of this empirical validation is the confirmation of several hypotheses regarding the method of data analysis in two separate case studies, we considered it was necessary to have a heterogeneous sample, albeit one which allowed each of the subjects to have expertise which is in some way related with the subject matter of both case studies. Thus, Fig. 95 shows that 44% of the subjects are archaeologists, due to the fact that the case studies selected fundamentally deal with archaeological heritage. It must be pointed out that, within this 44%, there are archaeologists specialised in different sub-disciplines and chrono-cultural periods, including experts in Metallurgy, Archaeological Science and other areas such as rock art and Prehistoric, Roman and/or Medieval Archaeology, as an example of the internal diversity of this subset. Other groups of experts included architects, restorers, museum managers, art historians, communicators and educators in Cultural Heritage matters. Furthermore, the sample has been diversified with experts in the field of geographical information systems applied to Heritage. These experts are able to offer an interesting perspective to the validation as they handle more advanced knowledge generation tools than mere spreadsheets.

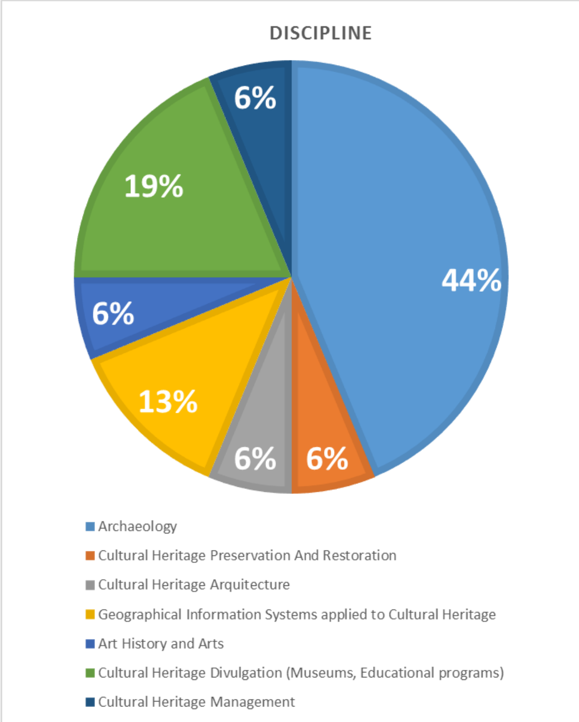

Fig. 95. Percentages of the sample corresponding to disciplines.

HERITAGE PROFILE

Finally, this section aims to offer a more detailed perspective of the sample by characterising specific aspects of the subjects as far as the knowledge generation in Cultural Heritage carried out over the course of their careers is concerned. This was achieved by asking them questions about how much experience they had in handling, managing, documenting and/or researching heritage data, the primary source for the generation of knowledge in the area.

The ranges shown have been defined according to intuitive intervals reflecting the degree of experience of the subject: someone with less than 6 years of experience is considered to be a professional with a low level of experience, increasing in intervals of 4 or 5 years of experience up to 20 years, at which stage it is considered that the individual has acquired professional maturity.

Fig. 96 shows the distribution of the sample by intervals of years of experience. It should be noted that our sample is quite heterogeneous, although subjects with more than 14 years of experience are predominant. We believe this confers robustness upon the sample when it comes to evaluating the data analysis methods used to carry out knowledge generation processes.

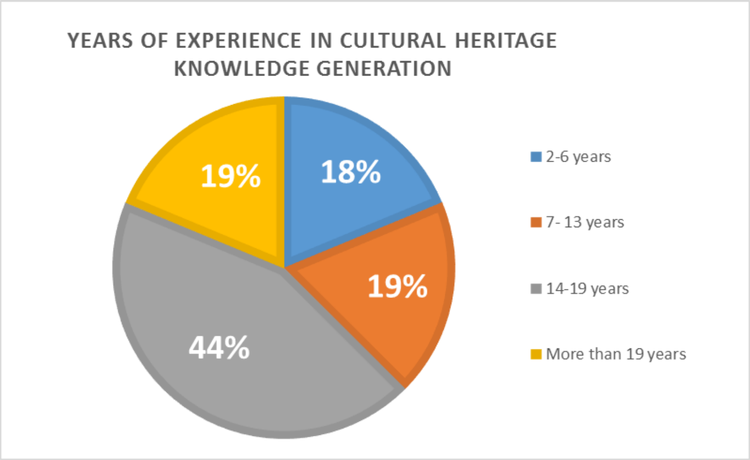

Fig. 96. Percentages of the sample responding to the question "How many years of experience do you have in handling, managing, documenting and/or researching heritage data?

However, it is possible for a professional in the field of Cultural Heritage to have spent many years handling raw heritage data, even working in research, but for their main functions to have been limited to extraction or characterisation, with knowledge generation and in-depth heritage interpretation tasks being performed by other members of the team. In order to avoid this situation, each subject was asked individually what percentage of his/her working time corresponded specifically to the generation of new knowledge in the field and implied the use of data analysis methods such as those being evaluated in the empirical validation. Fig. 97 shows the distribution of answers to this question and how (although the distribution is relatively heterogeneous) the majority of subjects have mainly worked throughout their career on the generation of knowledge. We believe, therefore, that the sample is robust enough in this aspect to be able to evaluate data analysis methods during the processes of knowledge generation.

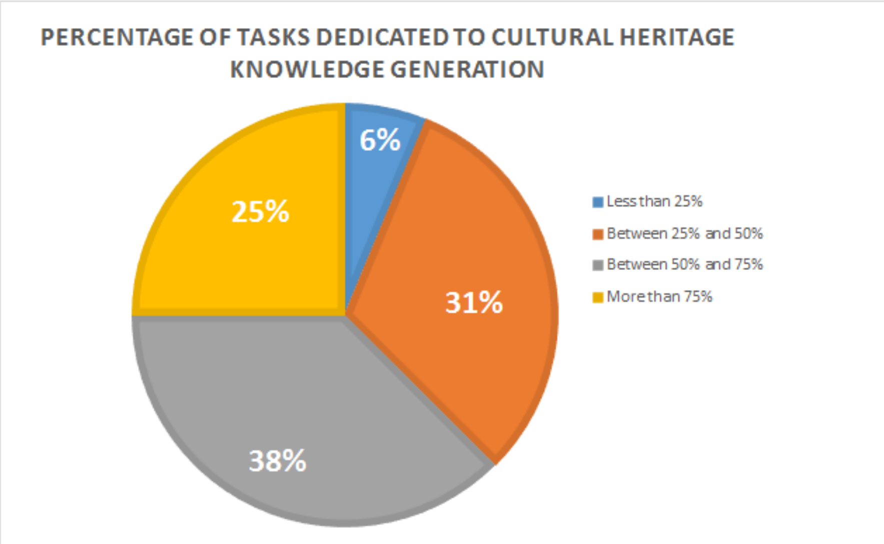

Fig. 97. Percentage of the sample responding to the following question: What percentage of your career would you say has been dedicated to knowledge generation tasks in Cultural Heritage?

Design Principles of the Validation:

In [226], a thorough review is carried out of the alternatives of validation design in Software Engineering following the terminology employed by Juristo & Moreno [164] in order to name different design alternatives. Following these studies, it can be observed that the most appropriate alternative for validations involving two treatments (such as that which concerns us) is the **paired design blocked by experimental objects**, in this case, the variable P, which represents the heritage problem whose data is analysed. This design presents the following advantages: (1) It maximizes the number of subjects in the validation, as it does not divide the size of the sample in two; (2) It limits the dependence of the problem selected, as we have two problems (P1 and P2); (3) The learning effect [226] between the two treatments is avoided, given that the subjects apply both treatments in different contexts (the defined problems P1 and P2).

Therefore, we selected the paired design blocking our variable P (Problem) for the validation. The subjects we divided into two groups (G1 and G2). Both groups used the traditional data method (M_1) in the first session (S1) and the method based on our SAKG framework-solution (M_2) in the second session (S2). The following table shows the design applied:

		P1	P2
Session 1	M_1	G1	G2
Session 2	M_2	G2	G1

Table 8. A summary of the design of the validation.

It should be pointed out that, although the design chosen avoids the majority of the threats to validity previously specified, some threats, which are intrinsic to this design, have been detected [226], mainly those due to the context of the sessions (noise, fatigue among the subjects, interruptions, etc.), which may vary in S1 and S2. Another aspect which may act as a threat to validity is the profile of the subjects. An attempt was made to mitigate this aspect by carrying out initial measuring via a questionnaire. Finally, it should be highlighted that the assignation of the subjects to the groups was carried out randomly, maintaining the same number of subjects in both groups in order to keep them balanced.

Instrumentation

The objects employed in the empirical validation were:

- An initial questionnaire regarding the subjects' profile (gender, age, level of education, discipline and years of professional experience with heritage information).
- A statement with the required data analysis tasks, which were different for problem 1 (P1) and for problem 2 (P2).
- Excel files with the real data employed in both problems (P1 and P2).
- Working prototypes of the framework-solution with the real data of both problems (P1 and P2).
- Two evaluative questionnaires for both methods (M1 and M2).
- A document of guidelines and a satisfaction questionnaire for the written reports.

All of the documents used in the validation can be consulted in Appendix III in the order in which they are listed above.

PROBLEMS

The paired design model blocked by experimental objects selected for this validation requires two separate problems (P1 and P2) to be defined in order to carry it out. The defined problems (P1 and P2) are described below.

Problem 1: A Romea

Problem 1 consists of carrying out an analysis of the data available regarding the historical and archaeological evidence found during the excavation of the archaeological site known as "A Romea" [189]. The case study is located in the excavation and prospection of a metallurgical zone in which objects of different materials, compositions and temporal and functional origins were found. In addition, parts of a barrow were documented via the discovery of structures, attributing temporal phases to the barrow: when it was built, when it was used, when it was abandoned, etc. The data analysis should determine the functional attributions of the archaeological site and the objects found, as well as the temporal phases associated to it based on those objects and structures. In order to do this, there is data available regarding its material composition, morphology, decoration and other aspects of interest for Cultural Heritage specialists concerning the objects and structures found. Furthermore, radiocarbon dating was available for some of the structures, along with geographic information for each documented element.

Problem 2: Forno dos Mouros

Problem 2 consists of carrying out an analysis of data available about historical and archaeological evidence found during the excavation of the site known as "Forno dos Mouros" [6, 177]. The case study is located in the excavation of a megalithic structure used for burials, in the style of a dolmen, in which objects and structures are documented. In addition, the dolmen has the remains of paintings inside. The data analysis must determine the temporal attributions of the objects and structures found. In order to do this, data is available regarding the material composition, morphology, decoration and other aspects of interest for Cultural Heritage specialists concerning the objects, structures and paintings found. Furthermore, geographic information for each documented element is available.

Both problems respond to two case studies from the heritage sub-area of Archaeology, in accordance with the main sub-area dealt with in this doctoral thesis.

DATA ANALYSIS TASKS

As the factor being applied is the "method of data analysis", it is necessary to define a series of data analysis tasks to be performed by the subjects, enabling the five selected variables to be evaluated. Taking into account the field in which the validation in set (that of Cultural Heritage), and previous studies regarding what cognitive processes are carried out in this field in order to generate knowledge [193], certain tasks relating to these cognitive processes have been defined. Each task emphasizes the performance of a specific cognitive process. Thus, the definition is similar for both problems, only varying in terms of the structure and content of the information being analysed in each problem (the answer will vary according to the problem dealt with due to this fact). The statements for the tasks are as follows:

- TASK A: This task concerns processes of the combination of values in order to find out the distribution and characteristics of the materials found in any heritage study.
    - Statement PROBLEM 1: Indicate and note down the total number of ceramic fragments, lithics and/or other materials which have been found at the site. Later, calculate again the totals of the ceramic fragments, lithics and/or other materials but, this time, also according to the method of extraction used.
    - Statement PROBLEM 2: Indicate and note down the total number of ceramic fragments, lithics or other materials which have been found at the site. Later, calculate again the totals of the ceramic fragments, lithics or other materials but, this time, also according to whether the fragments are decorated or not.
- TASK B: This task concerns grouping processes.
    - Statement PROBLEM 1: Indicate and note down the percentage of average fragmentation presented in the ceramic objects extracted mechanically.
    - Statement PROBLEM 2: Indicate and note down the percentage of average fragmentation presented in the ceramic objects extracted manually.
- TASK C: This task concerns processes of contextual situation in order to discover the temporal characteristics of the objects and/or material structures found in any heritage study.
    - Statement PROBLEM 1: Indicate and note down the different chronological attributes which you believe have been associated with the objects found in the site.
    - Statement PROBLEMA 2: Indicate and note down the different chronological attributes which have been associated with the ceramic fragments found in the site. Then, reason about the cultural attributes of the complete ceramic pieces: Are you able to associate a chrono-cultural attribute to each ceramic object? Indicate the ones associated to pieces PZ01 and PZ06.
- TASK D: This task concerns processes of the combination of values in order to discover functional aspects of the materials and structures found in any heritage study.
    - Statement PROBLEM 1: Indicate how many stratigraphic units have been defined and according to which criteria the groups of these stratigraphic units have been created. Then, indicate which units

make up the "Barrow Chamber" group and the "Alteration Path" group.
    - Statement PROBLEM 2: Indicate how many stratigraphic units have been defined and according to which criteria the groups of these stratigraphic units have been created. Then, indicate which units make up the "First megalithic zone" group and the "Chamber access: pit" group.
- TASK E: This task concerns processes of the analysis of the internal structure of the data.
    - Statement PROBLEM 1: Indicate which attributes (relevant characteristics) of the objects found have been documented.
    - Statement PROBLEM 2: Indicate which attributes (relevant characteristics) of the stratigraphic units found have been documented.
- TASK F: This task is related to processes of contextual situation in order to discover the temporal characteristics of the objects and/or material structures found in any heritage study.
    - Statement PROBLEM 1: Indicate and note down which temporal intervals (chronological assignments) have been attributed to the A Romea barrow in a global manner, paying attention to all the information you are given regarding the stratigraphy of the materials found.
    - Statement PROBLEM 2: Indicate and note down here which temporal intervals (chronological assignments) have been attributed to the Forno dos Mouros barrow in a global manner, paying attention to all the information you are given regarding the stratigraphy of the materials found.
- TASK G: Answer the following question: **What heritage conclusions do you draw from the case study in question?** by writing a brief text of approximately 300-500 words.
- TASK H: Point out, using the template created for this purpose, the errors which, in your opinion, can be observed in the written report which you have been given to evaluate.

The written reports produced are reflections of the knowledge generated as a result of the data analysis. Tasks G and H will serve, therefore, to evaluate these written reports at a later time in terms of the quality of the knowledge generated via the metrics defined for this purpose (correctness and satisfaction). By neither referring to the structure of the information nor to the specific content of each problem dealt with, problems P1 and P2 both have the same statement.

The Development Dynamics of the Empirical Validation

As far as the lines of action in carrying out the study are concerned, the subjects were given some brief instructions about the dynamics and they were allowed to ask some initial questions. No previous training of the subjects was considered necessary as far as the methods to be used were concerned: the traditional method of data analysis was well known by all the subjects, whereas the method of analysis using the framework-solution was not known beforehand. This difference is assumed within the validation in order to find out how intuitive the framework-solution is, although we are aware that some prior training in the latter method could affect (hopefully in a positive way) the results offered by the subjects with this method. However, our interest in finding out how intuitive the proposed method is, along with recommendations made in empirical studies in Software Engineering [309], led us to take the decision not to offer any prior training in either of the two methods, assuming the difference in familiarity of the subject with both methods and the difference in the degree of expertise between the two. The dynamics of the empirical validation were divided into two sessions (S1 and S2), as can be seen in Table 8. Each session consisted of specific phases:

1. In the first phase, the subjects filled in the demographic questionnaire, which was the same for everyone. Then, the subjects were divided into two groups, chosen at random. This phase was only carried out in the first session of the validation.
2. In the second phase, the subjects performed tasks A, B, C, D, E and F applying the method (or treatment) assigned in each case to the problem selected, depending on whether it was session S1 or session S2, according to the design shown in Table 8. Therefore, this phase was carried out in both sessions. Once the tasks were completed, each user filled in the corresponding satisfaction questionnaire, independently of the group to which they belonged.
3. In the third phase, each subject wrote a report of less than 500 words about the case study dealt with in the session. It should be noted that, depending on the group to which the subject belonged, he/she had performed the tasks following one method and on one problem in each session. He/she, based on the data analysis performed, had to answer the question: What heritage conclusions do you draw about the case study dealt with? This phase was also carried out in both sessions.
4. In the fourth phase, each subject had to evaluate a report written by a different subject. The possibility of one subject evaluating his/her own report was avoided. This task corresponded to task H and was carried out at the end of the second session. The subjects were able to evaluate reports written after using either method of data analysis and regarding either of the two problems. The full dynamics of the validation can be seen in Fig. 98.

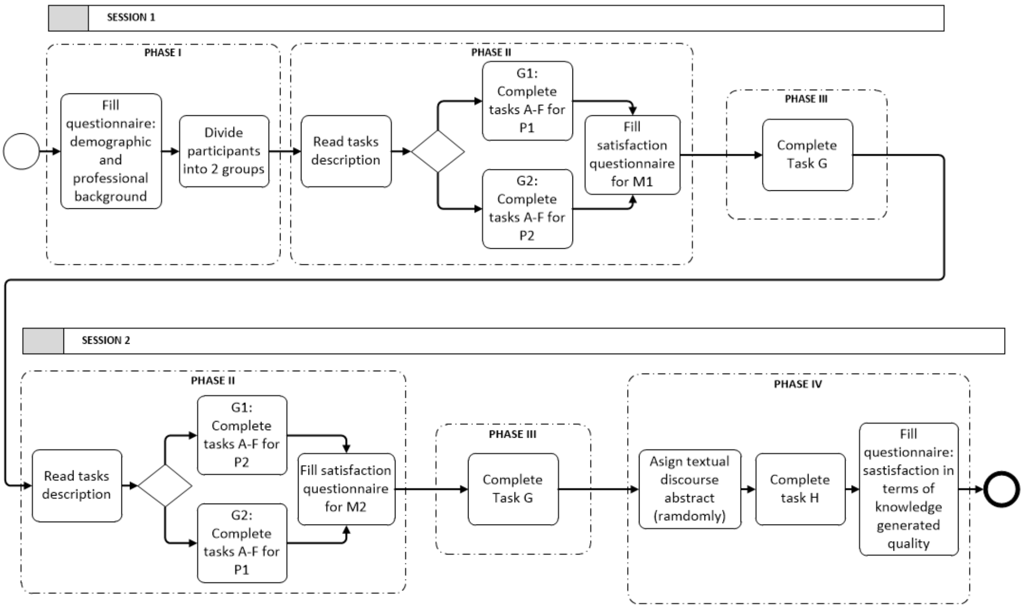

Fig. 98. The development dynamics of the empirical validation, indicating the phases corresponding to each session. The rectangles represent tasks, whereas the diamonds indicate the beginning of tasks performed in parallel.

An Evaluation of Validity Aspects

Due to the need for empirical validation of the framework-solution presented in this thesis, it was considered necessary to carry out an in-depth analysis of all the threats to its validity which could present themselves. Unlike the empirical studies described in the Chapter 5, which have an exploratory nature, this time the empirical validation presented here must be rigorous on a methodological level in order to guarantee the validity of the results produced. Due to this fact, on this occasion, the threats identified in the literature in the field of Software Engineering (Wohlin [309], based on Cook & Campbell [60]), have been analysed one by one in an attempt to identify those which may influence the validation presented and to describe how they have been mitigated (see from Table 9 to Table 12):

CONCLUSION VALIDITY

Threat	Reason	State	Treatment of the threat
Low statistical power	The size of the sample is not big enough.	Avoided	We avoid the threat by maximizing the number of subjects with repeated measures and calculating the statistical representativeness for each null hypothesis.
Subjects of random heterogeneity	The subjects have not been selected at random and their profile is heterogeneous.	Avoided	The subjects are selected at random from among all the volunteers. The profile is heterogeneous, albeit with a common feature: all of them are specialists in Cultural Heritage.
Fishing	The conductors of the empirical validation seek a specific result.	Avoided	We avoid this threat by processing all the data gathered in order to avoid introducing bias when filtering.
Reliability of measures	There is no guarantee that the results are the same when measuring the phenomenon again.	Partly suffered	The metrics for accuracy, efficiency, productivity and correctness of the knowledge generated are objective. The metrics for satisfaction are subjective, so they are suffered by the threat.

Threat	Reason	State	Treatment of the threat
Reliability of the implementation of the treatment	There is the risk that the application is not similar among the different people requesting the treatment or on different occasions.	Partly suffered	The implementation must be as standard as possible among the different subjects and occasions. We mitigate the threat of different occasions by controlling the sessions, and of different treatments by homogenising the possibilities of the tools used in the two treatments. In this way, we believe that the differences in application between subjects will be minimized.
Random irrelevancies in experimental settings	There are elements which are external to the empirical validation which may interfere in it.	Suffered	We cannot guarantee that the subject does not carry out any other task while performing the validation. We mitigate the threat by actively supervising the sessions.

Table 9. Analysis performed about conclusion validity threats.

CONSTRUCT VALIDITY

Threat	Reason	State	Treatment of the threat
Interaction of testing and treatment	The subjects apply the metrics to the treatments	Avoided	The conductors of the empirical validation apply the metrics.

Threat	Reason	State	Treatment of the threat
Mono-method bias	The empirical validation with only one type of measure may present bias.	Partly suffered	The variables regarding accuracy, satisfaction and quality of the knowledge generated present more than one metric, thus avoiding the threat. The variables regarding efficiency and productivity suffer the threat, which we minimize by automatizing the time measurement.
Hypothesis guessing	The subjects sense the purpose of the empirical validation and act in consequence.	Suffered	We minimize the threat by not commenting on the objectives, research questions and defined metrics with the subjects.
Evaluation apprehension	The subjects are apprehensive about being evaluated.	Avoided	We avoid this threat by not commenting on the evaluative nature of the validation with the subjects and including the tasks in a research talk/visit in order to find out about their working methods.
Interaction of different treatments	The result may be caused by the combination of treatments applied.	Suffered	Due to the fact that the traditional method is always applied first, the validation suffers this threat. We cannot ensure that the order of application does not affect the results.

Threat	Reason	State	Treatment of the threat
Mono-operation bias	An operationalisation of the treatments based on just one method may introduce bias.	Suffered	Due to the fact that the data analysis methods are analysed using specific tools (Excel and the framework-solution), the validation can be affected. It may be dangerous to generalise the results to other spreadsheets. As far as the framework is concerned, it must be validated as a data analysis method. Therefore, it must be chosen.

Table 10. Analysis performed about construct validity threats.

INTERNAL VALIDITY

Threat	Reason	State	Treatment of the threat
History	The different treatments are applied to the same object with a significant time difference.	Avoided	We avoid this threat by minimizing the time between sessions and by maintaining communication with the subjects during this time.
Learning of objects	The subjects may acquire knowledge from the first treatment and apply it to the second.	Avoided	We avoid this threat by using two different problems which do not allow the subjects to learn aspects of the object.
Subject motivation	Less motivated subjects may present worse results than more motivated ones.	Suffered	We mitigate the threat by using only volunteer subjects whose motivation in the validation is high.

Threat	Reason	State	Treatment of the threat
Maturation	The subjects react differently as time passes.	Avoided	We avoid this threat by applying the traditional method first as it is the one which is normally used.
Selection	The results are affected by how the subjects are selected.	Avoided	The subjects are volunteers in the validation.
Resentful demoralisation	The subjects only apply one treatment.	Not applicable	The subjects apply both treatments.
Mortality	The subjects may abandon the validation before the end.	Suffered	Due to the fact that the subjects are volunteers and that two sessions take place, the subjects may abandon the validation. We mitigate this threat by minimizing the time between sessions and maintaining communication with the subjects between sessions.
Compensatory rivalry	The subjects who apply only the less desired treatment may influence the results.	Not applicable	The subjects apply both treatments.

Table 11. Analysis performed about internal validity threats.

EXTERNAL VALIDITY

Threat	Reason	State	Treatment of the threat
Interaction of selection and treatment	The subjects do not represent the general population at which the validation is aimed.	Partly suffered	The subjects have different profiles but one common feature: all of them are specialists in Cultural Heritage. We believe that this fact mitigates the threat in terms of generalisation, although the results are only valid for similar profiles.
Object dependency	The results depend on the objects used and cannot be generalised.	Suffered	We minimize the threat using two objects for each treatment.
Interaction of history and treatment	The treatments are applied on different days: the circumstances of the moment may affect them.	Suffered	The threat is suffered due to the existence of two sessions. We minimize the threat by applying both treatments in the same room and at the same time during each session.
Interaction of setting and treatment	The elements used in the validation are obsolete.	Not applicable	The questionnaires used are published and in use.

Table 12. Analysis performed about external validity threats.

Operation

Preparation: The subjects in the empirical validation did not know the case studies being used nor were they familiar with the data. They were given minimal information about method 2 in the cases in which they needed to use that method, though they were not offered any prior training or informed of the hypotheses being dealt with in the study. By offering themselves as volunteers for the validation, they gave their consent to these aspects. The necessary materials referred to in the earlier section entitled “Instrumentation” were prepared in advance.

Execution: The subjects attended two sessions of between 60 and 90 minutes in length.

Validation of the data: No invalid data was detected. This can be attributed to the individuality and supervision of the process of executing the study.

Analysis and Interpretation

Other studies carried out in Software Engineering with a paired design blocked by experimental objects [81, 164, 226] were taken into account for the analysis and interpretation of the results. These studies generally use the general linear model with repeated measures (thereby maximizing the number of responses), known as GLM [81], in order to analyse the data obtained during the empirical validation, in which both levels for the factors (method M1 and method M2) are applied to each subject. However, prior studies [226] conclude that the existence of blocking variables (in our case, the variable P, corresponding to the heritage problem analysed) requires a greater treatment than that offered by the GLM model. Thus, the use of a **Mixed** statistical model with the type of covariance for "unstructured" [226] repeated measures is recommended.

Therefore, we define this model for the analysis, in which the factor (in our case the data analysis method) and the blocking variable (in our case the heritage problem P) are defined as fixed variables as we apply two levels of both variables to all the subjects participating in the validation. The subjects are defined as a random variable, due to randomness in the process of making up the sample (as was stated earlier, an open call for participation was made to a mailing list of heritage professionals in Spain or whose subjects were Spanish, with those offering themselves as volunteers making up our sample).

In order to be able to apply the aforementioned mixed model, we must first check if it complies with the assumption of normality of residuals. This condition can be checked by applying a K-S test to each response variable analysed during the application of the mixed model [81]. This test was carried out for each of our response variables, with all of them passing except the **Accuracy_TaskC** variable. For this reason, the application of the mixed model was made viable for all except the latter response variable, whose difference between the values obtained for each method is not big enough to apply a mixed model and. Therefore, we assume that this difference indicates that there are no significant levels for either of the two levels of the method.

The application of the mixed model enables us to find out whether the hypotheses made previously, and defined via the response variable, can be confirmed. In order to do this, we observe the **p-value** offered for each hypothesis to be tested, as well as the level of satisfaction offered by the model for each variable. If the level of significance α is less than 0.05, the null hypothesis must be rejected, due to the fact that there are significant differences between the two treatments. In the opposite case (α being greater than 0.05), there is no evidence to reject the null hypothesis. The application of the model and the analyses specified previously have been carried out using the SPSS V23 suite [138].

However, to what degree of magnitude is this difference significant? The **effect size** [122] enables us to know the magnitude of the differences for each factor. This is normally only applied in cases of null hypotheses refuted beforehand via the p-value. There are several coefficients which enable us to evaluate this effect size. In this case, the **Cohen's d** coefficient [58, 59] has been selected in order to calculate the effect size, due to the fact that its entries are studies of averages which are normally carried out when two treatments are applied to one subject. Cohen's d is defined as the difference between two averages divided by the standard deviation which the data presents. A value of the effect size of between 0.2 and 0.49 implies a small effect, between 0.5 and 0.79 a moderate effect while greater than 0.8 represents a large effect.

In this point, thanks to the application of the mixed model and the later measuring of the effect size, we can discover which null hypotheses are refuted and at what magnitude. The mixed model will also offer us a calculation of the p-value combining the response variables with the blocking variable for each hypothesis being tested (see Problem*Method column). This enables us to know whether the blocking variable (in our case the heritage problem in question) is interfering significantly in the hypothesis being tested.

Last of all, it is important to point out that the conclusions of the statistical studies (and other studies and/or models which we could have applied) also depend on the power of a statistical test, in other words, the probability which exists of the refutation of a null hypothesis. This probability gives us an idea of how representative the sample taken is with regard to the total population with which we are concerned and, therefore, what capacity of generalisation we reach with the validation that we are carrying out. The application of a mixed model does not allow for the statistical calculation of the power (as a statistical impossibility independently of the statistical tool we may use). Due to the importance of the information regarding the representativeness of the sample offered by this test, we have simulated a statistical test of standard repeated measures (as, in our case, we have two treatments which are applied to the same subjects) in order to calculate with the G*Power tool [91, 92] what sample size is necessary in a model of repeated measures in order to obtain a specific statistical power. In our case, we selected the value generally used in order to obtain a high power (power=0.95) and a moderate effect size (effect size=0.5). In order to obtain these values, a sample of at least **12 subjects** is required. Although this sample size is calculated for a model of repeated measures without a blocking variable, we believe that our sample of 16 subjects (and, therefore, within the magnitude of the estimate made) is adequate as, in a model of repeated measures, it implies a moderate-high statistical power from our empirical validation.

The following sections analyse the results obtained for the p-value and Cohen's d for each of the defined null hypotheses.

Results and discussion of hypothesis H01: Accuracy

Hypothesis H_{01} stated: Accuracy in tasks relating to the generation of knowledge in Cultural Heritage using the framework-solution is similar to the accuracy obtained when performing the same tasks with the traditional method of data analysis.

This accuracy is defined by the measurement of the percentage of correct answers given by the subjects when performing the defined knowledge generation tasks. The percentages were measured for each task (from task A to task F), in order to aggregate them with two more variables:

- *Accuracy_Total_AllNothing* indicates accuracy only for the tasks in which all the sub-tasks were performed correctly.
- *Accuracy_TotalWeighted* aggregates the percentages taking into account the individual percentage of each task and giving all the same tasks the same weight.

Table 13 shows the p-values and the Cohen's d coefficients obtained for each of the tasks and for the two accuracy variables which aggregate all the tasks. Cohen's d was only calculated if the Method factor obtained significant values.

Variable	**P-value**			**Cohen's d**
	Method	**Problem**	**Problem*Method**	
Accuracy_TaskA	**0.000**	0.107	0.409	1.60
Accuracy_TaskB	1	0.249	**0.004**	
Accuracy_TaskC	-	-	-	
Accuracy_TaskD	**0.007**	0.671	0.994	1.22
Accuracy_TaskE	**0.010**	0.678	0.120	1.17
Accuracy_TaskF	**0.003**	0.312	1	1.34

Accuracy_Total_AllNothing	**0.000**	0.745	0.723	2.01
Accuracy_TotalWeighted	**0.000**	0.943	0.824	2.12

Table 13. P-values and Cohen's d for the accuracy variables. The values in bold show significant p-values which refute the null hypothesis H_{01}.

As can be seen in Table **13**, the model offers p-values of less than 0.05 for accuracy in tasks **A, D, E** and **F** and in the variables which aggregate the total accuracy of the data analysis tasks taking into account only those performed correctly (***Accuracy_Total_AllNothing***) and giving the same weight to all the tasks (***Accuracy_TotalWeighted***).

For all the accuracy variables which offer significant results, the averages of the results obtained are higher for method M2 than for method M1 (see Appendix III for the averages), which indicates better results for accuracy when using the framework-solution than when using the traditional method. The values corresponding to Cohen's d coefficient for accuracy in tasks A, D, E and F for the aggregated variables are higher than 0.8, indicating a large effect size. This can be seen more clearly in Fig. 99 and Fig. 100, which show box-and-whisker plots for the two aggregate accuracy variables. Box-and-whisker plots are a visual presentation which describe several important characteristics of the variable represented, such as dispersion and symmetry. They are made by representing the three quartiles and minimum and maximum values of the data on a rectangle. The longer sides show the interquartile range. This rectangle is divided by a segment which indicates the position of the median and, therefore, its relation with the first and third quartiles (it should be remembered that the second quartile coincides with the median). Any atypical values are represented by small circles outside of the central rectangle. In this case, we can observe how, in both cases, the median, the first and third quartiles for accuracy using the SAKG framework-solution is greater than when using the traditional method with spreadsheets. This means that the subjects obtained better results in terms of aggregate accuracy when working with the framework-solution compared to the traditional method.

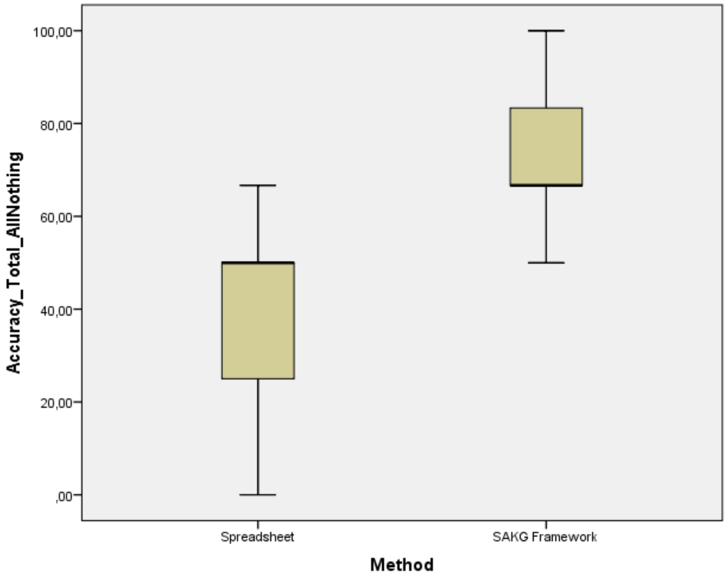

Fig. 99. A box-and-whisker plot for the Accuracy_Total_AllNothing variable.

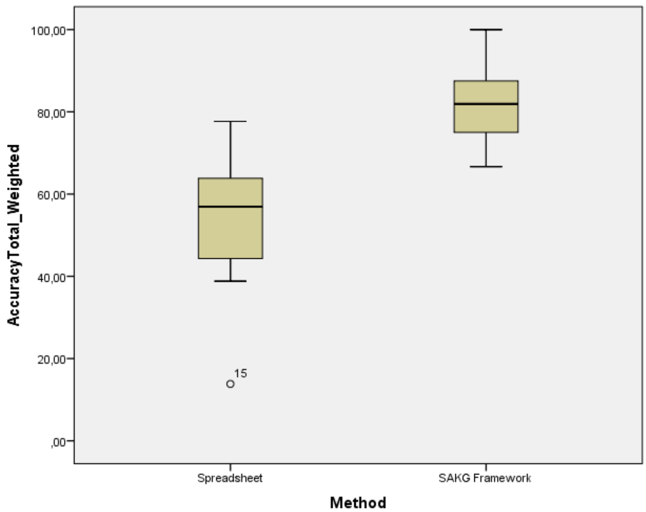

Fig. 100. A box-and-whisker plot for the Accuracy_Total_Weighted variable.

As far as the remaining tasks are concerned, there are no significant results for task B relating to grouping processes. In this case, the Problem*Method interaction offers a significant result, which means that our blocking variable P (the heritage problem being treated) is affecting the treatment (our Method). Fig. 101 shows a profile graph of the interaction produced in the values for task B. It can be seen how, in this case, the method is only significant for one of the problems (in this case the problem of A

Romea). Therefore, the subjects obtained significantly better results in terms of accuracy for task B only in the case of A Romea.

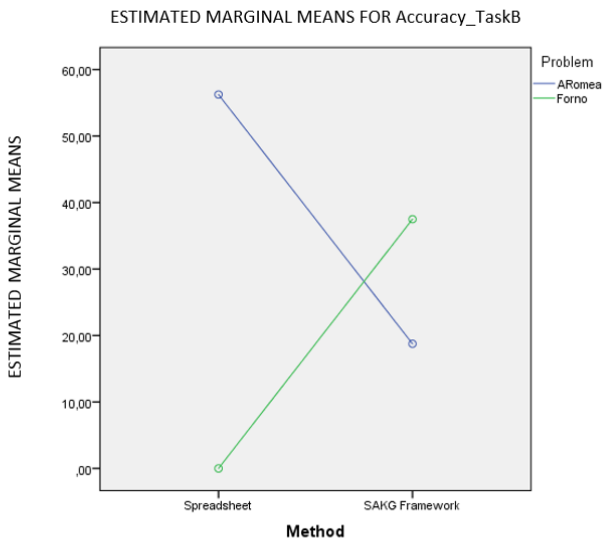

Fig. 101. A profile graph showing the Method*Problem interaction for the Accuracy_TaskB variable.

As far as the results for task C are concerned, it has not been possible to obtain results for the mixed model. This is due to the fact that, when applying the model to the values obtained for that task, a prior application criteria was not fulfilled (the residuals do not present a normal distribution). This means that the model does not show sufficient differences between the two treatments to offer results which guarantee the validity of the adjustment to the model. This can be seen by observing the accuracy values obtained for task C in Appendix III, which are very similar between the two methods (almost all of the subjects carried out task C correctly, independently of the method used).

Results and discussion of hypothesis H02: Efficiency

Hypothesis H_{02} stated: Efficiency in tasks relating to the generation of knowledge in Cultural Heritage using the framework-solution is similar to efficiency when performing the same tasks with the traditional method of data analysis.

This efficiency has been defined by the measurement of the response time when the subjects carry out these tasks. Measurements of the time taken for each task (from task A to task F) were taken, along with measurements of the total time employed.

Table 14 shows the p-values and Cohen's d coefficients obtained for each of the tasks and for the total efficiency. Cohen's d has only been calculated if the Method factor obtains significant values.

Variable	P-value			Cohen's d
	Method	Problem	Problem*Method	
Time_TaskA	**0.002**	*0.005*	0.087	1.00
Time_TaskB	0.206	0.360	0.078	
Time_TaskC	0.870	0.088	0.212	
Time_TaskD	**0.018**	1	0.142	0.92
Time_TaskE	**0.049**	0.172	*0.012*	0.77
Time_TaskF	**0.000**	0.844	0.239	1.29
Effort_T	**0.000**	0.078	0.074	1.45

Table 14. P-values and Cohen's d for the efficiency variables. The values in bold show significant p-values which refute the null hypothesis H_{02}.

As can be seen in Table 14, the model offers p-values of less than 0.05 for efficiency in tasks **A, D, E** and **F**, and for the **Effort_T** variable, which aggregates the total efficiency in data analysis tasks.

For all the accuracy variables which offer significant results, the average of the results obtained are higher for method M1 than for method M2 (see Appendix III to consult the averages), which indicates better results in terms of efficiency when using the traditional method than when using the framework-solution. If we examine each task, the Cohen's d coefficient for efficiency in task E (the **Time_TaskE** variable) shows a moderate effect size (between 0.5 and 0.75), which implies that the subjects obtained better efficiency results for the traditional method in task E than for the framework-solution, albeit with a moderate difference. The values corresponding to the Cohen's d coefficient for efficiency in the **Time_TaskA**, **Time_TaskD, Time_TaskF** variables and the aggregate variable **Effort_T** are higher than 0.8, which indicates a large effect size.

Fig. 102 shows the box-and-whisker plot for the aggregate efficiency variable. It can be observed how the median and the first and third quartiles for efficiency using the traditional method are greater than when using the SAKG framework-solution. This means that the subjects obtained better results in terms of efficiency (they improved their response times) when working with the traditional method than when using the framework-solution.

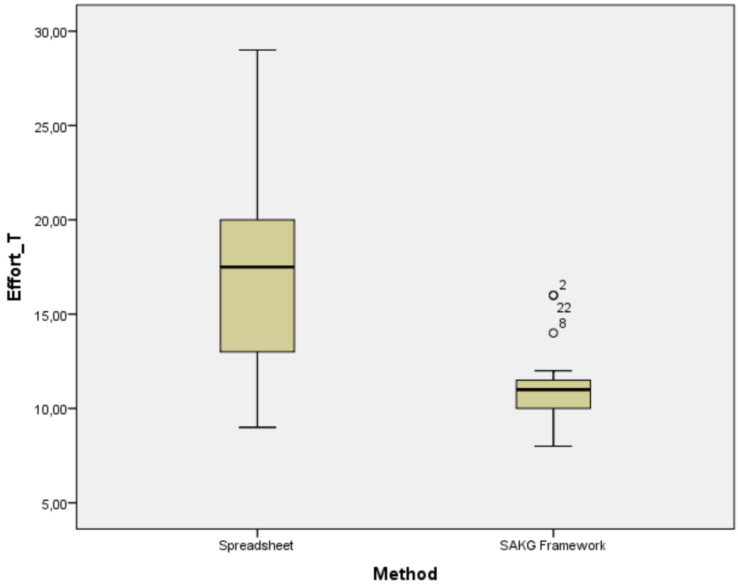

Fig. 102. A box-and-whisker plot for the Effort_T variable.

However, it should be noted that the graph in Fig. 102 shows atypical efficiency values for method M2, indicating subjects whose efficiency values using the SAKG framework-solution in some cases (see the raw data in Appendix III) equalled or even improved on those obtained with the traditional method. In spite of the fact that, in general, the subjects presented better results in terms of efficiency with the traditional method than with the SAKG framework-solution, it has to be taken into account that all the subjects have prior expertise in the traditional method, whereas no prior training was provided for the framework-solution. Although this will be discussed later, we believe that the difference in the level of expertise with the method applied may be a determining factor in the results obtained in terms of efficiency and that these atypical values arise in subjects who found the framework-solution more intuitive and, therefore, were able to overcome the expertise barrier.

To conclude the analysis, although the model offers significant values in terms of the method in efficiency of task A, it must be highlighted that it also offers significant values for the Problem, which means that there are differences in this task between subjects who worked with P1 (A Romea) and P2 (Forno dos Mouros). Fig. 103 shows the box-and-whisker plot in efficiency for task A, in which we can observe that the subjects evaluating problem P1 obtained better results than those evaluating problem P2.

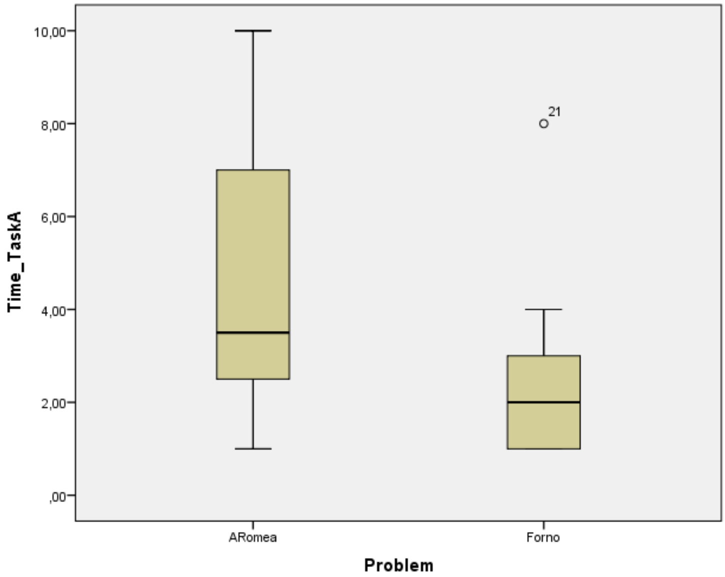

Fig. 103. A box-and-whisker plot for the Time_TaskA variable.

Furthermore, it is necessary to highlight the fact that, for the **Time_TaskE** variable, related to processes of analysing the internal structure of the data, the Problem*Method interaction offers a significant result, which means that our blocking variable P (the heritage problem in question) is affecting the treatment (of our Method). In Fig. 104, a profile graph can be seen of the interaction produced in the values for task E and in which it can be appreciated how, in this case, the method is only significant for one of the problems (in this case, the problem of A Romea). Therefore, only in the case of A Romea did the subjects obtain significantly better results in terms of efficiency with the traditional method for task E.

Last of all, there are no significant results for task B, related to grouping processes, or for task C, related to processes of contextual situation. Given that there were no significant results as far as the problem or the Problem*Method interaction are concerned either, it can be stated that, in these two tasks, hypothesis H_{02} is not refuted and, therefore, the response times are similar for both methods.

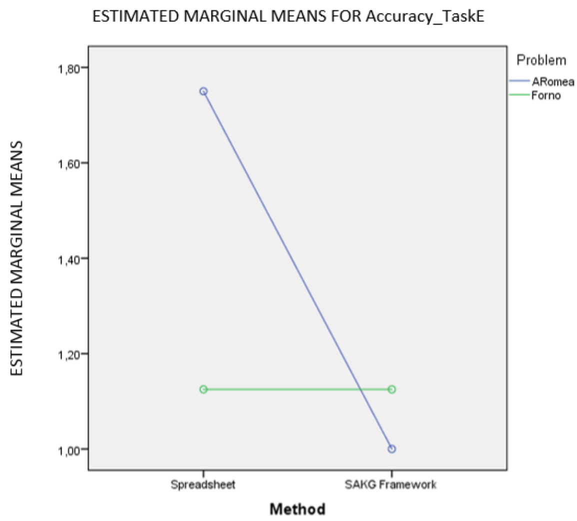

Fig. 104. A profile graph showing the Method*Problem interaction for the Time_TaskE variable.

Results and discussion of hypothesis H03: Productivity

Hypothesis H_{03} stated: Productivity in tasks relating to the generation of knowledge in Cultural Heritage using the framework-solution is similar to productivity when performing the same tasks with the traditional method of data analysis.

This productivity has been defined as the ratio of the accuracy obtained by the response time employed in performing the indicated data analysis tasks. Productivity was measured for each task (from task A to task F), in order to be able to aggregate this productivity with two more variables: ***Productivity_AllN*** (*AllNothing*), which indicates productivity only for tasks in which all the sub-tasks were carried out correctly and ***ProductivityWeighted***, which aggregates productivity taking into account the individual percentage of each task and giving it the same weight in all the tasks.

Table 15 shows the p-values and the Cohen's d coefficients obtained for each of the tasks and for the two aggregated productivity variables.

Variable	**P-value**			**Cohen's d**
	Method	**Problem**	**Problem*Method**	
Productivity_TaskA	**0.001**	*0.042*	0.679	1.59

Productivity _TaskB	0.327	0.379	0.151	
Productivity _TaskC	0.739	*0.014*	0.278	
Productivity _TaskD	**0.002**	0.171	0.125	1.32
Productivity _TaskE	**0.009**	0.758	0.088	1.20
Productivity _TaskF	**0.000**	0.145	0.156	1.98
Productivity _AllN	**0.000**	0.878	0.631	2.40
ProductivityWeighted	**0.000**	0.916	0.385	2.34

Table 15. P-values and Cohen's d for the productivity variables. The values in bold show significant p-values which refute the null hypothesis H_{03}.

As can be seen in Table 15, the model offers p-values of less than 0.05 for productivity in tasks **A, D, E** and **F** and in the variables which aggregate the total productivity of the data analysis tasks, taking into account only those performed correctly (***Productivity_AllN***) and giving it the same weight in all the tasks (***ProductivityWeighted***).

For all the productivity variables which offer significant results, the average of the results obtained are higher for method M2 than for method M1 (see Appendix III to consult the averages), which indicates better results in terms of productivity when using the framework-solution rather than the traditional method. The values corresponding to Cohen's d for accuracy in tasks A, D, E and F and for the aggregate variables are greater than 0.8, which indicates a large effect size. This can be seen more clearly in Fig. 105 and Fig. 106, which show box-and-whisker plots for the two aggregate productivity variables. We can observe how, in both cases, the median, the first and the third quartile for accuracy using the SAKG framework-solution are greater than when using the traditional method with spreadsheets. This means that, with the exception of one subject, who gave an atypical value in the case of the *ProductivityAllN* variable, the subjects obtained better results in terms of productivity in an aggregate way working with the framework-solution compared with the traditional method.

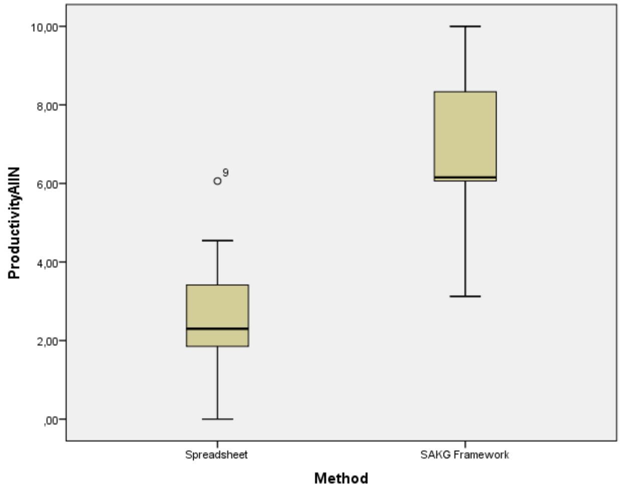

Fig. 105. A box-and-whisker plot for the ProductivityAllN variable.

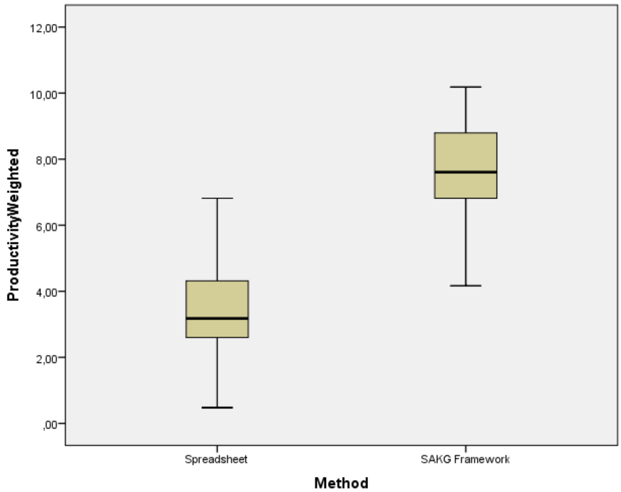

Fig. 106. A box-and-whisker plot for the ProductivityWeighted variable.

Furthermore, although the model offers significant values as far as the productivity method for task A is concerned, it must be highlighted that it also offers significant values for the Problem, which means that there are differences in this task between the subjects who worked with P1 (A Romea) and P2 (Fourno dos Mouros). Fig. 107 shows a box-and-whisker plot for productivity for task A, in which it can be observed that the subjects evaluating problem P2 obtained better results than those evaluating problem P1.

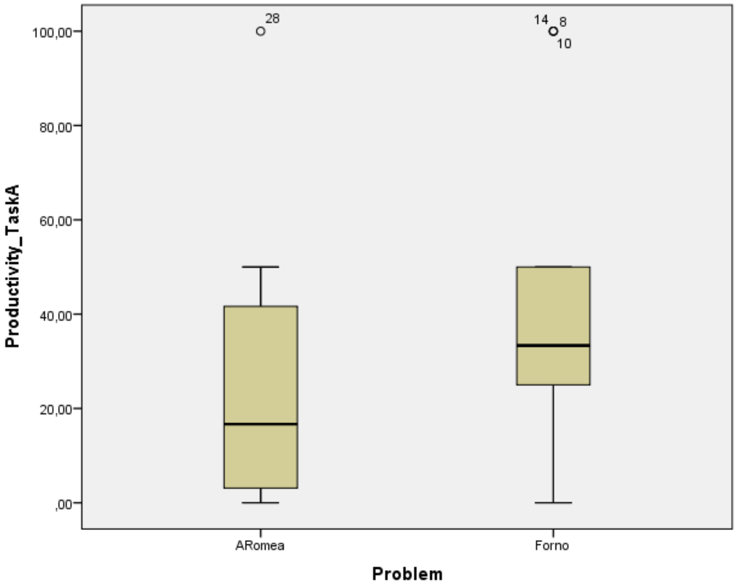

Fig. 107. A box-and-whisker plot for the Productivity_TaskA variable.

Finally, there were no significant results for task B, relating to grouping processes, or for task C, relating to processes of contextual situation. In the case of task B, neither were any significant results obtained in terms of the problem or the Problem*method interaction. Thus, we can affirm that hypothesis H_{03} is not refuted and, therefore, productivity is similar with both methods. Likewise, hypothesis H_{03} is not refuted for task C, although in this case, the model offers significant values for the Problem, which means that there are differences in this task between the subjects who worked with problem P1 (A Romea) and P2 (Fourno dos Mouros). Fig. 108 shows a box-and-whisker plot for task C, in which we can observe that the subjects evaluating problem P1 obtained better results than those evaluating problem P2.

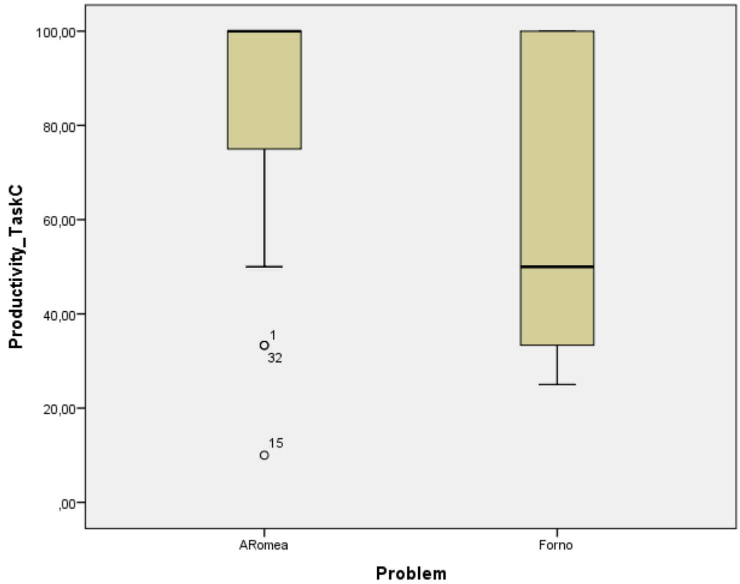

Fig. 108. A box-and-whisker plot for the Productivity_TaskC variable.

This particular issue in tasks A and C, in which the Problem is also significant without presenting interaction with the method, could indicate a degree of asymmetry between the two problems in these specific tasks.

Results and discussion of hypothesis H04: Satisfaction

Hypothesis H_{04} stated: The satisfaction shown by the subjects carrying out tasks relating to the generation of knowledge in Cultural Heritage using the framework-solution is similar to the satisfaction which they show when performing the same tasks with the traditional method of data analysis.

This satisfaction has been defined by measuring the scores given by the subjects according to a Likert scale dealing with three aspects: perceived usefulness (PU), perceived ease of use (PEOU) and intention to use (ITU).

Table 16 shows the p-values and the Cohen's d coefficients obtained for satisfaction in terms of PU, PEOU and ITU.

Variable	P-value			Cohen's d
	Method	Problem	Problem*Method	
PEOU	**0.002**	0.618	0.981	1.42
PU	**0.001**	0.671	0.955	1.50
ITU	**0.000**	0.814	0.700	1.51

Table 16. P-values and Cohen's d for the satisfaction variables. The values in bold show significant p-values which refute the null hypothesis H_{04}.

As can be seen in Table 16, the model offers p-values of less than 0.05 for values regarding perceived usefulness (PU), perceived ease of use (PEOU) and intention to use (ITU).

For all the satisfaction variables evaluated, the averages of the results obtained are higher for method M2 than for method M1 (see Appendix III for the averages), which indicates better results in the three aspects relating to satisfaction (perceived usefulness, perceived ease of use and intention to use) when using the framework-solution compared to the traditional method. If Cohen's d is applied, all the values are greater than 0.8, which indicates a large effect size. This can be seen more clearly in Fig. 109, Fig. 110 and Fig. 111, which show box-and-whisker plots for the three variables mentioned. We can observe how, in all cases, the median, the first and the third quartile for the satisfaction variables using the SAKG framework-solution are greater than when using spreadsheets. This means that the subjects expressed greater satisfaction in the three criteria when evaluating the framework-solution compared to the traditional method.

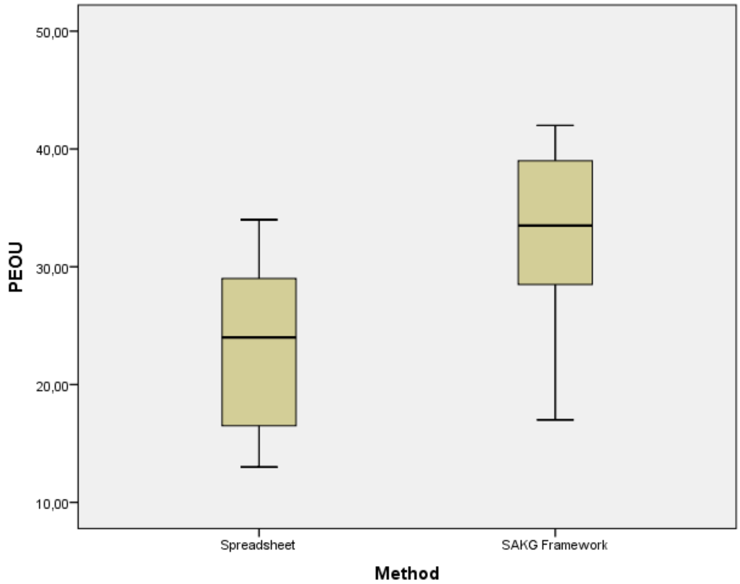

Fig. 109. A box-and-whisker plot for the PEOU variable.

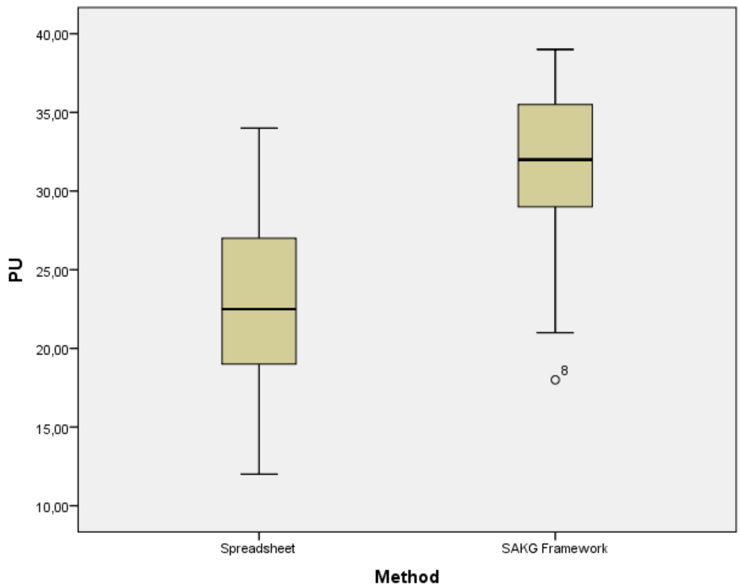

Fig. 110. A box-and-whisker plot for the PU variable.

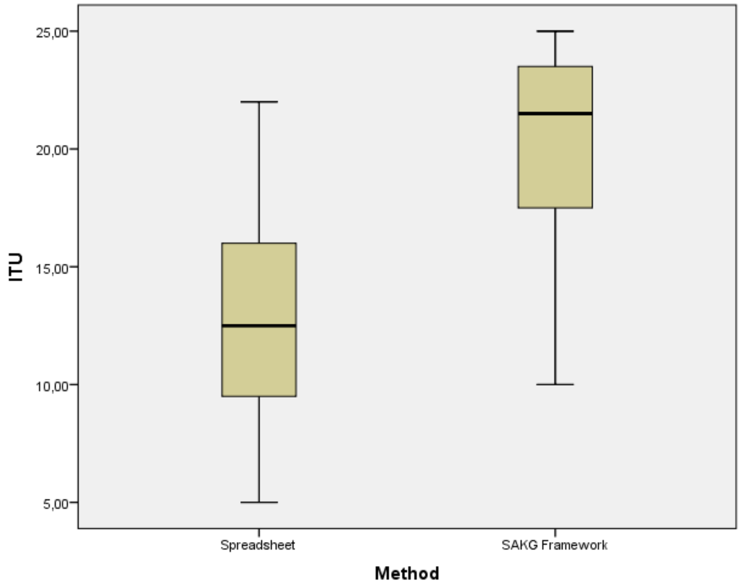

Fig. 111. A box-and-whisker plot for the ITU variable.

Results and discussion of hypothesis H05: The quality of the generated knowledge

Hypothesis H_{05} stated: The degree of correctness and satisfaction shown by the subjects when evaluating the generated knowledge as a product (a written report) of the process of data analysis in Cultural Heritage using the framework-solution is similar to the degree of correctness and satisfaction which is shown when carrying out the same evaluation with the traditional method of data analysis.

This quality refers to two specific characteristics: the correctness of the generated knowledge, measured as the number of errors reported by specialists in the field when analysing the written report of another subject according to the method of data analysis used to produce it and the satisfaction shown by the subject with the written report, measured by the score obtained when evaluating the report via 19 sentences in a Likert scale questionnaire (see Appendix III for the aspects dealt with in the questionnaire).

Table 17 shows the p-values and Cohen's d coefficients obtained for each of the defined correctness and satisfaction variables.

Variable	P-value			Cohen's d
	Method	Problem	Problem*Method	
Satisfaction_KnowledgeGen	**0.000**	0.718	0.476	0.99
ReportErrors_Total	**0.005**	0.680	0.639	0.85

Table 17. P-values and Cohen's d for the variables relating to the knowledge generated. The values in bold show significant p-values which refute the null hypothesis H_{05}.

As can be seen in Table 17, the model offers p-values of less than 0.05 for the variables relating to the quality of the knowledge generated. On the one hand, the ***Satisfaction_KnowledgeGen*** variable measures the score obtained from the Likert questionnaire (see Appendix III). The subjects completed this questionnaire when evaluating another colleague's written reports regarding the case studies, after analysing the data with both methods. On the other hand, the ***ReportErrors_Total*** variable analyses the number of errors identified by the subjects when evaluating each report, drawing up a ratio of errors according to the analysis method used to produce the report.

In the case of the ***Satisfaction_KnowledgeGen*** variable, the averages of the results obtained are higher for method M2 than for method M1 (see Appendix III to consult the averages), indicating better results in terms of satisfaction when evaluating the written reports produced using the framework-solution than those produced using the traditional method. The value corresponding to the Cohen's d coefficient for the ***Satisfaction_KnowledgeGen*** variable is greater than 0.8, which indicates a large effect size. This can be seen more clearly in Fig. 112, which shows the box-and-whisker plot for this variable. We can observe how the median, the first quartile and the third quartile when evaluating the report produced using the SAKG framework-solution are higher than when evaluating the report produced using spreadsheets. This means that the subjects expressed more satisfaction when evaluating reports produced after the analysis using the framework-solution than when evaluating reports produced following an analysis with the traditional method.

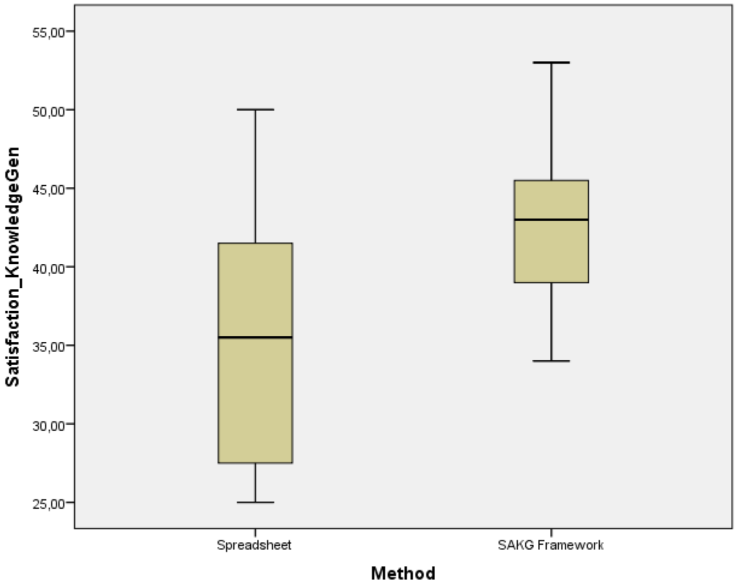

Fig. 112. A box-and-whisker plot for the Satisfaction_KnowledgeGen variable.

As far as the ***ReportErrors_Total*** variable is concerned, the averages of the results obtained are higher for method M1 than for method M2 (see Appendix III to consult the averages), indicating a higher ratio of errors when evaluating the written reports produced using the traditional method than those produced using the framework-solution. The value of Cohen's d for the ***ReportErrors_Total*** variable is greater than 0.8, which indicates a large effect size. This can be seen more clearly in Fig. 113, which shows the box-and-whisker plot for this variable. We can observe how the median, the first and the third quartile for ***ReportErrors_Total*** using the traditional method are greater than when using the SAKG framework-solution. This means that the subjects identified a significantly higher number of errors in the reports produced following an analysis using the traditional method than in the reports produced following an analysis with the framework-solution.

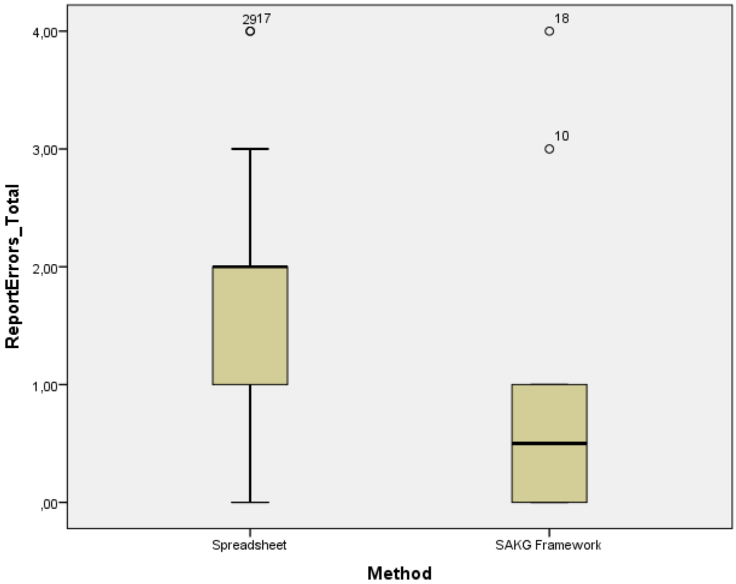

Fig. 113. A box-and-whisker plot for the ReportErrors_Total variable.

Presentation and Package

This chapter consists of the report of the presentation of the empirical validation carried out, in terms of design and execution, the analysis and later interpretation of the results obtained and the initial implications of these results in the validation of the framework-solution presented throughout this thesis.

The raw data obtained over the course of the empirical validation, as well as the full results of the statistical analyses carried out using the SPSS V23 suite, can be consulted in Appendix III.

Conclusions

In summary, the null hypotheses formulated have been refuted for almost all of the variables analysed (with the exception of some, which measure variables for specific tasks). It should be highlighted that they have been refuted for all the response variables which measure tasks in an aggregate manner, even for both methods of task aggregation, taking into account the tasks performed with full accuracy and productivity and those which take into account intermediate states of accuracy and productivity.

However, this does not mean that the framework-solution presents better results in all of the response variables which have been measured. The SAKG framework-solution presents far better results in terms of accuracy, productivity, satisfaction of

the subjects in terms of the three variables involved (perceived usefulness (PU), perceived ease of use (PEUO) and intention to use (ITU)) and in terms of the quality of the generated knowledge in the variables analysed concerning correctness (*ReportErrors_Total*) and satisfaction (*Satisfaction_KnowledgeGen*). These results are promising for the method proposed in this doctoral thesis.
Due to the fact that some variables were also evaluated for each task performed, we can carry out a more in-depth analysis of which tasks have provided better results in each response variable tested. This will allow us to gain an initial perspective of the assistance offered to the generation of knowledge and which cognitive processes have been assisted satisfactorily and which have not. Below, we shall offer detailed conclusions for each response variable dealt with.

As far as accuracy is concerned, the subjects clearly improved their rate of correct answers when using the SAKG framework-solution for tasks relating to processes of combining values (tasks A and D), in addition to those concerning processes analysing the internal structure of the data (task E). Furthermore, they also improved their responses in one of the tasks relating to processes of contextual situation to discover the temporal characteristics of the data (task F), although they did not do so in the other task for the same cognitive process (task C). However, accuracy was not improved for the task regarding grouping processes (task B).

In terms of productivity, the pattern observed for accuracy is repeated.

As far as efficiency is concerned though, the traditional method of using spreadsheets offered better results than the SAKG framework-solution for tasks relating to processes of combining values (tasks A and D) and in tasks concerning processes analysing the internal structure of the data (task E). Furthermore, the subjects also improved their response times in one task relating to processes of contextual situation to discover the temporal characteristics of the data (task F). Due to these results for efficiency, an analysis of behaviour in efficiency for each task performed has been carried out. Fig. 114 and Fig. 115 show box-and-whisker plots corresponding to efficiency in each task.

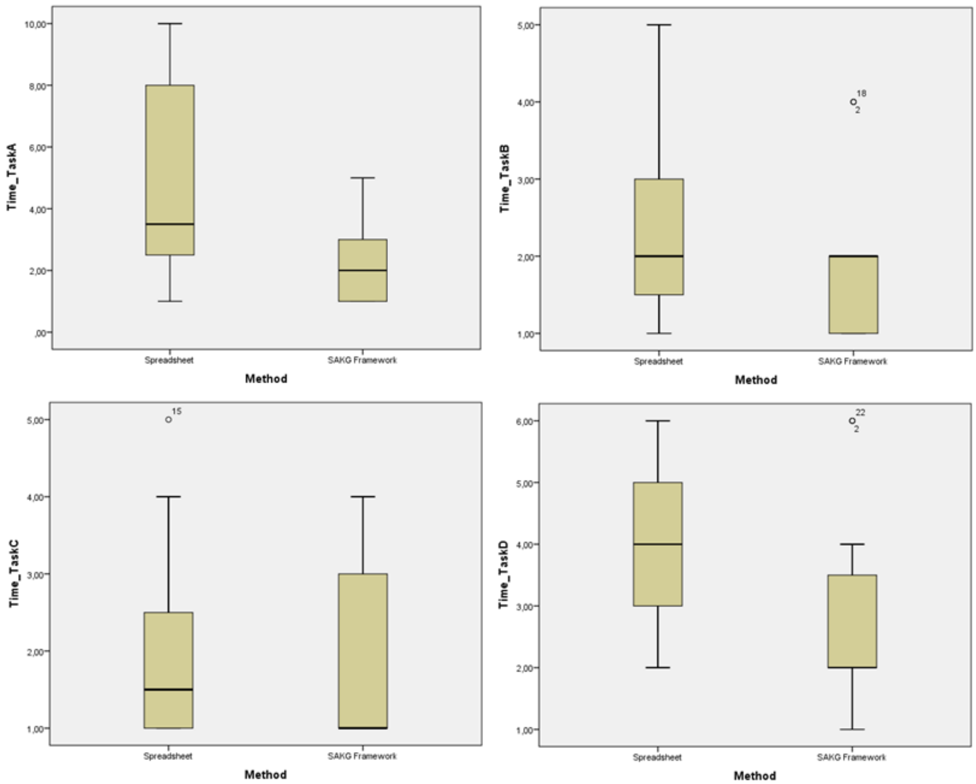

Fig. 114. Box-and-whisker plots for the efficiency variables in tasks A, B, C and D.

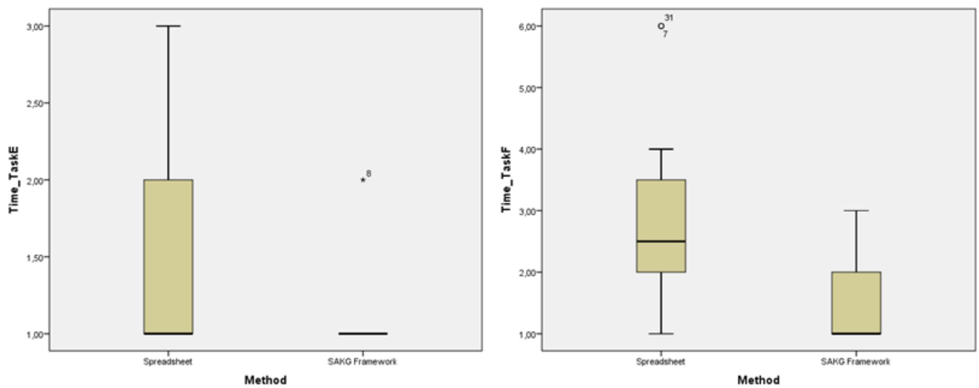

Fig. 115. Box-and-whisker plots for the efficiency variables in tasks E and F.

As can be appreciated in the graphs, there are tasks in which efficiency using the traditional method is clearly greater than with the proposed framework-solution, for example in the cases of tasks E and F:

- Task E is related to processes of analysing the internal structure of the data. The subjects were quicker to offer a response regarding the internal structure of the data when they were using spreadsheets than when accessing the data via the Structure IU interaction unit. On an exploratory level, we believe that the subjects reach the structure of the information more quickly when using spreadsheets as this structure is presented in the same interface as the data itself. In the framework-solution, they need to access the specific interaction unit via the menu in order to view the structure, which implies one more step in terms of navigation, thus slowing down access to the information. Furthermore, the difference in the level of expertise of the subjects may also have an influence in this efficiency. However, the results in accuracy and productivity for this same task were better when using the Structure IU interaction unit within the framework-solution. Therefore, we believe that, even though the internal structure of the data is accessed more quickly with the traditional method, the Structure IU interaction unit presents significant improvements in terms of the subjects' degree of comprehension about this structure in the validation.
- Task F is related to processes of contextual situation in order to discover temporal characteristics of the data. The subjects were quicker to give an answer regarding temporal aspects of the case studies when using spreadsheets than when accessing the information via the Timeline IU interaction unit. On an exploratory level, we believe that the subjects reached the temporal information more quickly when using spreadsheets as this information is presented in a table format. The subjects search for temporal information (similar dates or data) in the spreadsheet and quickly formulate their response based on this information. However, in the framework-solution, they need to gain access to the specific interaction unit via the menu in order to view the temporal information. This implies one more step in terms of navigation, which slows down the access to this information. Furthermore, the difference in the subjects' level of expertise may also have an influence on efficiency. However, the results in terms of accuracy and productivity for this same task were better when using the Timeline IU interaction unit within the framework-solution. Therefore, we believe that, even though the temporal information of the data is reached more quickly with the traditional method, the Timeline IU interaction unit presents significant improvements in terms of the subjects' degree of comprehension about this structure in the validation by, for example, offering a better view of the temporal phases involved in each case study.
- The results in terms of efficiency for other tasks, such as those relating to processes of combing values, present closer values between the two methods

(tasks A and D). In task D, even some atypical values can be observed for subjects who presented better times with the framework-solution. On an exploratory level, we believe, therefore, that although the subjects may present better response times when using spreadsheets compared to accessing the information via the Value-Combination IU interaction unit, this interaction unit has enabled the barrier of the subjects' prior level of expertise to be overcome and offers an acceptable level of behaviour in terms of efficiency. This, together with the good results offered in this type of task in terms of accuracy and productivity, offers promising results for providing assistance to cognitive processes relating to the combination of values. This proximity between values in both methods is an aspect which can also be observed in task C, relating to processes of contextual situation in order to discover the temporal characteristics of the data.

- Task B, relating to grouping processes, presents some atypical values in favour of the framework-solution. However, neither accuracy nor productivity in this task presents significant levels implying improvements when using the framework-solution. On an exploratory level, we believe that this task, relating to grouping processes, is the one which has shown the worst behaviour in general terms in the use of the framework-solution.

To sum up, and to repeat what has previously been pointed out, we believe that the subjects' level of familiarity with both methods and the absence of any previous training with the method based on the framework-solution (thus presenting differences between both methods for learnability [148]) may have a significant influence on this result in favour of the traditional method using spreadsheets in terms of efficiency and, therefore, it would be necessary to carry out a validation with prior training in the use of the framework-solution in order to eliminate this factor. However, with the results provided by this validation, it is necessary to take into account the fact that perhaps the framework-solution does not improve response times compared to the traditional method, independently of the degree of familiarity of the subject with the methods being evaluated and his/her degree of expertise in using them. The remaining response variables analysed present good results when evaluating aspects of accuracy, productivity, user satisfaction and correctness and satisfaction with the knowledge generated, when assisted by the framework-solution proposed in this thesis compared with the traditional method employed in Cultural Heritage, based on table formats such as spreadsheets.

Both of these issues (the influence of prior familiarity with methods M1 or M2 and the difference of results between efficiency and the rest of the analysed variables) and more detailed aspects surrounding the generation of knowledge provided and implications in specific cognitive processes will be discussed in depth regarding the doctoral thesis as a whole in Chapter 13 entitled “Discussion”.

PART V: Final Considerations

An investment in knowledge pays the best interest

- Benjamin Franklin

Chapter 13: Discussion

If wisdom were offered me with this restriction, that I should keep it close and not communicate it, I would refuse the gift. -Seneca

Introduction

Over the course of the previous chapters, the problem of providing software assistance to the generation of knowledge in Cultural Heritage has been explored, explained in detail and conceptualised. In addition, a full proposal offering a solution in the form of a conceptual framework has been developed. This framework consists of three parts, each with their corresponding software models (the subject model, the cognitive processes model and the presentation and interaction model), along with a metamodel in order to formally express the connections and possible interoperability between the aforementioned models. Finally, two validations of different kinds (analytical and empirical) were designed and made in order to validate the proposed solution.

This chapter analyses the whole research process previously described from the point of view of "Design Science Methodology", providing an answer to the main research question posed and to the secondary research questions, all of which were set out in Part I. In addition, this chapter will specifically deal, in a critical way, with areas identified, over the course of the research process, as being in need of improvement and how they can be tackled.

The Development of the Hypothetico-deductive Reasoning Adopted

As was described in Part I, this thesis takes as its starting point an initial hypothesis which provides the backbone for the whole research process, stating that that **it is possible to significantly improve knowledge-generation processes in Cultural Heritage by way of providing software assistance to the user with knowledge extraction and information visualization techniques**. Based on this hypothesis, the main research question *MQ* was defined: **To what extent is it possible to improve knowledge generation processes in Cultural Heritage by way of software assistance to the user with knowledge extraction and information visualization techniques?**

The study of previous projects and of the fields involved in an attempt to respond to this question led to the emergence of several secondary questions, making the research in progress more specific and enabling the creation of a set of techniques, tools, and methodologies explained in detail in Part II. Below, the answers offered by this research to the secondary questions which arose are described.

Secondary Question SQ1

Firstly, our research determined the need to identify problems existing in the processes of knowledge generation in Cultural Heritage, in such a way that we could tackle them with software assistance. Thus, the secondary research question SQ1 arose: **What problems exist in knowledge generation processes in Cultural Heritage as they are normally carried out?**

Following a thorough study of the process of knowledge generation in Cultural Heritage through written sources, the tools employed for this aim and empirical research (described in Chapter 5), we were able to identify seven problems, which have all been dealt with in depth in [195]. We shall outline each of them here and describe how they have been dealt with in the solution proposed in this research project:

1. The intentional use of uncertainty in the intermediate reasoning to generate knowledge. This uncertainty is not supported by existing software tools.
2. The absence of explanation and, consequently, of monitoring of the cognitive process being carried out in each case, detecting, for example, cognitive processes with a strong temporal and/or spatial component. It is necessary to characterise them in order to provide software assisted knowledge generation in the field.
3. The absence of information storage concerning the tasks carried out with the information, such as which questions are asked of the data during the knowledge generation process. This impedes feedback in existing software systems, which would allow them to adapt to this process.
4. The previous point also implies an absence of support for the collaborative generation of knowledge, as it cannot be known which cognitive tasks have been carried out and which have not, thereby making group work more complicated.
5. A lack of priority management of the information on which the knowledge generated is based.
6. A lack of vision regarding the structure of the information on the part of the end users, thus making the creation and testing of hypotheses based on the data more difficult.

7. Homogeneous procedures applied to reasoning, derived from direct observation, and reasoning derived from more complex mechanisms (relation between data, abstraction, interpretation, etc.). This situation could include confusion about the level of the DIKW hierarchy [7] in which reasoning is situated and the level of subjectivity and uncertainty that is managed.

The framework-solution proposed deals with all seven of these problems, albeit with different degrees of scope in their evolution:

- Problem 1 is dealt with in the framework-solution via the vague support provided by ConML [144] as a language and CHARM [145] as an abstract model of reference. This forms the basis of our subject model. Its use in each specific case remains, therefore, the choice of software analyst, who will be able to include more or less elaborate mechanisms in order to deal with vagueness in the subject model of each type of software assistance.
- Problem 4 has only been dealt with in the framework thanks to the cognitive processes metamodel. The empirical validation in groups has enabled us to find out how the prototype we built behaves, based on the framework in multi-user contexts. However, the use of the proposed framework for the construction of collaborative software tools (that is to say, ones in which the users are not only able to use the tool, but are also able to react with the results of other users at the same time) has not been dealt with in the solution proposed in this thesis, but will be dealt with in future research.
- Problems 2, 3 and 7 are dealt with in the framework thanks to the cognitive processes metamodel, which allows one or several cognitive processes being assisted to be instanced, saving the one being assisted in each case, along with the actions being carried out by the user for a specific data subset.
- Problems 5, 6 and, to some extent, problem 2 are dealt with thanks to specific interaction units and individual patterns for the treatment of temporal and/or geographic aspects and for handling levels of importance and reasoning based on the structure of the information. All of these aspects are present in the hierarchy of presentation and interaction patterns defined in the framework.

Secondary Question SQ2

Secondly, we determined that the majority of the problems detected, in order to be assisted via software, required a characterisation of the most common cognitive processes in Cultural Heritage. Thus, the secondary research question SQ2 arose: **What are the most common cognitive processes carried out by specialists in Cultural Heritage in the generation of knowledge?**

In an attempt to respond to this question, characterisations of existing cognitive processes in similar fields were studied and discourse analysis techniques were applied to textual sources produced in Cultural Heritage, allowing the most common cognitive processes to be characterised into four groups of primitives: Building (inferences based on the structure, rather than on particular values, of the data), Clustering (inferences based on the grouping of the data), Situating (inferences based on situating the data in a particular context or setting) and Combining (inferences regarding the basis of the combination and/or the comparison of the values of the different elements of the data).

The details of the characterisation and methodology proposed in order to integrate discourse analysis techniques into Software Engineering is described in Chapter 4 of this thesis and have been published widely [192, 197]. The formal response to question *SQ2* is, therefore, the cognitive processes metamodel present in our framework-solution, which formalizes this characterisation, and which is described in Chapter 8 of this thesis.

Secondary Question SQ3

Finally, the problems detected in the process of knowledge generation in Cultural Heritage enabled us to establish that not only was it necessary to characterise the most common cognitive processes in the field, but also that the most appropriate type of software assistance to the user for each cognitive processes had to be determined. In this regard, the initial hypothesis put forward concerned two types of assistance: via information visualisation and knowledge extraction techniques. Due to the broad nature of the proposal of this thesis, it has been impossible for us to deal with both techniques in the same degree of depth. Therefore, the framework-solution only incorporates assistance via information visualisation and only deals with aspects of knowledge extraction on a case study level [84], as we shall describe later in the critical analysis.
Having taken this decision, the third secondary research question *SQ3* arose: **Which are some appropriate information visualisation techniques to assist each one of the cognitive processes identified within the field of Cultural Heritage?**
In an attempt to answer this question, empirical studies, described in Chapter 4, were carried out and the results presented in Appendix III were obtained. To summarise, eight commonly used information visualisation techniques were analysed. The techniques demonstrating the best results were bubble charts for cognitive processes of a Clustering and Combining nature. For cognitive processes of a Situating nature, no technique offered conclusive results, so the decision was taken to design

interaction units specifically for this purpose, as was the case for cognitive processes of a Building nature.

This information, along with the study of existing software tools and their presentation and interaction patterns (described in Chapter 9), led us to define a hierarchy of patterns which encapsulated the solutions for presentation and interaction observed in the interaction units for each cognitive process. The formal answer to question *SQ3* is, therefore, the metamodel of the presentation and interaction mechanism described in Chapter 9, which enables the analyst to select the individual patterns which he/she considers most suitable for assisting a certain cognitive process in each case. The selection made for the case study of A Romea is based on the empirical results of the Cultural Heritage professionals, which had previously been obtained.

Main Question MQ

Once the three secondary questions had been answered and taking into account the fact that the answer to the main question is, according to the initial hypothesis, affirmative, we wanted to carry out an analysis of the evidence which backs up the affirmative answer to the *MQ*, following all the research which had been carried out.

First of all, we believe that **it is indeed possible to improve the processes of knowledge generation in Cultural Heritage by means of providing software assistance to the user via information visualisation techniques**. The evidence which we have found over the course of this research is as follows:

- Evidence has been observed, reflected throughout this thesis and in other studies, as well as through the appearance of projects, proposals, infrastructures, disciplines, etc., which establish the need for software assistance in the field of Cultural Heritage. An excellent example of this is the appearance of *Digital Humanities* as a discipline, which leads us to believe there is a need for software assistance per se. In relation to this, the presence of certain assistance mechanisms which have already been implemented and/or conceptualised, at differing stages of development, has been detected, especially in the application of geographic information systems in the field, which would indicate that software assistance is, indeed, possible. This evidence is described in the bibliographic review carried out throughout this thesis, though especially in Chapter 4.
- Coincidences have been found in the generation of knowledge in the field in different users, which allows for the formalisation of software assistance. These coincidences have been observed from the very beginning of the

research process, both empirically (in the prior empirical studies carried out as a result of the Thinking Aloud sessions and the models constructed by the specialists (see Appendix I) and on an abstract level, as can be seen in the appearance, confirmation and later formalisation of the textual patterns which arose from the analysis of archaeological discourses.

- How well the conceptual framework presented in order to represent assistance to knowledge generation worked in the case study presented in this thesis (A Romea) and in a second case study used during the empirical validation (Forno dos Mouros). This represents evidence in itself that software assistance is possible in this context.
- Further proof found is the statistically significant improvement in terms of accuracy and productivity in tasks relating to the generation of knowledge assisted by visualisation techniques compared to those performed without assistance (via spreadsheets). These statistically significant improvements occur in three of the four groups of cognitive processes (Building, Situating and Combining) (see the definition of the defined data analysis tasks carried out for the empirical validation in Chapter 12).
- Likewise, a statistically significant improvement was found in terms of end-user satisfaction when carrying out tasks relating to knowledge generation which are assisted by visualisation techniques compared to those performed without assistance (via spreadsheets).
- Finally, another statistically significant improvement was found in terms of the quality of the knowledge generated. The written reports produced following an analysis of data using the framework which the experts in Cultural Heritage then analysed received better scores and contained fewer errors than those reports written following an analysis of data via spreadsheets.

All of this evidence supports the initial hypothesis that providing software assistance to knowledge generation in the field of Cultural Heritage is possible (if we understand by software assistance the definition maintained over the course of this research). What is more, we must respond to the question: **To what extent is it possible to improve these processes?** The promising results obtained from the validations of the proposed framework-solution allow us to state that the proposed solution offers a type of software assistance which significantly improves knowledge generation processes based on the combination of values, the analysis of the structure of information and its contextual situation, all of which have been identified as relevant in Cultural Heritage. It does so in terms of accuracy, productivity, satisfaction and quality of the knowledge generated.

However, other aspects of interest have been detected in which the software assistance proposed as a solution has not obtained such satisfactory results, and has even presented certain restrictions. All of these aspects will be dealt with in the following section.

A Critical Analysis

First of all, there are a series of restrictions which must be taken into account when it comes to evaluating the degree to which the initial hypothesis presented in this thesis is supported. These restrictions arise from the results offered in the validations of the solution which have been carried out:

- The validations do not present statistically significant results in terms of efficiency for the solution proposed when compared with the unassisted data analysis. As was described in the chapter entitled Empirical Validation, we believe that one of the factors which may have an influence in this regard is the level of prior expertise possessed by the subjects of the validation in the two methods of analysis being compared. Due to the absence of prior training with the prototype of the solution presented, the subjects possessed greater expertise in spreadsheets than with the prototype. This implies a difference in the level of familiarity between the two methods. This may have repercussions, particularly in terms of the degree of efficiency measured. However, it is possible that other factors also have an influence, such as the degree of learnability of the prototype itself not being sufficient. Note that learnability is defined according to ISO/IEC 9126, as "the capability of a software product to enable the user to learn how to use it" [148, 296]. We assume, therefore, that it is necessary to carry out a larger empirical study with differing degrees of expertise on the part of the subjects and incorporating mechanisms for prior training in order to be able to identify the factors which affect this result.
- The sample selected for the validation is statistically representative when it comes to comparing the two methods. That is to say, it is possible to generalise about the significant improvements of our proposed solution compared to the traditional method (spreadsheets). However, for an individual analysis of the proposed framework, a bigger sample, with greater heterogeneity, is necessary in order for us to not only confirm which aspects are improved compared with other methods but also to draw conclusions with a higher degree of generalisation, such as whether the framework-solution improves the quality of the written reports produced or the degree

of accuracy in the tasks, without taking into account the traditional methods used for prior data analysis.

Another relevant aspect is the sphere of application of the proposed framework-solution. First of all, the lack of treatment of knowledge extraction mechanisms, which were proposed in the initial hypothesis in the framework-solution, reduces software assistance designed for information visualisation techniques. Although this treatment is put forward as an area of future research in this thesis, we would like to point out that, from our point of view, software assistance integrating these mechanisms would be more complete but it would have to be designed and validated in order to evaluate its performance as part of the proposed framework-solution.

Secondly, it should be emphasized that the solution proposed in this thesis has been empirically tested by professionals in the field belonging to different institutions and of different profiles. We believe that the proposed solution, apart from the methodological implications of the chosen software models, offers software assistance to Cultural Heritage specialists, independently of their work methodology, their perspective of Cultural Heritage and other variables which are commonly used in Heritage, such as historical periods or chrono-cultural adscriptions, which are the speciality of the expert, etc. The capacity of the mechanisms used for the subject model (ConML and CHARM) in order to handle the models with subjectivity, temporality and vagueness, together with a high level of abstraction in the definition of the cognitive processes being assisted (Building, Combining, Clustering, Situating), allows us to make the applicability of the framework independent of these variables.

Thirdly, due to the fact that Cultural Heritage is a broad and complex discipline, made up of strongly connected sub-disciplines, the initial hypothesis is sustained in sub-areas of Cultural Heritage, such as Archaeology and History, in which it has been widely tested. Heritage areas such as Anthropology and Art may offer up case studies which can put the models to the test in terms of conceptual representation and suitability of the software assistance provided to their professionals, which must be tested. In the same way, we believe that the treatment of cognitive processes in any sphere of application could improve software assistance in other fields not related to Cultural Heritage. However, in-depth study of the chosen field of application is necessary in order to discover to what extent this assistance is applicable.

Finally, it should be pointed out that there is not only one form of software assistance and that this thesis takes the view that there is not only one way to reach this assistance. Therefore, it is possible that other methods or techniques, which have not been considered during this research process, may also obtain good results in terms of providing software assistance to the generation of knowledge in Cultural Heritage. Over the course of this research, an in-depth study of other prior projects was carried out, although the field in question is so broad that it is impossible to state whether this review covered one hundred per cent of the spectrum of existing studies. However, we believe that the studies examined are sufficient in terms of number and relevance to cover a broad spectrum of the state of the art in the fields in question. The flexibility of the conceptual mechanisms integrated into the framework-solution with metamodels dealing with concepts at a high level of abstraction and hierarchies of patterns allow us to consider the incorporation, or the study along similar lines, of other models and techniques, which have not previously been considered in this research process.

The critical analysis offered here, far from minimizing the scientific contributions made, demonstrates that this research is a work in progress, which opens up future lines of action. Both the contributions made throughout this research and the emerging lines of research are dealt with in the following chapter.

Chapter 14: Conclusions

In literature and in life we ultimately pursue, not conclusions, but beginnings.

-Sam Tanenhaus

Introduction

This thesis proposes a complete conceptual framework based on software models for the development of software to assist Cultural Heritage researchers in the process of knowledge generation. This chapter aims to condense the contributions presented to the scientific community into the different disciplines and areas involved. The chapter begins by summarising the main contributions of the research. The following section lists the main publications and dissemination activities of the results obtained over the course of the thesis. Although it is not an exhaustive list, due to the sheer volume involved, this section aims to illustrate the heterogeneity and transdisciplinary nature of the contributions made by presenting some of them in forums relating to both Software Engineering and Cultural Heritage. This shows how this research (and other projects of a similar nature) achieves an efficient form of co-research, which makes contributions in both disciplines. Finally, the chapter points out the emerging lines of research and future possibilities opened up by this thesis.

Main Contributions of this Research

The conceptual framework proposed for providing software assistance to the generation of knowledge in Cultural Heritage offers significant contributions, which are described below.

Main contribution

We have shown how a software system for providing assistance to the generation of knowledge in Cultural Heritage using software models is conceptualised, designed, prototyped and validated. The software prototype which has been implemented also constitutes a unique research tool which illustrates the whole process. This contribution presents the following implications:

First Contribution

We have carried out an in-depth study of the particularities of the field being assisted (Cultural Heritage), integrating support systems into the framework presented for dealing with aspects such as temporality, subjectivity and vagueness in conceptual terms. At the present time, we do not know of any previous study with similar characteristics.

Second Contribution

We offer a solid and tested characterisation of cognitive processes in Cultural Heritage in the form of a metamodel, which can be used for the construction of similar systems or for use in conceptual terms for any application requiring the definition of cognitive processes in the field.

Third Contribution

We offer a focus on visualisation patterns in the form of a hierarchical metamodel which is independent of the field of application and is not exclusive to one type of interface. This gives the mechanism a great degree of flexibility of application for the definition of presentation and interaction mechanisms in interfaces for software assistance systems aimed at the generation of knowledge.

Fourth Contribution

This research offers a complete methodology, including a modelling language based on ISO/IEC 24744, for the application of discourse analysis techniques in Software Engineering. We have shown how this application proves to be especially useful for those parts of the engineering process requiring the analysis of freestyle textual sources, such as requirement specifications, documents for translations of systems, etc. Furthermore, some contributions have been made in terms of the automatization and use of discourse analysis techniques for the automatic extraction of methodological information from textual sources.

Fifth Contribution

Finally, we have defined a method to identify traces of cognitive processes which are present in textual sources and validate it thanks to the Thinking Aloud protocol. The preliminary studies regarding its validity presented good results (see Appendix I), although a rigorous analysis with a larger number of uses of the methodology is necessary in order to determine its suitability. The empirical studies carried out following this methodology with the collaboration of Cultural Heritage specialists represent a contribution in themselves, given the scarcity of studies of this nature found during the research for this thesis. These studies have allowed us to produce a better characterisation of the end users of systems assisting in the generation of knowledge in general and to identify their particularities for specialists in Cultural Heritage.

The research process undertaken has a strong interdisciplinary component, not only for its initial approach (in which the application of software assistance to Cultural Heritage, a discipline in which the use of software in its knowledge generation processes is not typical, is desired) but also for the need, which was generated during its execution, to use techniques and tools which are characteristic of other disciplines in order to study the chosen field and the possibilities for assistance within it. For this reason, we believe that, apart from the specific contributions listed, the main contribution of the research presented here is the bi-directional relationship which has been established between both disciplines, given that 1) research has not only been carried out in Software Engineering, producing a framework supporting assistance in a little-explored field of application and integrating, both methodologically and technically, discourse analysis into the process of software development, but also 2) the research frontiers in the field of Cultural Heritage have also been advanced in terms of the improvement of its stratigraphic visualisation systems, the application of Thinking Aloud techniques for the study of knowledge generation in the field and the possibility of analysing its textual sources and formally modelling the results.

Publications and Other Dissemination Activities of the Results

The contributions listed in the previous section have been presented in numerous peer-reviewed scientific forums, with the aim of obtaining validation and proposals for improvement from the scientific community. For each publication referenced, information is provided regarding which contributions of the thesis are most related. As was explained at the beginning of the chapter, this section does not aim to offer an exhaustive list of the author’s publications in the area during the research process but only to highlight the most relevant ones and to attempt to demonstrate the heterogeneity of forums and scientific communities which have supported the contributions. These contributions are listed in each sub-section in chronological order. The position of the author in the publication indicates the degree of contribution made in the work.

Publications

1. González-Pérez, Cesar; Martín-Rodilla, Patricia; Parcero-Oubiña, César; Fábrega-Álvarez, Pastor; Güimil-Fariña, Alejandro. (2012) **Extending an Abstract Reference Model for Transdisciplinary Work in Cultural Heritage**. In Metadata and Semantics Research. Juan Manuel Dodero, Manuel Palomo-Duarte, Pythagoras Karampiperis (Eds.) Springer 2012 Communications in Computer and Information Science. Vol 1. pp. 190-201. ISBN: 978-3-642-35232-4.
2. Martín-Rodilla, Patricia. (2013) **Knowledge-assisted Visualization in the Cultural Heritage Domain - Case Studies, Needs and Reflections**. In Proceedings of the International Conference on Computer Graphics Theory and Applications and International Conference on Information Visualization Theory and Applications. Sabine Coquillart, Carlos Andújar, Robert S. Laramee, Andreas Kerren, José Braz (Eds.) pp. 546-549. ISBN: 978-989-8565-46-4.
3. Martín-Rodilla, Patricia. (2013). **Software-Assisted Knowledge Generation in the Archaeological Domain: A Conceptual Framework**. In Proceedings of the Doctoral Consortium of the 25th International Conference on Advanced Information Systems Engineering (CAiSE 2013) Marta Indulska, Barbara Weber (Eds). June 2013. Valencia, Spain.
4. Martín-Rodilla, Patricia. (2014). **An Empirical Approach to the Analysis of Archaeological Discourse**. In Across Space and Time. Selected Papers from the 41st Computer Applications and Quantitative Methods in Archaeology Conference (Perth, WA, 25-28 March 2013). A. Traviglia (Ed.). Perth Australia. Amsterdam University Press. ISBN: 978-908-9647-153.
5. Gonzalez-Perez, Cesar; Martín-Rodilla, Patricia; Blanco-Rotea, Rebeca. (2014). **Expressing Temporal and Subjective Information about Archaeological Entities**. In Across Space and Time. Selected Papers from the 41st Computer Applications and Quantitative Methods in Archaeology Conference (Perth, WA, 25-28 March 2013). A. Traviglia (Ed.). Perth Australia. Amsterdam University Press. ISBN: 978-908-9647-153.
6. Martín-Rodilla, Patricia; Panach, José Ignacio; Pastor, Óscar. (2014). **User Interface Patterns for Rich Applications in the Context of Cultural Heritage Data**. In Proceedings of IEEE 8th International Conference on Research Challenges in Information Science, RCIS 2014, Marrakech, Morocco, May 28-30, 2014. Marko Bajec, Martine Collard, Rébecca Deneckère (Eds.). Marrakech, Marruecos. ISBN 978-1-4799-2393-9.

7. Martín-Rodilla, Patricia; González-Pérez, César. (2014). **An ISO/IEC 24744-Derived Modelling Language for Discourse Analysis.** In Proceedings of IEEE 8th International Conference on Research Challenges in Information Science, RCIS 2014, Marrakech, Morocco, May 28-30, 2014. Marko Bajec, Martine Collard, Rébecca Deneckère (Eds.). Marrakech, Marruecos. ISBN 978-1-4799-2393-9.
8. González-Pérez, César; Martín-Rodilla, Patricia. (2014). **Integration of Archaeological Datasets through the Gradual Refinement of Models**. In Selected Papers from the 42nd Computer Applications and Quantitative Methods in Archaeology (CAA) (Paris, France, 22-25 April 2014) Vol 1, pp 193-204. Amsterdam University Press. Paris, France. Archaeopress, Oxford. ISBN 9781784911003.
9. Epure, Elena Viorica; Martín-Rodilla, Patricia; Hug, Charlotte; Deckenère, Rebecca; Salinesi, Camille. (2015). **Process Model Discovery from Textual Methodologies: Applied in Archaeology**. In Proceedings of the IEEE 9th International Conference on Research Challenges in Information Science, May 13-15 2015, Athens, Greece. ISBN 978-1-4673-6630-4.
10. Martín-Rodilla, Patricia; González-Pérez, César; Mañana-Borrazás, Patricia. (2015). **A conceptual and visual proposal to decouple material and interpretive information about stratigraphic data**. In Keep the revolution going. Selected Papers from the 43rd Computer Applications and Quantitative Methods in Archaeology Conference (Tuscany-Italy 30th March-3rd April 2015). Archaeopress Publishing Ltd. Oxford, UK. ISBN 978-1-78491-337-3
11. Martín-Rodilla, Patricia; Giachetti, Giovanni; González-Pérez, César. (2015). **Achieving software-assisted knowledge generation through model-driven interoperability**. In "XX Jornadas de Ingeniería del Software y Bases de Datos (JISBD). Sociedad Nacional de Ingeniería del Software y Tecnologías de Desarrollo de Software (SISTEDES)". September 2015. Santander, Spain.
12. González-Pérez, César; Martín-Rodilla, Patricia; Epure, Elena Viorica. (2015) **Formalisation and Reuse of Methodological Knowledge for Archaeology across European Organizations**. Accepted contribution for the 44th Computer Applications and Quantitative Methods in Archaeology Conference. April 2016. Oslo, Norway.
13. González-Pérez, César; Martín-Rodilla, Patricia. (2016) **Using Model Views to Assist with Model Conformance and Extension.** Accepted contribution for Proceedings of the IEEE 10th International Conference on Research Challenges in Information Science, 1-3 June 2016, Grenoble, France.

Table 18 shows the relation between each publication referred above and the main contributions of this thesis addressed by the publication:

Publication	First Contribution	Second Contribution	Third Contribution	Fourth Contribution	Fifth Contribution
1	X				
2					X
3	X	X	X		X
4		X		X	
5			X		
6		X		X	
7	X				
8				X	
9	X		X		
10	X	X	X		
11				X	X
12	X			X	
13	X				

Table 18. Relation between each publication referred above and the main contributions of this thesis addressed by the publication.

Other Dissemination Activities

Teaching

- April 2012. Teaching program for specialization and highly specialization courses of Spanish National Research Council. Postgraduate course CSIC-Incipit: “Introduction of Conceptual Modelling for Cultural Heritage”. 2012 Edition. UNESCO Code: 3399 1203.18 51;55. Santiago de Compostela, Spain (60 hours).

- June 2012. Course Conceptual Modelling for Cultural Heritage. Training plan for GPAC - Built Heritage Research Group, Basque Country University (UPV/EHU) and Zain Foundation. Vitoria, Spain (30 hours).
- University Academic Year 2013/2014. University course "Archaeological Information Modelling", including as part of the Master in Archaeology and Antiquity Sciences. RD 1393/2007. Faculty of Geography and History. University of Santiago de Compostela, Spain.
- May 2014: Seminar "Conceptual Modelling for Cultural Heritage: usefulness, strategies and potential" 7th-8th May 2014. Internal program of training for employees. National Center for Restoration and Preservation in Cultural Heritage. Santiago de Chile, Chile. (10 hours).
- University Academic Year 2013/2014. University course "Estimation and metrics in Software Development", including as part of the Master in Software Engineering. Faculty of Enginnering, Andrés Bello University. Campus of Viña del Mar, Chile. (64 hours).
- University Academic Year 2014/2015. University course "Archaeological Information Modelling", including as part of the Master in Archaeology and Antiquity Sciences. RD 1393/2007. Faculty of Geography and History. University of Santiago de Compostela, Spain.
- University Academic Year 2015/2016. On-line Course "Conceptual Modelling for Cultural Heritage". Permanent training program of National Distance Education University (UNED) Foundation, in collaboration with Digital Humanitites Innovation Laboratory (LINDH- UNED) and Institute of Heritage Sciences (Incipit-CSIC). October 2015 - April 2016. (400 hours). http://www.fundacion.uned.es/actividad/idactividad/10306
- University Academic Year 2015/2016. University course "Archaeological Information Modelling", including as part of the Master in Archaeology and Antiquity Sciences. RD 1393/2007. Faculty of Geography and History. University of Santiago de Compostela, Spain.

Workshops and Lectures

- Martín-Rodilla, Patricia. "Más allá de los Datos: Extracción y Generación de Conocimiento y Sus posibilidades en Patrimonio Cultural". Research Talks Program of Institute of Heritage Sciences (CSIC). Santiago de Compostela, Spain. February 2012.
- Martín-Rodilla, Patricia. "Extending an Abstract Reference Model for Transdisciplinary Work in Cultural Heritage". Research Talks Program of Institute of Heritage Sciences (CSIC). Santiago de Compostela, Spain. November 2012.

- Martín-Rodilla, Patricia. “Assisted Knowledge Generation in the Cultural Heritage Domain” Human Centred Technology Design Seminar Program. University of Technology Sydney. Sydney, Australia. April 2013.
- Martín-Rodilla, Patricia. "Supporting cognitive processes through software models: the archaeological case". PROS seminar series conference program. Centro de Investigación en Métodos de Producción de Software (PROS). Polytechnic University of Valencia. June 2013.
- Martín-Rodilla, Patricia. “Inferencias y razonamiento en arqueología: caracterización, resultados empíricos y su impacto en la relación arqueólogo-software”. Research Talks Program of Institute of Heritage Sciences (CSIC). Santiago de Compostela, Spain. October 2014.
- Martín-Rodilla, Patricia. “Software-assisted knowledge generation in archaeology: from textual sources to software assistance tools”. Centre de la Recherche en Informatique”. Conference at Universidad Paris-1 Pantheon-Sorbonne. Paris, France. November 2015.
- González-Pérez, César; Martín-Rodilla, Patricia; Hug, Charlotte. WS3 “Hands-On Archaeological Conceptual Modelling 2” Workshop in the 43rd Annual Conference on Computer Applications and Quantitive Methods in Archaeology”. Siena, Italy. 30 March- 3 April 2015.
- Martín-Rodilla, Patricia. “Software Engineering & Cultural Heritage: Roadmap and transdisciplinary possibilities” NOVA Laboratory for Computer Science and Informatics (NOVA LINCS). Faculty of Sciences and Technology. NOVA University of Lisbon. Lisbon, Portugal. October 2015.

Emerging Lines of Research

Over the course of several chapters of this doctoral thesis, reference has been made to the research lines dealt with in this work and to how the contributions made allow for advances in these lines and even to how new lines of investigative research have been opened up. Below, we shall outline the implications and emerging lines of research, which are the fruit of the proposals put forward in this thesis. They are listed from lowest to highest in terms of scope and implication: from the most immediate actions for the improvement of the solutions proposed, via the implications and areas of interest which are open in the short to medium term, to possible complex lines of research which may be developed in the future.

As far as areas for improvement in the solutions proposed throughout this doctoral thesis are concerned, we believe that, in the short term, a validation of the models proposed as part of the conceptual framework through a broad range of case studies is necessary, especially in non-archaeological sub-areas of Heritage. Although the subject model has been tested in other Heritage sub-disciplines and the rest of the models which make up the framework are independent in nature from the field of application due to their abstract definition, the cognitive processes and software presentation and interaction models have only been tested in case studies belonging to the sub-disciplines of Archaeology and History. Complex Heritage areas, such as Anthropology and Art may offer case studies which put the models to the test in terms of conceptual representation and suitability of the software assistance offered to their professionals. In the same way, the exhaustive validation of these models would enable us to detect other cognitive processes in Cultural Heritage and other similar fields, which may be assisted, and to find out whether there are other software presentation and interaction patterns which should be incorporated into the proposed conceptual framework.

In addition to the work of improving the proposed solutions, the conceptual framework presented here opens up other possibilities in the medium term regarding studies in software assistance. We consider it especially relevant to promote:

- Studies of the connection between cognitive processes and solutions in terms of software interaction, including the exploration, in software assistance spheres, of other proposals made in terms of the integration of cognitive processes in Software Engineering, such as approaches based on Intention Mining [167, 201, 257], and of established graphic interface representation language proposals [2]. These approaches may enrich expressiveness and connect the solution presented in this thesis with existing studies, expanding them to applications related to software assistance, in which they have not yet been applied.
- Studies on how analysts use this conceptual framework in order to define software assistance (which cognitive processes they choose to assist, which presentation and interaction hierarchy pattern they employ, etc.).
- In relation to the studies of use mentioned above, we believe it is necessary to define new metrics in order to evaluate the level of assistance obtained in knowledge generation in any area or field and that the empirical work presented here should offer a solid foundation in order to continue working along these lines.
- Developments complementing those which have been made over the course of this doctoral research (basically focused on model-directed interoperability) in order to incorporate model-directed software paradigms into the conceptual framework presented. This will provide the proposed solution with a greater degree of dynamism and will enable semi-automatic solutions for instantiation of the conceptual framework to be explored, along with evolutionary models for each of the aspects dealt with in the framework.

- Studies on the connection between the work carried out and the application of discourse analysis techniques in Software Engineering, especially in the requirements phase, in which their connection with existing notations and approaches in requirements engineering has already been explored. The aim of these studies is to attempt to promote these approaches with a linguistic and philosophical vision and to close the gap which exists between the specifications of textual requirements and the closest requirements models, such as Mind Maps [42, 83], Use Cases [154], and goal-oriented notations such as i* [47, 98, 124, 314] or KAOS [69, 294].

Finally, we believe that it is important to highlight the fact that this doctoral thesis is set in a research context in which co-researcher and transdisciplinary approaches such as this one between Software Engineering and Cultural Heritage have been gaining in importance over recent years. A good example of this are the studies grouped together under the name of Digital Humanities [280]. The current relevance of these approaches in the research community [104, 106] allows our research to be a starting point, not a final destination, in research on the relationship between Software Engineering and Cultural Heritage, opening up new lines, and sub-lines, of research in the long term, the most important aspects of which are:

- Lines of research relating to the application of Thinking Aloud Protocols (TAP) as a technique for the characterisation, definition and extraction of cognitive processes in Humanities areas.
- The continuation of the line of research initiated regarding the integration of the methodology and of the discourse analysis language presented here in any research process which requires the analysis, structuring and semantic extraction of textual sources written in a free style. Some particularly interesting aspects here are:
    - The application of the methodology and the language presented here in numerous cases within the process of software development. Initially, the possibility of incorporating them into processes of analysis and requirements structuring has been explored with good results [197]. The continuation of this line of research may offer good results in other similar processes in Software Engineering, such as automatic translation, the indexing of textual sources [40], annotation systems, etc.
    - The application of the methodology and the language presented here in numerous cases within the analysis of scientific valuations and methodological literature in Cultural Heritage, encapsulating what knowledge has been generated based on particular data about our past and allowing us to extract methodological entities from the texts.

These analyses would allow us to trace the process of knowledge generation in Cultural Heritage more clearly. This approaches could allow us to continue currently works related to different uses of textual information in digital humanities [61, 105, 235, 239, 275, 276].

- The continuation of the line of research initiated regarding software assistance, expanding the types of assistance offered, placing particular emphasis on software assistance via knowledge extraction techniques, which was initially proposed in the planning stages of this research process, but was only explored during the case study [84]. This line of research aims to study the relation between the discourse analysis language presented here and the possibilities for data-mining and text-mining associated with it. This will allow us to incorporate a type of software assistance into the conceptual framework which does not only work by way of adapted visualisations, but also via recommendations about which techniques of “Textual and Data Mining” (TDM) may offer better results according to the type of documental corpus being analysed. As far as this line of research is concerned, the case study carried out in the field of Cultural Heritage, offers new possibilities for the application of natural language processing techniques for the extraction of heritage information on both inferential and methodological levels of discourse.

To sum up, this doctoral thesis provides a solution for the conceptualisation, definition, design and implementation of software assisted knowledge generation in the field of Cultural Heritage. In addition, it establishes ways of tackling software assistance in other similar, though unexplored, fields. Through this research, and other similar studies, it is hoped that the relationship between Software Engineering and Cultural Heritage will continue to be transformed, thereby favouring the bidirectional application of research results between the two disciplines. In this future scenario, the specialist in Cultural Heritage will not simply be a user of software tools which he/she applies in a specific process within the chain of knowledge generation. Rather, as an expert, he/she will integrate parts of the Software Engineering corpus into his/her work methodology in the generation of knowledge.

Therefore, as was mentioned at the beginning of this chapter, thanks to the research carried out between the two disciplines involved, each of the contributions mentioned here opens up new possibilities in its discipline of origin.

APPENDIX I: A Compendium of the Prior Empirical Studies

This appendix presents the complete process of definition, design, execution and analysis followed in each of the four empirical studies carried out during the exploration of the problem of this research. It is organised into sections which go into meticulous detail regarding each of the studies carried out upon testing each contribution according to this process [309].

EMPIRICAL STUDY 1

Objective(s) of the Empirical Study —Scoping—

This empirical study had two main objectives:

a) On the one hand, the intention was to test the defined methodology for discourse analysis in Software Engineering, scrupulously following the steps designed, proving the suitability of its application to each of the 40 fragments of discourse analysed.
b) On the other hand, our second objective was to check whether the discourse language which was designed was appropriate for modelling different kinds of discourse (by different authors, institutions, on different topics, etc.).

According to Wohlin, these objectives can be formalised by:

a) Analysing the proposed methodology for the purpose of evaluation with regard to the degree of suitability to discourse analysis in Cultural Heritage from the point of view of researchers interested in gaining a better knowledge of discourse analysis in Cultural Heritage in the context of both public and private Cultural Heritage institutions.
b) Analysing the proposed modelling language for the purpose of evaluation with regard to the degree of suitability to discourse analysis in Cultural Heritage from the point of view of researchers interested in gaining a better knowledge of discourse analysis in Cultural Heritage in the context of both public and private Cultural Heritage institutions.

Planning the Study

Context: The empirical study was carried out with real tools and real problems. A corpus of 40 fragments of discourse was selected from six real textual sources (management and research reports in Cultural Heritage available on-line). The study was, therefore, situated in a specific but broad context with a sample of specialists in Cultural Heritage belonging to both public and private institutions on a national scale). It could be considered that the empirical study is in an on-line context because it was carried out in the professional environment in which it would be put into practice (public and private management and research institutions in the field of Cultural Heritage).

The Formulation of the Hypothesis: Two hypotheses were verified. Informally, they are:

- The proposed methodology is not appropriate for discourse in Cultural Heritage. This lack of suitability should be reflected in the fact that it does not allow for agile analysis of the discourse, with many problems being identified by the participants regarding understanding of the modelling process and a low level of satisfaction among specialists in Cultural Heritage.
- The proposed language is not appropriate for discourse in Cultural Heritage. This lack of suitability should be reflected in the fact that it does not allow for agile analysis of the discourse, with many problems being identified by the participants regarding understanding of the modelling process and a low level of satisfaction among specialists in Cultural Heritage.

Response variables are those which formalise the variable being measured. In this case, we shall formalise the suitability of the methodology and the proposed language to discourse analysis in Cultural Heritage by the use of two response variables for each hypothesis: the number of problems identified and the degree of satisfaction of the participant according to a Likert scale of five possible values. Based on these informal hypotheses, we can now define H_0 y H_0' as null hypotheses and their alternative hypotheses:

H_0: The proposed methodology is not suited to discourse analysis in Cultural Heritage, with numerous problems being identified by the specialists in the field and the degree of satisfaction being low.

The number of problems shall be considered high when, for each fragment of discourse to be evaluated, more than five problems are shown by the participant. The fragments of discourse being evaluated are small so more than five problems will generally indicate that the participant is not able to follow the methodology or use the language fluently. It should be noted that the following symbols have been used for the definition of the hypotheses:

$\uparrow$ Indicates that the variable accompanying the symbol has a tendency to increase.

$\downarrow$ Indicates that the variable accompanying the symbol has a tendency to decrease.

&& Indicates the union of conditions in the hypothesis.

H_0: M (Methodology) = $\uparrow$P (Problems reported) && $\downarrow$ SD (Satisfaction Degree)

Alternative Hypothesis H_1: M (Methodology) = $\downarrow$P (Problems reported) && $\uparrow$SD (Satisfaction Degree)

H_0': The proposed language is not suited to discourse analysis in CH, with numerous problems being identified by the specialists in the field and a low degree of satisfaction.

H_0': L (Language) = $\uparrow$ P (Problems reported) && $\downarrow$ SD (Satisfaction Degree)

Alternative Hypothesis H_1': L (Language) = $\downarrow$P (Problems reported) && $\uparrow$ SD (Satisfaction Degree)

The selection of variables: The independent variables were selected, these were: the modelling skills and experience of the participants and those of the methodology and the language being evaluated. The variables relating to the skills of the participants would be controlled by way of a prior questionnaire. The methodology and the language being evaluated are the treatments to be applied.

The suitability to discourse analysis in Cultural Heritage, formalised by the number of problems identified and the degree of satisfaction of the participants, are the dependent variables.

The selection of subjects: The sample of participants corresponds to the s*imple random sampling* model. A sample of eight specialists in the field of Cultural Heritage was selected, drawing them from five different public and private Spanish institutions (Incipit-CSIC, the Xunta de Galicia (the Galician regional government), private companies in the area of cultural management, the University of Santiago de Compostela and CCHS-CSIC). These participants were selected at random from the more than 20 specialists who expressed an interest in collaborating with this study.

Design Principles: As far as randomisation is concerned, on an initial level, the objects were not assigned at random to the subjects. In other words, all of the participants evaluated models and their associated fragments of text from the six reports. However, on the second level, it can be considered that there was a certain degree of randomisation, given the fact that the participants randomly evaluated different models from among those of each report. The objective of the study is not to evaluate this methodology and the proposed modelling language compared with other constructs. Therefore, we believe that this level of randomisation is sufficient. The assignations of objects were not random as the order of evaluation was not relevant.

As far as the blocking of variables is concerned, we believe that the decision to evaluate several fragments of text from different sources and their models blocked, to a certain extent, the impact of the sources and the text itself in the resulting models. In addition, the influence of the participants' skills in modelling was taken into account, being measured by a prior questionnaire.

Finally, it would have been desirable to apply the principle of balancing but, due to the difficulty in finding a large number of subjects, they all evaluated models of fragments from six texts. Therefore, balancing did not occur.

Instrumentation: The choice of objects can be considered as random as, although some of the texts belong to the institutions for which the participants work, others form part of international institutional repositories, unconnected to the participants. In the case of reports belonging to the participants' institutions, none of the participants was the author of any of the texts.

As far as the lines of action in the execution of the study are concerned, the modelling procedure is defined by the methodology being evaluated. Instructions were given regarding the methodology and material on the language, and the participants were allowed to ask initial questions about them. It was not considered necessary to train the participants in advance about the methods to be used as the aim of the study consisted precisely in establishing the suitability of the methods in untrained conditions. Mistakes were measured and problems identified both in terms of use of the methodology and semantic problems (lack of understanding, doubts, etc.) when evaluating the model with regard to its associated fragment following the proposed language. Furthermore, questions were asked about the participants' degree of satisfaction (according to a Likert scale from Extremely Low, Low, Average, High and Extremely High) with the procedure (that is to say the methodology) and with regard to their understanding of the modelling language itself.

Evaluation of aspects of validity: According to the definition of Wohlin based on Cook & Campbell [60] with regard to types of threats in software experimentation, it was considered necessary to highlight beforehand the following threats to the validity of the study:

- With regard to its internal validity, it is considered that the low number of participants could compromise the results if the objective of the study were to establish causal conclusions. However, as was explained at the beginning of this chapter, the empirical study does not aim to establish these relations, thus minimising this threat.
- With regard to its external validity, it is considered that the probability of the results being repeated in other contexts is high, due to the randomisation of the objects used, as well as to the fact that other similar studies and experiments [193] have been carried out in Cultural Heritage contexts.
- As far as the conclusion validity is concerned, it is considered that the random choice of textual reports and of the fragments to be modelled within these reports constitutes a guarantee for the representativity of the texts. Likewise, conducting sessions in person, with just one participant each time, minimised threats regarding the quality of the data obtained.
- As far as the construct validity is concerned, we should take the low level of statistical generalisation presented into account, fundamentally due to the influence of threats related to social aspects, the possible variability within the evaluated models and the modelling skills of the participants. Furthermore, it would be necessary to carry out a larger number of similar empirical studies in order to avoid the problems of "*fishing and the error rate*". In other words, this study manages to identify a relation between variables which in reality does not occur on a greater scale in a higher number of studies. It should be remembered that this degree of generalisation is not the final aim of the empirical study.

The Execution of the Study —Operation—

Preparation: The participants in the study did not know the fragments of text to be analysed nor the heritage reports from which they were extracted. They were informed of the methodology and the language but not of the hypotheses being dealt with in the study. By offering themselves as volunteers for this study, they gave their consent for this. All the necessary materials were prepared beforehand: an initial questionnaire about the participants' personal and professional profile, the fragments of text selected and their associated models, information regarding the language and the questionnaire about the degree of satisfaction.

Execution: The participants were received one by one in individual sessions lasting between an hour and an hour and a half. An explanation was given to each volunteer regarding the methodology and some basic notions of the language and they were asked to sketch a model for each fragment, following the methodology and stating any doubts, problems and mistakes which they observed in its application. Later, they were shown a final model made by experts in modelling for each fragment of text. They were asked to evaluate the model, comparing it with their sketch and giving information about each semantic and/or syntactical problem which they identified. Finally, they were questioned about their level of satisfaction, both concerning the methodology and the language, as well as the model presented.

Data validation: No invalid data was detected. This can be attributed to individuality and supervision in the process of the execution of the study.

Analysis and Interpretation: Results

Results of the use of the methodology (P): The rate of problems detected in the understanding and application of the described methodology is extremely low.

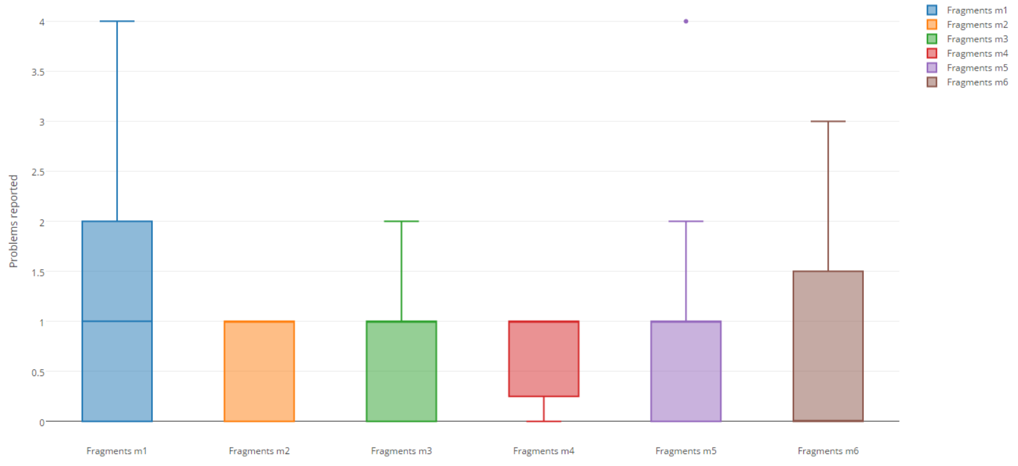

Fig. 116. Distribution of problems detected in the understanding and application of the methodology according to the textual fragments analysed.

As can be seen in Fig. 116, between 0 and 4 problems were detected in the fragments corresponding to the different textual reports, this can be put down to the simplicity of the methodology, its ease of understanding and/or application or other factors which allow us to see a level of suitability to the purpose which concerns us. It should be noted that none of the participants are specialists in Software Engineering and, therefore, modelling methodologies are foreign to them in the course of their daily work (although some of them may have a degree of knowledge of some of their basic principles). In addition, none of the participants had prior contact with the methodology designed nor were they aware of the aim of this methodology.

As far as the **degree of satisfaction with the use of the methodology (SD)**, which the participants expressed, is concerned, more than half expressed a level of satisfaction higher than 3 (Average), as can be seen in Fig. 117:

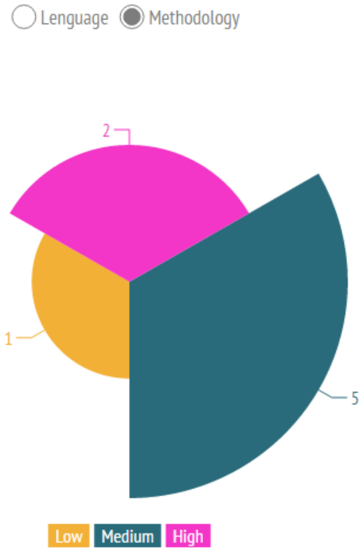

Fig. 117. Degree of satisfaction concerning the methodology employed, as expressed by the participants.

Results of the discourse modelling using the proposed language (P): The rate of problems detected relating to understanding and applying the language itself increases slightly in all the reports compared to when methodological aspects are concerned. This can be put down to the fact that the language has many more elements which can cause problems of semantic understanding on the part of the participant, taking into account the fact that it represents a greater learning curve. Furthermore, there is a resistance to modelling following the established form of notation with participants preferring to express the casuistry of each fragment being modelling verbally during the study. The participants also asked for examples in order to understand the different definitions of the main concepts of the language. These aspects are of great relevance when it comes to proposing a solution to the problem in question (see Fig. 118).

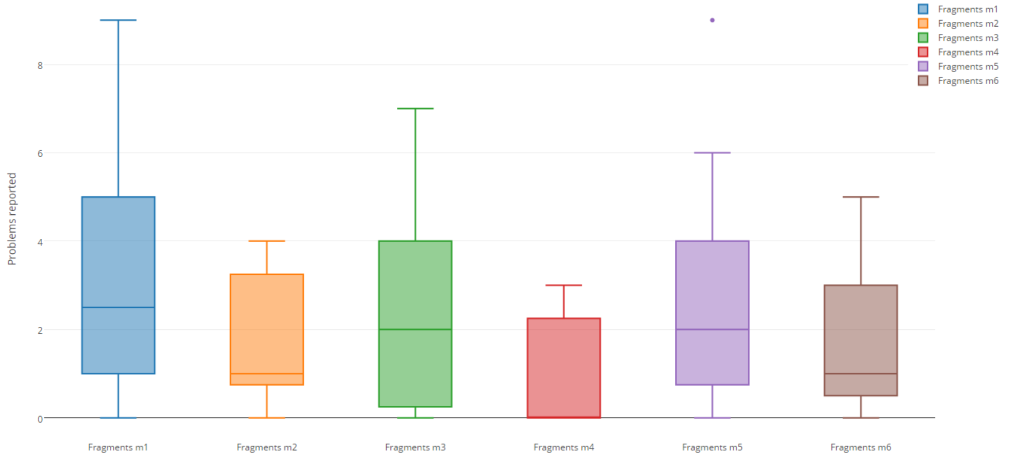

Fig. 118. Distribution of problems detected in the comprehension and application of the modelling language according to the textual fragments analysed.

As far as the **degree of satisfaction with the use of the language (SD)** is concerned, the tensions detailed above may lie behind the lower degree of satisfaction than was the case with the methodology. However, there is still a relatively high degree of satisfaction, perhaps due to the fact that each participant has had to reflect on conclusions in their own field during the study, as they themselves made clear during the sessions (see Fig. 119).

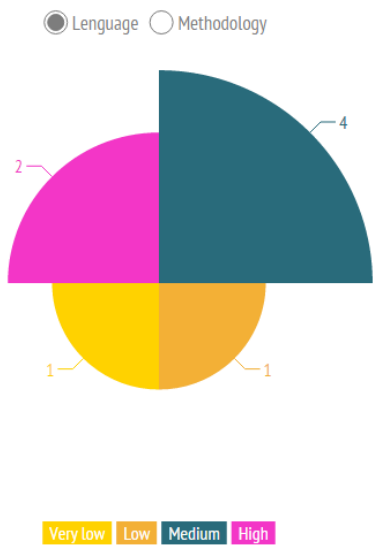

Fig. 119. Degree of satisfaction regarding the modelling language, as expressed by the participants.

Presentation and Package

This appendix represents the presentation format chosen in the empirical study 1.

EMPIRICAL STUDY 2

Objective(s) of the Empirical Study —Scoping—

The objective of this empirical study, in Wohlin's terms, can be defined as:

a) Analyse the characterisation of cognitive process for the purpose of evaluation regarding the degree of its suitability to the field of Cultural Heritage from the perspective of researchers with an interest in gaining knowledge of the functioning of this characterisation in the field of Cultural Heritage in the context of public and private Cultural Heritage institutions.

Planning the Study

Context: The empirical study was carried out with real tools and problems (20 fragments of discourse extracted from management and research reports in Cultural Heritage, which are available on-line). However, the characterisation used can be considered as a "toy example" object as it is not commonly used by experts in this field. The study is set in a specific but broad context (a sample of specialists in Cultural Heritage drawn from both public and private institutions on a national scale). It could be considered that the context of this empirical study is on-line as it was carried out in a professional context in which it would be used (public and private management and research institutions in Cultural Heritage). It should be remembered, at this point, that the study was carried out using a methodology based on TAP (*Thinking Aloud Protocols*), specifically designed for the purpose of this empirical study and described in the Chapter 5 entitled "Prior Empirical Results".

The formulation of the hypothesis: a hypothesis was verified, which was informally defined as:

- The defined characterisation of cognitive processes is not suitable for the field of Cultural Heritage. This is reflected in the fact that the percentage of coincidence between the categorisations of the selected fragments of discourse among the different experts in the field is low. Therefore, the characterisation employed may not be sufficiently representative, suitable, understandable or generalisable in the field.

In this case, we shall formalise the suitability of the characterisation of cognitive processes for the field of Cultural Heritage by way of one response variable: The average percentage of coincidence between the assignations of cognitive processes which the specialists in the field made to specific fragments of discourse. Taking this informal hypothesis as a basis, we can now define H_0 as a null hypothesis and H_1 as an alternative hypothesis:

H_0: The average percentage of coincidence (C_{AP}) among the assignations of cognitive processes to the selected fragments of discourse among different specialists in the field in each group of fragments is less than 50%. H_0: $C_{AP} < 50\%$

Alternative hypothesis H_1: $C_{AP} >= 50\%$

Selection of variables: The fragments to be evaluated and the associated cognitive processes were selected as the independent variables. In addition, experience with TAP protocols, controlled via a questionnaire prior to participation, was taken into account as an independent variable.

The dependent variable would be the suitability of the characterisation of cognitive processes to the field of Cultural Heritage, formalised via the average percentage of coincidences of assignations of cognitive processes performed by the specialists in order to characterise the fragments of discourse.

Selection of subjects: The sample of participants corresponds to the *Simple random sampling* model. A sample of six Cultural Heritage specialists was selected from three different institutions (both public and private) (Incipit CSIC, Xunta de Galicia (the regional government of Galicia) and a private company specialised in cultural management) chosen randomly from the 20 specialists who showed an interest in collaborating in this process.

Design principles: As far as randomisation is concerned, the objects were not assigned randomly to the subjects. That is to say, all the participants evaluated the 20 selected fragments extracted from four different reports. The participants evaluated the fragments of discourse and categorised them randomly. However, we believe that the order of evaluation is not relevant.

As for the need to block variables, we consider that the decision to evaluate several fragments of texts from different sources blocked, to a certain degree, the impact of the sources and the text itself in the resulting models. The influence of the participants' modelling skills were also taken into account, with an attempt to measure this aspect being made via a prior questionnaire.

Last of all, it would have been desirable to apply the balancing principle but, due to the difficulty in finding a high volume of subjects, they all evaluated the same fragments, therefore, balancing did not occur.

Instrumentation: The choice of the objects can be considered as random, due to the fact that, although some of the texts belonged to the participants' own institutions, others came from international institutional repositories unrelated to their institutions. In the case of the reports from the institutions consulted, none of the participants were the authors of the texts.

As far lines of action in the execution of the study are concerned, the participants were provided with a document containing the instructions for participation, along with a questionnaire and information regarding the characterisation of cognitive processes which should be used for their answers. No prior training was necessary for the participants to reply to the questionnaire.

Evaluation of aspects of validity: According to the Wohlin's definition, based on Cook & Campbell [60], it was considered necessary to highlight the following threats to the validity of the study beforehand:

- As far as its internal validity is concerned, we consider that the low number of participants in the study could compromise the results if the objective of the study were to establish causal conclusions. However, as was explained at the beginning of the chapter, the empirical study does not have the objective of establishing this type of relations, thus minimising this threat.
- As far as its external validity is concerned, we consider that the probability of the results being repeated in other environments is high, due to the randomisation in the objects used and the fact that other similar studies and experiments have been carried out in Cultural Heritage contexts [193].
- As far as the conclusion validity is concerned, we consider that the random selection of textual reports and of the fragments to be characterised within these reports constitutes a guarantee of representativity of the texts. Furthermore, conducting the sessions in person, with only one participant at a time, minimised the threats regarding the quality of the data obtained.
- As far as its construct validity is concerned, we must take into account the fact that the low number of participants did not allow us to make a statistical generalisation of the results. Another possible threat could be the suitability of the selected measures as the average percentage may not permit a more in-depth analysis of the data obtained. However, carrying out the studies according to the TAP protocol allows us to obtain more data in the future. The differences in the participants' profiles and professional skills could also have an influence on the categorisation of the selected fragments of discourse.

The Execution of the Study —Operation—

Preparation: The participants in the study did not know the fragments of text which were to be characterised. They were given information about the characterisation of the cognitive processes to be used but not about the hypotheses being tested in the study. By offering to participate as volunteers in this study, they gave their consent to these conditions. The necessary materials were prepared beforehand: an initial questionnaire about their professional profile and previous experience in TAP (None, Low, Average, and Expert), the selected fragments of text and the characterisation to be used.

Execution: The participants were received one by one in individual sessions of between 45 minutes and one hour in length, thus avoiding problems relating to fatigue in TAP protocols [180]. Each of them was given an explanation of the characterisation of cognitive processes to be used and they were told that they would be recorded according to the TAP protocol described in Fig. 19 (see Chapter 5 entitled "Prior Empirical Results" for a detailed definition of the methodology of the empirical study). Then, they were asked to characterise the fragments of discourse, describing aloud the reasons for their choices and/or doubts.

Validation of the data: No invalid data was detected. This can be attributed to the individuality and supervision of the process of execution of the study.

Analysis and Interpretation: Results

Results according to percentage of coincidence (C_{AP}): Fig. 120 and Fig. 121 show the participants' answers regarding the characterisation of the 20 fragments of discourse. Fig. 120 shows the fragments in which the variability of the answers is only of two different values. In other words, the specialists in Cultural Heritage only differed in two possible cognitive processes when characterising the fragments of discourse. Fig. 121 shows those fragments with a greater degree of variability in the answers. In both cases, the most chosen option also corresponds to the option of the modeller/doctoral candidate, although this finding would be analysed after the study.

As can be seen in both figures, the majority of the specialists coincided in the cognitive process which they associated with the fragment in question.

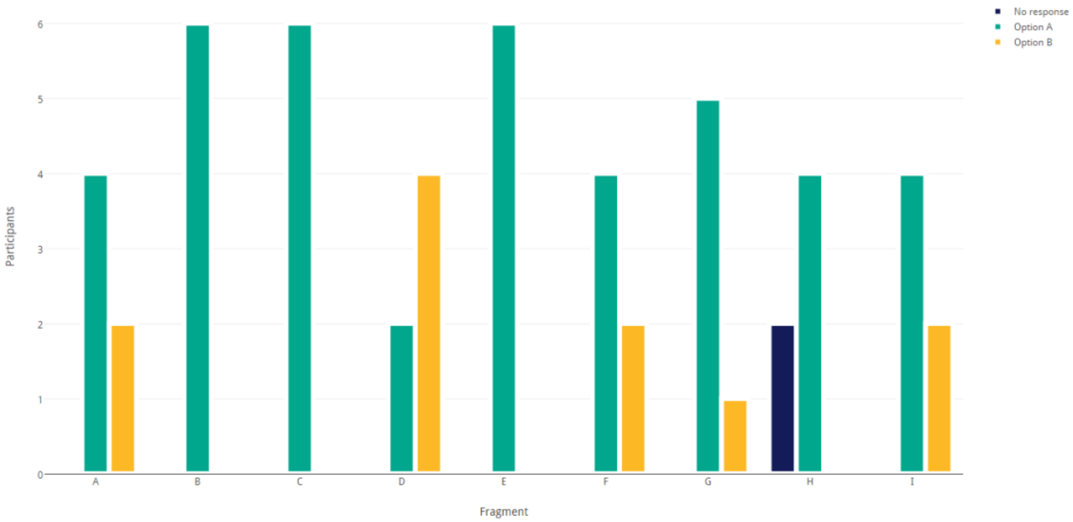

Fig. 120. The participants' answers for fragments A-I. As can be seen, in the majority of cases, there is a consensus as far as the cognitive process assigned to the fragment is concerned.

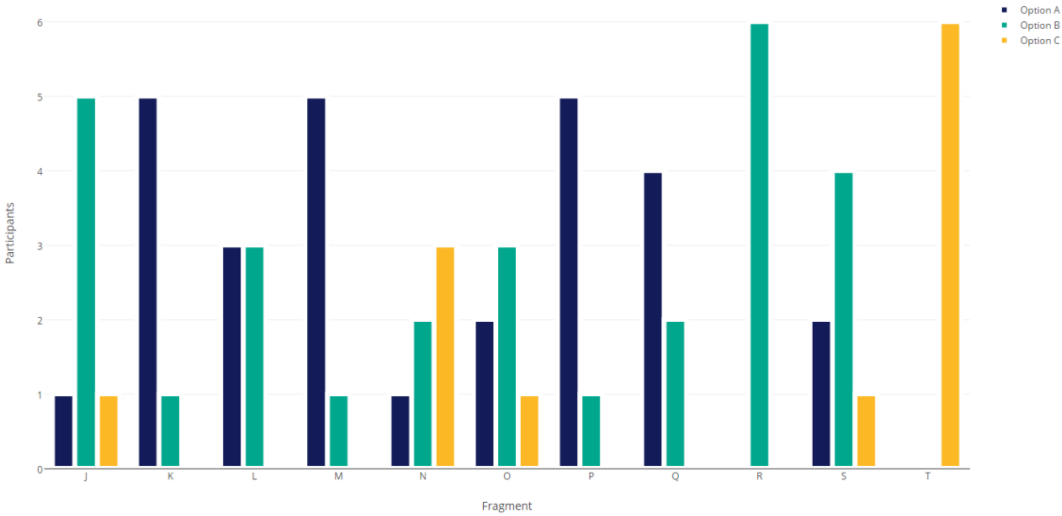

Fig. 121. The participants' answers for fragments J-T. As can be seen, in the majority of cases, there is a consensus as far as the cognitive process assigned to the fragment is concerned.

Table 19 shows the values in each step for the dependent variable C_{AP}:

Fragment	**A**	**B**	**C**	**D**	**E**
C_{AP}	66,6%	100%	100%	66,6%	100%
Main Cognitive Process	EXPLANATION	EVALUATION	ELABORATION	PARALLEL	GENERALISATION
Cognitive Process (pre-choice)	EXPLANATION	EVALUATION	ELABORATION	PARALLEL	GENERALISATION
Fragment	**F**	**G**	**H**	**I**	**J**
C_{AP}	66,6%	83,3%	66,6%	66,6%	50%
Main Cognitive Process	GENERALISATION	VIOLATED	CONTRAST	EXPLANATION	PARALLEL
Cognitive Process (pre-choice)	GENERALISATION	VIOLATED	CONTRAST	EXPLANATION	PARALLEL

Fragment	A	B	C	D	E
Fragment	K	L	M	N	O
C_{AP}	83,3%	50%	83,%3	50%	50%
Main Cognitive Process	EVALUATION	EXPLANATION	EVALUATION	PARALLEL	EVALUATION
Cognitive Process (pre-choice)	EVALUATION	EXPLANATION	EVALUATION	PARALLEL	EVALUATION
Fragment	P	Q	R	S	T
C_{AP}	83,3%	66,6%	100%	66,6%	100%
Main Cognitive Process	OCCASSION	CONTRAST	CONTRAST	EXEMPLIFICATION	BACKGROUND
Cognitive Process (pre-choice)	OCCASSION	CONTRAST	CONTRAST	EXEMPLIFICATION	BACKGROUND

Table 19. Coincidence Percentage C_{AP} obtained for each of the fragments A-T

It can be concluded that, although a much higher volume of participants would be needed to obtain an acceptable degree of statistical generalisation, the coincidence percentage C_{AP} in the characterisation of cognitive processes among specialists in the area is acceptable, passing the 50% (0.5) established as a hypothesis. Furthermore, this coincidence in all cases of the most selected cognitive process, by the author and by the specialists in the field, enables a line of action to be drawn. Thus, the proposed characterisation is established as suitable for use as a basis for the solution proposed in this doctoral research.

Presentation and Package

This appendix represents the presentation format selected for empirical study 2.

EMPIRICAL STUDY 3

Objective(s) of the Empirical Study —Scoping—

In Wohlin's terms, the objective of the empirical study can be expressed as:

a) Analyse 8 types of aggregate information visualisations with the purpose of evaluation regarding the degree of precision obtained according to the cognitive process in Cultural Heritage which they assist from the perspective of researchers interested in gaining knowledge about which visualisations demonstrate greater precision in this field in the context of public and private Cultural Heritage institutions.

Planning the Study

Context: The empirical study was carried out partly with real tools (the data is real) but with "toy examples" (all the visualisations created are "toy examples" as they are not commonly used by experts in the field). The empirical study is set in a specific but broad context (a sample of specialists in the field of Cultural Heritage belonging to public and private institutions on a national level). It can be considered that the study's context is on-line as it was carried out in the professional context in which it would be used (public and private institutions in the areas of Cultural Heritage management and research).

The formulation of the hypothesis: only one hypothesis was tested. It can be informally expressed as:

- The visualisation technique employed, along with its degree of suitability for certain cognitive processes in Cultural Heritage, does not have an influence on the degree of precision obtained by the participants when carrying out certain tasks. This is reflected in the mistake rate in tasks related with those processes. In other words, the mistake rate will be the same in tasks carried out with unspecific visualisations as with visualisations adapted to the cognitive process being assisted.

Based on this informal hypothesis, we can now define H_0 as a null hypothesis and H_1 as the alternative hypothesis:

H_0: with n being the visualisation adapted to the cognitive process required and m being the visualisations which have not been adapted, the mistake rate MR (V_x) in tasks related to that process is the same when using m visualisations as when using n visualisations. H_0: MR (V_m) = MR (V_n)

Alternative hypothesis H_1: with n being the visualisation adapted to the cognitive process required and m being the visualisations which have not been adapted, the mistake rate MR (V_x) in tasks related to that process is different when using m visualisations to when using n visualisations. H_1: MR (V_m) ≠ MR (V_n)

Selection of variables: The visualisations to be evaluated and the tasks to be carried out were selected as the independent variables. In addition, the specialists' skill in the selected visualisation techniques was considered as an independent variable. This was controlled via an initial questionnaire.

The dependent variable was the precision with which the tasks were carried out, formalised via the mistake rate calculated per task for each visualisation obtained by the specialist. In each case, these visualisations were identified as belonging to group n (visualisation adapted to the cognitive process required) or to group m (visualisation not adapted to the cognitive process required).

In spite of the fact that they are not included in the study, the behaviour of two other dependent variables was considered as an interesting aspect for evaluation:

- The distribution of the preference (DP) shown by the users for the visualisation technique according to the cognitive process (from the first level of our characterisation) which they were asked to perform.
- The general mistake rate per task carried out (MRT). This refers to the mistake rate of the specialist in carrying out a specific task, without taking into account the visualisation employed to do this. This can enable us to find out which tasks prove more difficult for the specialist in Cultural Heritage, independently of the visualisation technique employed to carry them out.

Selection of subjects: The sample of participants corresponds to the *Quota sampling* model (This type of sampling is used to get subjects from various elements of a population). In total, the study had 16 participants (not selected randomly), all of them were specialists in Cultural Heritage belonging to 8 different public and private institutions in Spain (Incipit CSIC, Xunta de Galicia (the regional government of Galicia), private companies in the area of cultural management, the University of Santiago de Compostela, the University of Vigo and CCHS-CSIC).

Design Principles: As far as randomisation is concerned, the objects were assigned randomly to the subjects. The tasks were carried out with a visualisation (not selected randomly) identified for that task and with an unidentified random visualisation for the task. Later, all the visualisations were shown to the participants so that they could choose their favourite one to carry out the task in question.

As far as the need for blocking variables is concerned, no variables were found to block, although the participants' prior skill with the visualisations which they were presented with was taken into account via an initial questionnaire. Last of all, the principle of balancing was applied manually to ensure that the selected visualisation was evaluated by all the participants and that the rest of the visualisations were evaluated (tasks were performed with them) by a balanced number of participants in each case.

Instrumentation: The objects were not selected randomly due to the fact that the visualisations were carried out ad hoc for this empirical study. A list of the visualisation techniques to be evaluated was made beforehand and a visualisation was made with real data from the sub-discipline of Archaeology for each of the techniques (see Table **20**):

Visualisation Techniques

1. **Stacked Bar Chart**
2. **Line-based Chart**
3. **Simple Bar Chart**
4. **Bubble-based Chart**
5. **Customized Venn Diagram**
6. **Treemap**
7. **Geographical map**
8. **Scatter Chart**

Table 20. Information visualization techniques evaluated in the empirical study 3

The tasks to be carried out were:

A. The participants had to respond about the specific number of archaeological objects present in the data which comply with several combinations of specific values: S shape and associated decoration and balloon shape without decoration.
B. The participants had to respond about the number of objects which make up the groups of decorated and non-decorated elements according to their shape. Then, they had to group them inversely, responding about the number of grouped elements by shape according to whether they were decorated or not.
C. The participants had to identify the increase or decrease in the groups of archaeological objects which were decorated according to their shape: Which shape was the most decorated? And the least?
D. The participants had to respond regarding the specific dates when the actions for the preservation of the objects were carried out and if there was a change in the registered state of conservation which could be put down to this intervention.
E. The participants had to identify the number of sites marked as sources in the data of the "Hillfort" type and "Iron Age" period in Galicia.

It should be noted that the tasks defined attempted to maintain a low level of difficulty due to the fact that many authors have stated that the complexity of tasks combined with a high degree of freedom can lead to a large number of errors, which would be reflected in our rate and would not be attributed to our dependent variables [173]. Figures from Fig. 122 to Fig. 129 show the visualisations created with real data from the sub-discipline of Archaeology for the carrying out of the study.

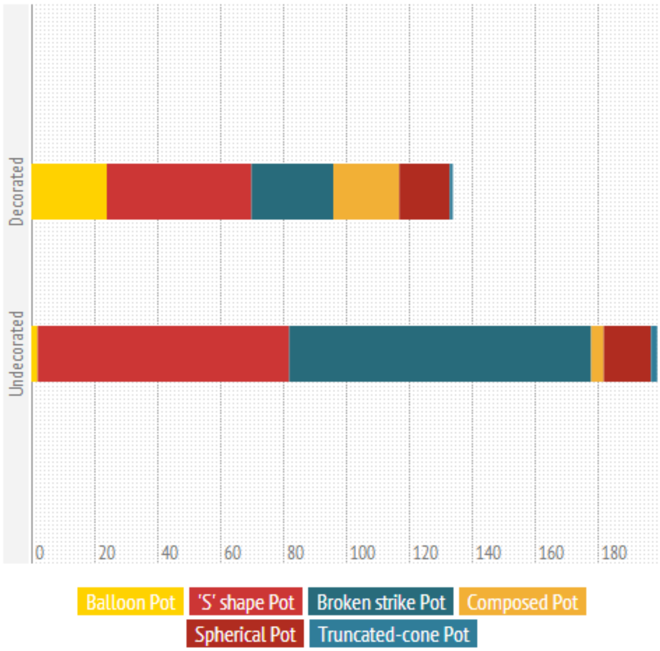

Fig. 122. Visualisation 1: Stacked Bar Chart

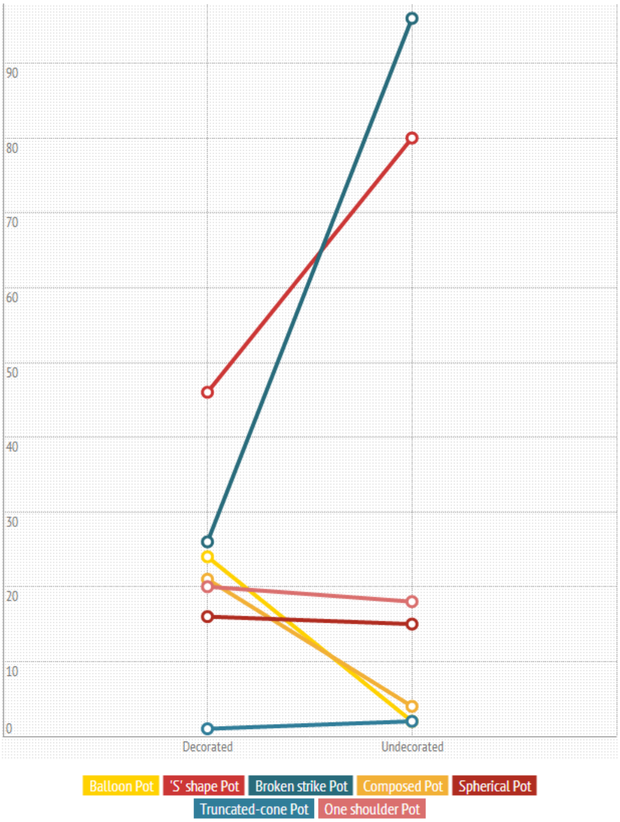

Fig. 123. Visualisation 2: Line-based Chart.

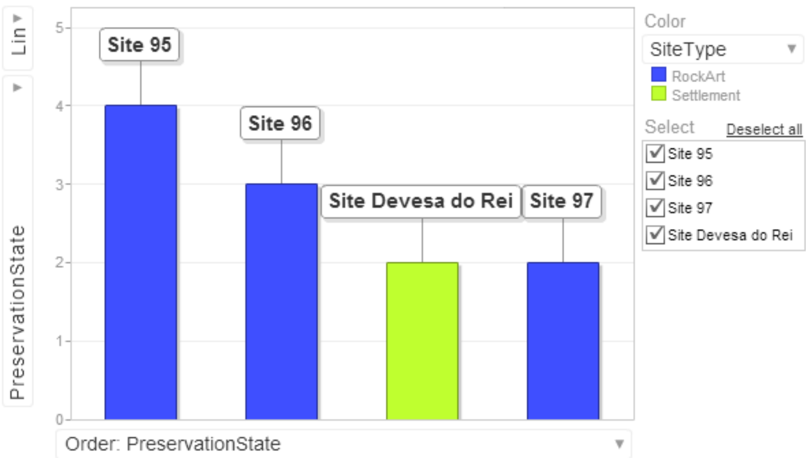

Fig. 124. Visualisation 3: Simple Bar Chart.

Fig. 125. Visualisation 4: Bubble-based Chart.

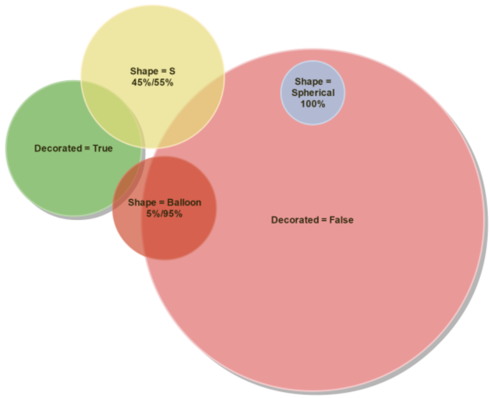

Fig. 126. Visualisation 5: Customized Venn-diagram.

Fig. 127. Visualisation 6: Treemap.

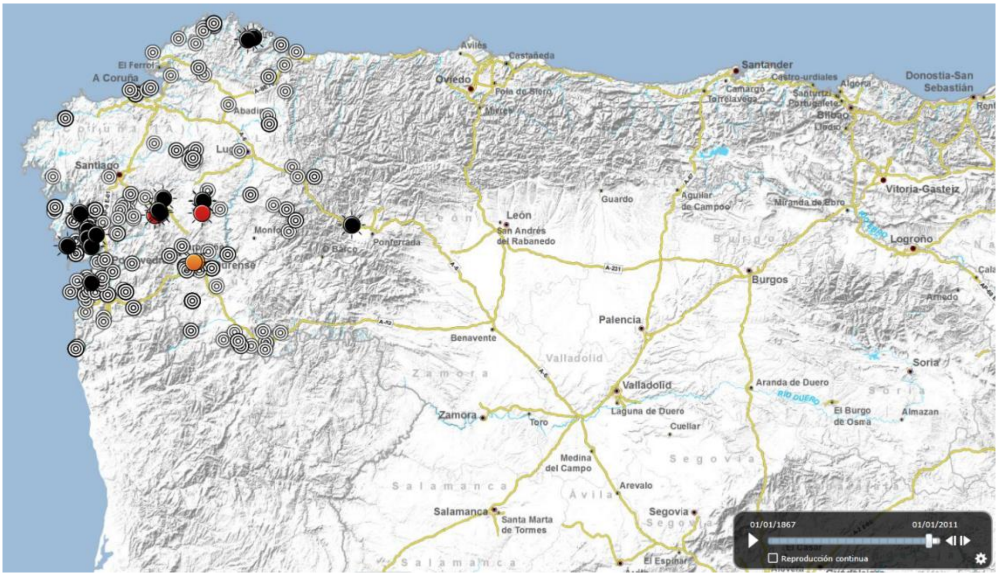

Fig. 128. Visualisation 7: Geographical map.

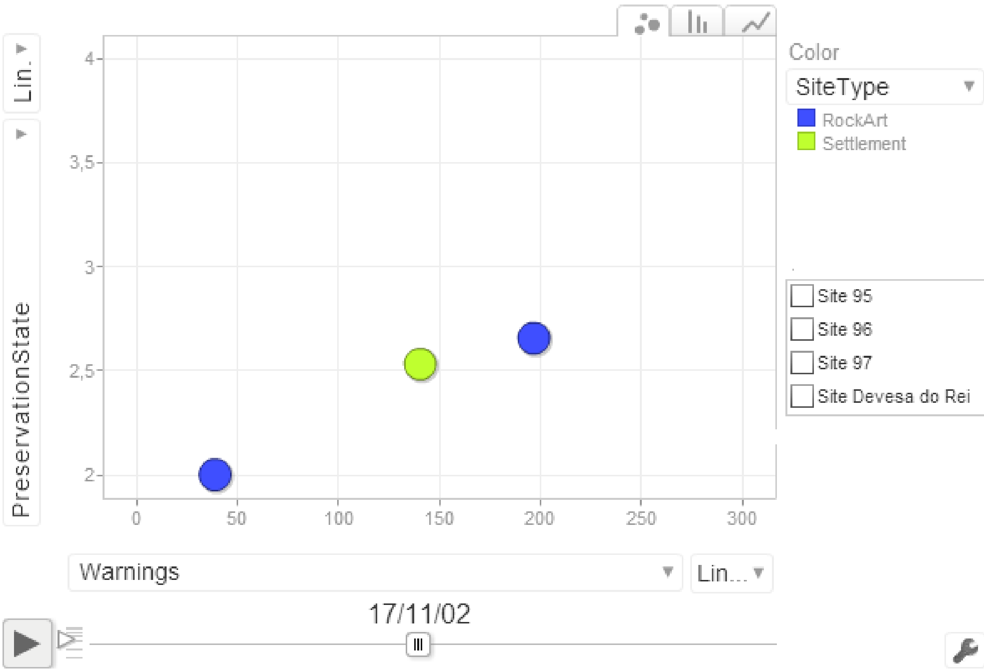

Fig. 129. Visualisation 8: Scatter Chart.

Later, the distribution among the tasks (with the associated cognitive process, see Table 21) and the visualisation technique thought to be most appropriate for it, along with other techniques to which it can be compared, was carried out.

Task/Cognitive Process	Visualisation Technique selected	Other Visualisation Techniques compared
A/ Combining	4 (Bubble-based Chart)	1,2,3,5,8
B / Clustering	4 (Bubble-based Chart)	1,2,3,5,6
C/ Clustering-Building	6 (Treemap)	2,4,8
D/ Combining-Building	8 (Scatter Chart)	1,2,3,4,5
E/ Situating	7 (Geographical Map)	4,8

Table 21. Task/Cognitive Process Visualisation Technique selected Other Visualisation Techniques compared

As far as lines of action in the study are concerned, the participants were provided with some instructions about the tasks to be carried out and the visualisations to be used in each case. No prior training was necessary for the participants in order for them to do the study.

Evaluation of aspects of validity: Following Wohlin's definition, based on Cook & Campbell [60], it was considered necessary to highlight the following threats to the validity of the study beforehand:

- As far as its internal validity is concerned, it was considered that the number of participants in the study minimised this risk as it was considered to be an acceptable number. Furthermore, as was explained at the beginning of the chapter, the aim of this empirical study was not to establish these relations, thus this threat was minimised.
- As far as its external validity is concerned, it was considered that the probability of the results being repeated in other contexts of the sub-discipline of Archaeology is high, although its generalisation to other sub-disciplines of Cultural Heritage is a risk. All of this can be seen in other studies carried out in Cultural Heritage [193].
- As far as its conclusion validity is concerned, it was considered necessary to choose objects which represent data from other origins in order to minimise the possibility of the data selected affecting the study. Conducting the sessions in person, with only one participant at a time, minimised the threats regarding the quality of the data obtained.
- As far as its construct validity is concerned, a possible threat could be the suitability of the selected measures. The differences in the participants as far as their skills with the visualisation techniques to be evaluated are concerned could also have an influence when it comes to evaluating both methods.

The Execution of the Study —Operation—

Preparation: The participants were not aware of the data or the visualisations employed. They were told about the characterisation of the cognitive processes to be used but not about the hypotheses being dealt with in the study. By offering themselves as volunteers for the study, they gave their consent for this. The necessary materials were prepared beforehand: an initial questionnaire about the participants' professional and personal profiles and any previous experience with these types of visualisations, the statements for the tasks and the visualisations.

Execution: The participants were received one by one in individual sessions lasting between one hour and one and a half hours. They were asked to read the statements and carry out the tasks. The visualisations stored their answers automatically, thus providing us with information about errors and correct answers. After they had carried out the tasks, they were shown all the visualisations and were asked about which of them they had used for each one of the four cognitive processes of the first level of abstraction of the proposed characterisation (Combining, Clustering, Situating and Building).

The validation of the data: No invalid data was detected. This can be attributed to the individuality and the supervision of the process of the study's execution.

Analysis and Interpretation: Results

Results according to mistake rate per task and visualisation MR (V_x): Fig. 130 shows the distribution of the mistake rate MR according to the visualisation employed to carry out each of the tasks. As can be seen, the visualisation with the lowest mistake rate in all cases is the selected visualisation, except in the case in which the process being assisted is Clustering/Building. That is to say, except when we attempt to assist in a better understanding of the internal structure of information in order to form groups. In that case, the selected visualisation is the Treemap but the mistake rate for other visualisations demonstrates better behaviour in tasks associated to Clustering/Building than the TreeMap visualisation. Therefore, hypothesis H_1 is confirmed except in this case, which enables us to detect the necessity for a better adapted visualisation for this specific case than those proposed in the study.

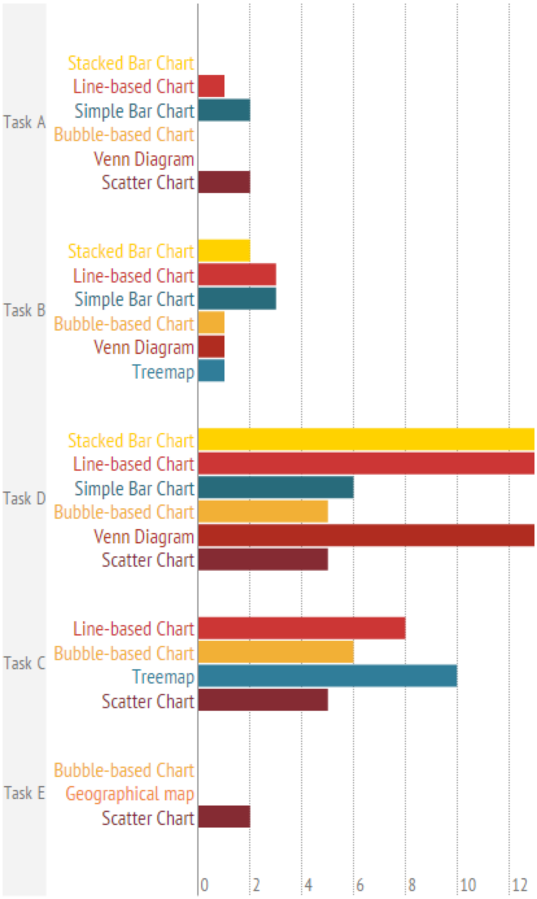

Fig. 130. Mistake rate per task and visualisation MR (Vx).

Results according to Distribution of Preference (DP): Fig. 131 shows the distribution of preference DP. The participants' choices generally coincided with the visualisations determined beforehand as those best adapted to the cognitive process associated to each task, although no clear technique was observed in the case of the Building tasks. That is to say, the participants did not find it any simpler or more intuitive to access the structure of the information via one technique, with the technique designed specifically (the treemap) proving to be particularly complex. Due to this fact, we can consider establishing techniques better adapted for the visualisation of the structure of the information as a line of action.

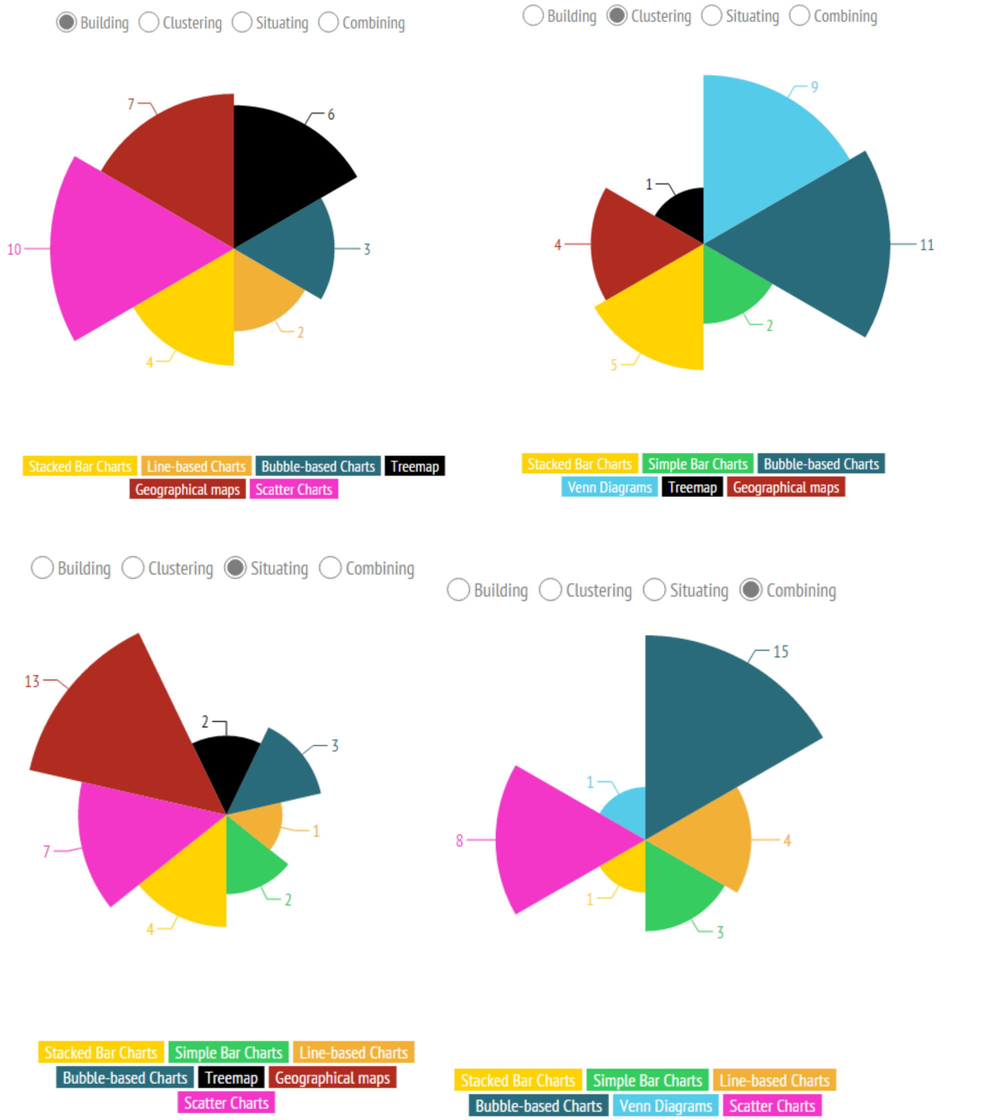

Fig. 131. Preferences expressed by the participants according to the type of associated cognitive process (DP).

Results according to the general mistake rate per task carried out (MRT): Fig. 132 shows the behaviour of MRT. As can be seen, tasks A, B and E presented extremely high ratios of correct answers with very few errors. These tasks are those relating to combinations of values, grouping or other similar activities in geographical contexts. However, tasks C and D show much higher MRT values. These tasks, corresponding to the detection of tendencies and searching for correlations between temporal values, indicate that perhaps it is necessary to emphasize these points with the creation of more adapted visualisations than those presented here.

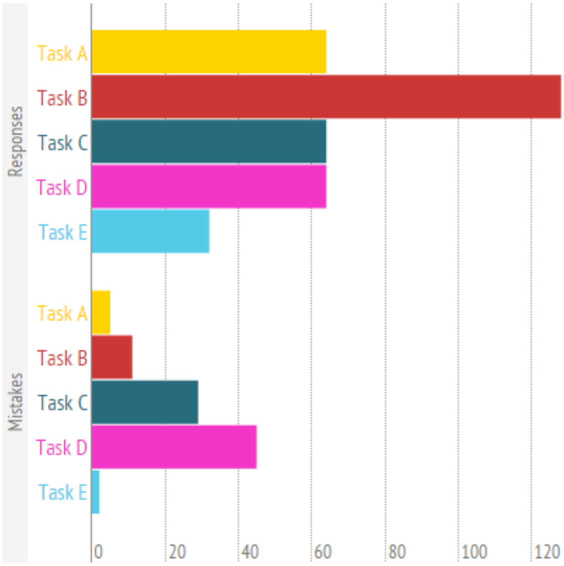

Fig. 132. Mistake rate compared to participants' answers for each task carried out (MRT).

Presentation and Package

This appendix represents the presentation format chosen for empirical study 3.

EMPIRICAL STUDY 4

Objective(s) of the Empirical Study —Scoping—

In Wohlin's terms, the objective of the empirical study is expressed as:

a) Analyse two methods of data analysis for the purpose of evaluation regarding the degree of understanding and the influence on the data analysis carried out from the perspective of researchers studying data analysis processes in Cultural Heritage in the context of public and private Cultural Heritage institutions.

Planning the Study

Context: This empirical study was carried out partly with real tools (the data was real as was its visualisation for analysis in Excel) and partly with "toy examples" (all the created visualisations, as they are not commonly used by specialists in the field of Cultural Heritage). The empirical study was set in a specific, though broad, context (a sample of specialists in Cultural Heritage belonging to both public and private institutions on a national scale). It can be considered that the context of the study is on-line as it was carried out in the professional context in which it would be used (public and private institutions in the areas of management and research in Cultural Heritage). It should be remembered here that the study was carried out using a methodology based on TAP (*Thinking Aloud Protocol*), as described in the Chapter 5 entitled “Prior Empirical Results”.

Formulation of the hypothesis: Two hypotheses were verified. They can be informally described as:

- The method of data analysis used does not have an influence on the degree of understanding of the data on the part of the participant. This is reflected in the participant’s perception regarding the level of readability and understanding of both methods, which does not vary.
- The method of data analysis used does not have an influence on the type of data analysis carried out. This is reflected in that a change in the method does not lead to changes in the participant’s focus of attention (what does the participant focus on initially to analyse the data?). Although it will not be formalised, we shall also see if no changes occur regarding the aspects which the participant claims are lacking in terms of data analysis.

Based on these informal hypotheses, we can now define H_0 and H_0' as null hypotheses and their alternative hypotheses as:

H_0: The participants demonstrated a similar level of readability and understanding (RUL) to method 2 (with the proposed visualisations) compared to working with Excel (method 1). It could even be the case that, within the TAP protocol, the participants may show that their RUL is independent of the method used.

H_0: RUL (m_2) = RUL (m_1)

Alternative Hypothesis H_1: RUL (m_2) ≠ RUL (m_1)

H_0': The set of x factors shown as Focus does not vary according to the method applied. H_0': FF (x, m_1) = FF (x, m_2)

Alternative Hypothesis H_1': The set of x factors shown as Focus varies according to the method applied. H_1': FF (x, m_1) ≠ FF (x, m_2). We have the impression that this variation is caused with aspects more related to the analysis of the data itself than with the presentation method, which could indicate that the step towards the generation of knowledge is taken more intuitively when using information visualisation techniques than when using the Excel spreadsheet method.

Selection of variables: The specialists’ skills in both methods of data analysis were selected as an independent variable. These were controlled via an initial questionnaire. The dependent variable in each case would be the degree of understanding, formalized by way of the RUL variable and the influence on the analysis of the data, formalised by the vector FF(x) applying each method.

Selection of subjects: The sample of participants corresponds to the *Simple random sampling* model. A sample of six specialists in Cultural Heritage coming from 3 different public and private institutions (Incipit CSIC, Xunta de Galicia (the regional government of Galicia) and a private company specialised in the area of cultural management) was selected. They were selected randomly from among the 25 specialists who expressed an interest in participating in the study.

Design Principles: As far as randomisation is concerned, the objects were not assigned randomly to the subjects. In other words, all the participants evaluated both methods. The participants evaluated the methods randomly, sometimes method 1 first and then method 2 or vice versa. However, we believe that the order of evaluation is not relevant.

As for the need to block variables, no variables were found to be blocked, although the influence of the participants' skills in both methods of analysing data would be taken into account, being measured via an initial questionnaire.

Last of all, it would have been desirable to apply the balancing principle. However, due to the difficulty in finding a high volume of subjects, all of them evaluated both methods so balancing did not occur.

The type of design for the empirical study would be a factor with two treatments for each hypothesis.

Instrumentation: The objects were not selected randomly, due to the fact that the visualisations were made ad hoc for the purposes of this study. As far as lines of action in carrying out this study are concerned, the participants were provided with a statement with the instructions for taking part. No prior training was necessary for the participants to answer the questionnaire.

The evaluation of aspects of validity: According to Wohlin's definition, based on Cook & Campbell [60], it was considered necessary to highlight beforehand the following threats to the validity of the study:

- As far as its internal validity is concerned, the number of participants in the study is low, which could compromise the results if the objective of the study were to establish causal relations. However, as was explained at the beginning of the chapter, this empirical study did not aim to establish this type of relations, thus minimising this threat.
- As far as its external validity is concerned, it is considered that the probability of the results being repeated in other contexts is high, due to the randomisation of the objects used, as well as to the fact that other similar studies and experiments have been carried out in Cultural Heritage contexts [193].
- As far as its conclusion validity is concerned, it is considered to be necessary to choose objects which represent data from other origins in order to minimise the possibility of the selected data influencing the study. The fact that the sessions were conducted

in person, with only one participant at a time, minimised the threats regarding the quality of the data obtained.

- As far as its construct validity is concerned, it should be taken into account that the small sample of participants did not allow us to make a statistical generalisation of the results. What is more, it would be necessary to carry out a greater number of similar studies and experiments in order to avoid the "*fishing and error rate*" problem, in other words, for this study to succeed in identifying a relationship between variables which, in reality, would be the suitability of the selected measures. However, carrying out studies using the TAP protocol enables more data to be obtained in the future. The differences in the participants, as far as skills in the methods involved are concerned, may also have an influence when it comes to evaluating both methods.

The Execution of the Study —Operation—

Preparation: The participants were not aware of the data or the visualisations employed. They were not informed not about the hypotheses being dealt with in the study. By offering themselves as volunteers for the study, they gave their consent for this. The necessary materials were prepared beforehand: an initial questionnaire about the participants' professional profiles and any previous experience with data analysis methods and the data presented in both methods.

Execution: The participants were received one by one in individual sessions lasting between 45 minutes and one hour, thus avoiding problems deriving from fatigue in TAP protocols. They were all informed that they were going to be recorded, according to the TAP protocol described in Fig. 19 (see Chapter 5 entitled "Prior Empirical Results" for a detailed definition). Then, they were asked to evaluate (Low, Average, High) the level of readability and understanding of the data with both methods. The following step was to ask them freely about what aspects they focused their attention on in order to understand the data and analyse it. Last of all, they were asked about what aspects they considered were lacking in the presentation method in order to be able to analyse the data better. All of this was explained by the participants, who spoke out loud about the reasons for their choices and/or doubts.

The validation of the data: No invalid data was detected. This can be attributed to the individuality and the supervision of the process of the study's execution.

Analysis and Interpretation: Results

Results according to Readability and Ease of Understanding (RUL): Fig. 133 shows the behaviour of the values given by the participants regarding readability and level of understanding on a scale of three values (Low, Medium and High). As can be seen, the level of readability and the level of understanding both increase with method 2, which corresponds to the use of visualisation techniques.

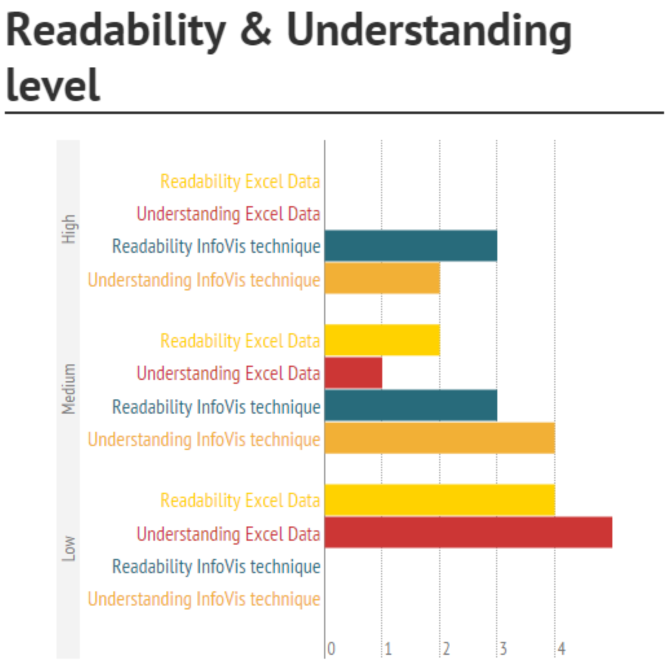

Fig. 133. Level of readability and understanding (RUL) expressed by the participants according to method of data analysis (Excel vs. information visualisation Techniques).

Of course, with this we do not claim to declare an improvement in the related tasks but just an increase in perception regarding readability and understanding of the data on the part of the participants. However, this aspect is of vital importance in the research in question, given that assistance to the generation of knowledge must also deal with perceptive aspects of the stakeholders themselves in the process.

Results according to the set of x factors of Focus of Attention (FF): Fig. 134 shows a spider chart representing several factors which have an influence on a certain element, in this case those which the participants mentioned in the *Thinking Aloud* sessions as relevant when starting their data analysis process. As can be seen, the patterns of method 1 and method 2 differ significantly, thus confirming our hypothesis H_1'. In spite of not having formalised this in a hypothesis, we also wished to evaluate the behaviour of the vector of factors referenced by the participants as aspects which they consider to be lacking when it comes to analysing data using both methods. This analysis presents also important variations depending on the analysis method employed –see Fig. 135—. In both figures, the factors on which they focus their attention when using the Excel data analysis method are shown in blue. The same analysis when using information visualisation techniques is shown in orange.

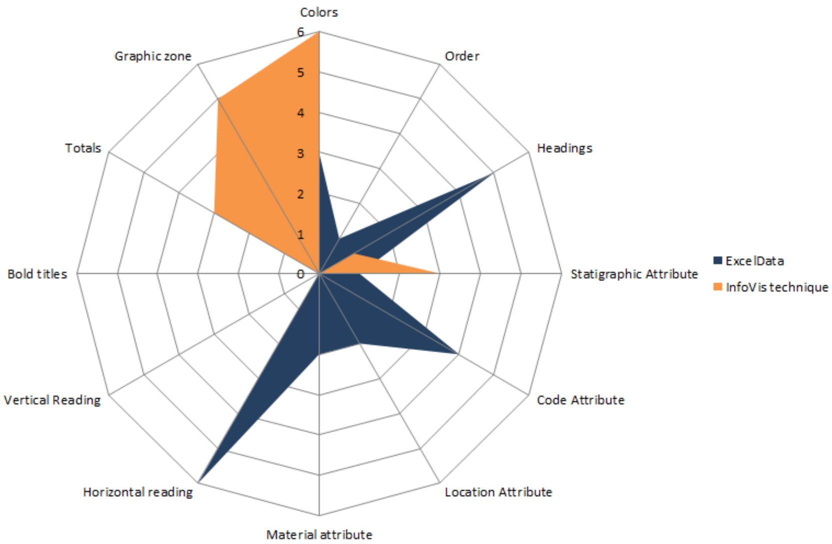

Fig. 134. Factors which attract the participant's focus of attention (FF) when using both methods of data analysis.

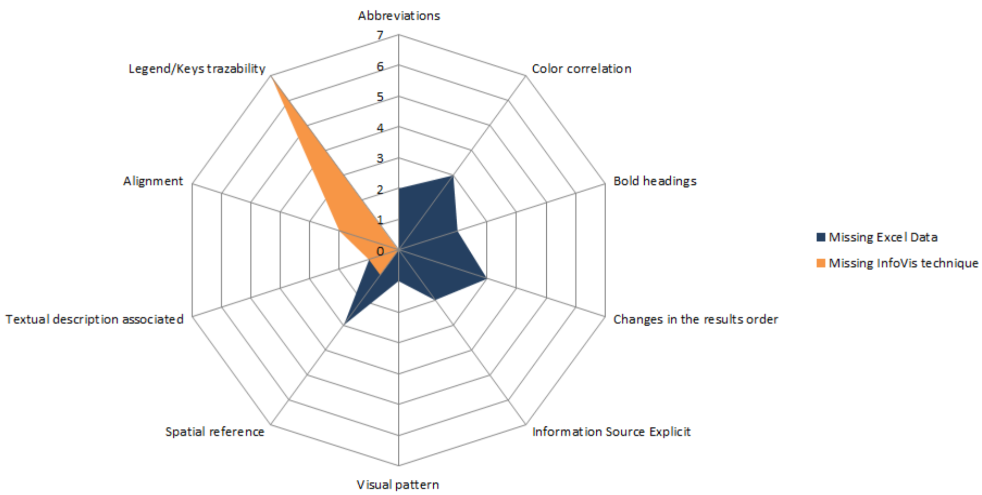

Fig. 135. Aspects sought but not found by the participants employing both methods of data analysis.

Presentation and Package

This appendix represents the presentation format chosen for empirical study 4.

APPENDIX II: Case Study Implementation

This appendix presents the structure and implementation of A Romea subject model performed, and includes:

- The complete implementation as a relational database of CHARM model
- The implementation of the extension created to support the particularities of the A Romea case study.
- The conceptualization and implementation in a relational database format of the mechanisms to use Cluster and Packages explained in Part IV.

The database file and other additional materials related to the case study of A Romea are also available on line through this link. Note that all structures —CHARM and the extension created for the case study— support multilingual definition. Thus, the tables which includes the suffix "_Xlat" corresponds to language specifications.

THE SUBJECT MODEL

Tables and relations specification

1. Table: _Languages

Columns

Name	Data Type	Size
Id	Long Integer	4
Code	Text	2

Number of items: 2

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	_Languages	_Languages_Xlat	Forced; Cascade Delete
1 to N	_Languages	BaseTypes_Xlat	Forced
1 to N	_Languages	Classes_Xlat	Forced
1 to N	_Languages	EnumeratedItems_Xlat	Forced
1 to N	_Languages	EnumeratedTypes_Xlat	Forced
1 to N	_Languages	Generalizations_Xlat	Forced
1 to N	_Languages	Packages_Xlat	Forced
1 to N	_Languages	SemiAssociations_Xlat	Forced

2. Table: _Languages_Xlat

Columns

Name	Data Type	Size
Id	Long Integer	4
Owner	Long Integer	4
Language	Long Integer	4
TheName	Text	32

Number of items: 4

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	_Languages_Xlat	_Languages	Forced; Cascade Delete

3. Table: Associations

Columns

Name	Data Type	Size
Id	Long Integer	4
PrimarySemiAssociation	Long Integer	4
SecondarySemiAssociation	Long Integer	4

Number of items: 124

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	Associations	Links	Forced
1 to N	Associations	SemiAssociations	Forced

4. Table: Attributes

Columns

Name	Data Type	Size
Id	Long Integer	4
OwnerClass	Long Integer	4
RedefinedOriginal	Long Integer	4
MinCard	Long Integer	4
MaxCard	Long Integer	4
IsSorted	Boolean Yes/No	1
BaseType	Long Integer	4
EnumeratedType	Long Integer	4
IsTemporal	Boolean Yes/No	1
IsSubjective	Boolean Yes/No	1

Number of items: 80

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	Attributes	Attributes_Xlat	Forced; Cascade Delete
1 to N	Attributes	Values	Forced
1 to N	Attributes	BaseTypes	Forced
1 to N	Attributes	Classes	Forced
1 to N	Attributes	EnumeratedTypes	Forced

5. Table: Attributes_Xlat

Columns

Name	Data Type	Size
Id	Long Integer	4
Owner	Long Integer	4
Language	Long Integer	4
TheName	Text	64
Definition	Memo	-

Number of items: 160

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	Attributes_Xlat	_Languages	Forced
1 to N	Attributes_Xlat	Attributes	Forced; Cascade Delete

6. Table: BaseTypes

Columns

Name	Data Type	Size
Id	Long Integer	4

Number of items: 5

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	BaseTypes	Attributes	Forced
1 to N	BaseTypes	BaseTypes_Xlat	Forced; Cascade Delete

7. Table: BaseTypes_Xlat

Columns

Name	Data Type	Size
Id	Long Integer	4
Owner	Long Integer	4
Language	Long Integer	4
TheName	Text	64
Definition	Memo	-

Number of items: **10**

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	BaseTypes_Xlat	_Languages	Forced
1 to N	BaseTypes_Xlat	BaseTypes	Forced; Cascade Delete

8. Table: Classes

Columns

Name	Data Type	Size
Id	Long Integer	4
IsCHARM	Boolean Yes/No	1
IsAbstract	Boolean Yes/No	1
IsTemporalAspect	Boolean Yes/No	1
IsSubjectiveAspect	Boolean Yes/No	1
DominantGeneralization	Long Integer	4
Package	Long Integer	4
ClusterRoot	Boolean Yes/No	1

Number of items: **183**

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	Classes	Attributes	Forced
1 to N	Classes	Classes_Xlat	Forced; Cascade Delete
1 to 1	Classes	Clusters	Forced
1 to N	Classes	Generalizations	Forced
1 to N	Classes	Objects	Forced
1 to N	Classes	ParticipantClassesInClusters	Forced; Cascade Delete
1 to N	Classes	SemiAssociations	Forced

1 to N	Classes	SpecializedClassesOfGeneralizations	Forced
1 to N	Classes	Generalizations	Forced
1 to N	Classes	Packages	Forced
1 to N		ClassesInPackages	Not Forced

9. Table: Classes_Xlat

Columns

Name	Data Type	Size
Id	Long Integer	4
Owner	Long Integer	4
Language	Long Integer	4
TheName	Text	64
Definition	Memo	-
Comments	Memo	-

Number of items: 366

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	Classes_Xlat	_Languages	Forced
1 to N	Classes_Xlat	Classes	Forced; Cascade Delete

10. Table: ClassesInPackages

Columns

Name	Data Type	Size
Package	Long Integer	4
ParticipantClass	Long Integer	4

Number of items: 100

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	ClassesInPackages	Packages	Not Forced
1 to N	ClassesInPackages	Classes	Not Forced

11. Table: Clusters

Columns

Name	Data Type	Size
Id	Long Integer	4

IsCHARM	Boolean Yes/No	1
MainClass	Long Integer	4

Number of items: 11

Relations

Relation	Source Table	Destination Table	Relation features
1 to 1	Clusters	Classes	Forced
1 to N	Clusters	ParticipantClassesInClusters	Forced; Cascade Delete

12. Table: EnumeratedItems

Columns

Name	Data Type	Size
Id	Long Integer	4
Type	Long Integer	4
SuperItem	Long Integer	4

Number of items: 245

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	EnumeratedItems	EnumeratedItems_Xlat	Forced; Cascade Delete
1 to N	EnumeratedItems	EnumeratedItems	Forced

13. Table: EnumeratedItems_Xlat

Columns

Name	Data Type	Size
Id	Long Integer	4
Owner	Long Integer	4
Language	Long Integer	4
TheName	Text	64
Definition	Memo	-

Number of items: 490

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	EnumeratedItems_Xlat	_Languages	Forced
1 to N	EnumeratedItems_Xlat	EnumeratedItems	Forced; Cascade Delete

14. EnumeratedTypes

Columns

Name	Data Type	Size
Id	Long Integer	4
IsCHARM	Boolean Yes/No	1
Package	Long Integer	4

Number of items: 37

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	EnumeratedTypes	Attributes	Forced
1 to N	EnumeratedTypes	EnumeratedItems	Forced
1 to N	EnumeratedTypes	EnumeratedTypes_Xlat	Forced; Cascade Delete
1 to N	EnumeratedTypes	Packages	Forced

15. EnumeratedTypes_Xlat

Columns

Name	Data Type	Size
Id	Long Integer	4
Owner	Long Integer	4
Language	Long Integer	4
TheName	Text	64
Definition	Memo	-
Comments	Memo	-

Number of items: 74

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	EnumeratedTypes_Xlat	Attributes	Forced
1 to N	EnumeratedTypes_Xlat	EnumeratedTypes	Forced; Cascade Delete

16. Table: Generalizations

Columns

Name	Data Type	Size
Id	Long Integer	4
GeneralizedClass	Long Integer	4

Number of items: 76

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	Generalizations	Classes	Forced
1 to N	Generalizations	Generalizations_Xlat	Forced; Cascade Delete
1 to N	Generalizations	SpecializedClassesOfGeneralizations	Forced; Cascade Delete
1 to N	Generalizations	Classes	Forced

17. Table: Generalizations_Xlat

Columns

Name	Data Type	Size
Id	Long Integer	4
Owner	Long Integer	4
Language	Long Integer	4
Discriminant	Text	64

Number of items: 152

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	Generalizations_Xlat	_Languages	Forced
1 to N	Generalizations_Xlat	Generalizations	Forced; Cascade Delete

18. Table: Packages

Columns

Name	Data Type	Size
Id	Long Integer	4
IsCHARM	Boolean Yes/No	1

Number of items: 9

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	Packages	Classes	Forced
1 to N	Packages	EnumeratedTypes	Forced
1 to N	Packages	ClassesInPackages	Not Forced
1 to N	Packages	Packages_Xlat	Forced; Cascade Delete

19. Table: Packages_Xlat

Columns

Name	Data Type	Size
Id	Long Integer	4
Owner	Long Integer	4
Language	Long Integer	4
TheName	Text	64
Description	Memo	-
Comments	Memo	-

Number of items: 18

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	Packages_Xlat	_Languages	Forced
1 to N	Packages_Xlat	Packages	Forced; Cascade Delete

20. Table: ParticipantClassesInClusters

Columns

Name	Data Type	Size
Cluster	Long Integer	4
ParticipantClass	Long Integer	4

Number of items: 13

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	ParticipantClassesInClusters	Clusters	Forced; Cascade Delete

21. Table: SemiAssociations

Columns

Name	Data Type	Size
Id	Long Integer	4
OwnerClass	Long Integer	4
RedefinedOriginal	Long Integer	4
MinCard	Long Integer	4
MaxCard	Long Integer	4
IsSorted	Boolean Yes/No	1
IsWhole	Boolean Yes/No	1

IsStrong	Boolean Yes/No	1
IsTemporal	Boolean Yes/No	1
IsSubjective	Boolean Yes/No	1

Number of items: 248

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	SemiAssociations	Classes	Forced
1 to N	SemiAssociations	Associations	Forced
1 to N	SemiAssociations	Associations	Forced
1 to N	SemiAssociations	SemiAssociations_Xlat	Forced; Cascade Delete

22. Table: SemiAssociations_Xlat

Columns

Name	Data Type	Size
Id	Long Integer	4
Owner	Long Integer	4
Language	Long Integer	4
TheName	Text	64
Role	Text	64
Definition	Memo	-

Number of items: 496

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	SemiAssociations_Xlat	_Languages	Forced
1 to N	SemiAssociations_Xlat	SemiAssociations	Forced; Cascade Delete

23. Table: SpecializedClassesOfGeneralizations

Columns

Name	Data Type	Size
Generalization	Long Integer	4
SpecializedClass	Long Integer	4

Number of items: 184

Relations

Relation	Source Table	Destination Table	Relation features

1 to N	SpecializedClassesOfGeneralizations	Classes	Forced
1 to N	SpecializedClassesOfGeneralizations	Generalizations	Forced

24. Table: Objects

Columns

Name	Data Type	Size
Id	Long Integer	4
Identifier	Text	64
TypeClass	Long Integer	4
Description	Text	255

Number of items: 3461

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	Objects	Classes	Forced
1 to N	Objects	Links	Forced
1 to N	Objects	Links	Forced
1 to N	Objects	Values	Forced

25. Table: Links

Columns

Name	Data Type	Size
Id	Long Integer	4
TypeAssociation	Long Integer	64
PrimaryObject	Long Integer	4
SecondaryObject	Long Integer	4
PhaseSelector	Long Integer	4
PerspectiveSelector	Long Integer	4
Description	Short Text	255

Number of items: 4050

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	Links	Associations	Forced
1 to N	Links	Objects	Forced
1 to N	Links	Objects	Forced

26. Table: Values

Columns

Name	Data Type	Size
Id	Long Integer	4
OwnerObject	Long Integer	4
TypeAttribute	Long Integer	4
Contents	Short Text	255
PhaseSelector	Long Integer	4
PerspectiveSelector	Long Integer	4

Number of items: 11601

Relations

Relation	Source Table	Destination Table	Relation features
1 to N	Values	Attributes	Forced
1 to N	Values	Objects	Forced

APPENDIX III: Empirical Validation Materials

This appendix presents all the materials created and employed for the empirical validation carried on during this PhD thesis and presented throughout the Chapter 12. Firstly, the appendix contains the original questionnaires using for the validation. Secondly, the Results Obtained section detailed the raw data corresponding to the real answers of the subjects to the different variables measured. Finally, the last section detailed the output obtained from SPSS v23 [138] tool during the analysis process using a linear mixed model**.**

MATERIALS

Questionnaire: Demographic profile

Please, fill the following data about your demographic profile. Note that all data provided are only used in the context of the current research and processed in an anonymous manner.

Gender (Male/Female): **Date of birth**:

Education (following Spanish educational levels):

Primary Studies

Secondary Studies

Technical Qualifications

University Degree (3 years)

University Degree (4 years)

University Degree (5 years)

M.Sc. or equivalent.

PhD.

Education degree title or discipline:

____

Main discipline related to his current job:

____

Main sector related to his current job:

a)Public administrations b)Private sector c)NGOs d)Self-employment/freelance e)Unemployment f)Other______

Main function of his current job:

a) Management b) Teaching c) Research activities d) Technical activities related to my field e) Other____

Years of experience in the discipline related to his current job:

____

Years of experience in curating, management, documentation, research or similar activities with Cultural Heritage data:

____

Since your first job, what percentage of your activities have been related to interpretation of Cultural Heritage data (not only extraction and storage)?

a) Less than 25%,
b) Between 25% and 50% of my working experience.
c) Between 50% and 75% of my working experience.
d) More than 75% of my working experience.

Problem I. A Romea: Data analysis tasks

The A Romea case study emerges during the archaeological works performed by the company Ambiotec S.L. between December of 1999 and February of 2000. The archaeological team documented the A Romea hillfort, an unpublished archaeological site. The following data that you can explore through Excel spreadsheets or through the iOS prototype of the software-assisted knowledge generation framework belongs to the A Romea excavation remains and research results obtained. Please, explore the data following the method I or II and ask the questions annotating your start and end time:

TASK A: Please, enter here the total number of fragments found in the A Romea site in function of the material associated to them. In addition, enter also the total number of fragments found in the A Romea site in function of the excavation method performed.

START TIME:	END TIME:

TASK B: Please, enter here the average fragmentation percentage of the ceramic objects found in the A Romea site and extract by a machine excavation method

START TIME:	END TIME:

TASK C: Please, enter here the different temporal values assigned to the objects found in the A Romea site.

START TIME:	END TIME:

TASK D: Please, enter here the stratigraphic units defined in the A Romea site and the criterion used to group these stratigraphic units. In addition, enter also what stratigraphic units belong to the “Barrow’s chamber” group and the “Alteration path” group.

START TIME:	END TIME

TASK E: Please, enter here the attributes (important features documented by the archaeological team) of the metallic object fragments found in the A Romea site.

START TIME:	END TIME:

TASK F: Please, enter here the temporal intervals associated to the A Romea's barrow at a general level having into account all data presented about the stratigraphic study and the objects and fragment found in the site. In addition, indicate the name of the tumular phase associated to Final Neolithic stage: What's happened in A Romea in that period?

START TIME: END TIME:

TASK G: Please, ask the following question through a textual abstract (300-500 words): What are the Cultural Heritage conclusions that you can obtain after exploring the A Romea data?

START TIME: END TIME:

TASK H: Please, enter here the mistakes and inconsistencies that you can identify in the abstract provided to you for evaluation, following the guidelines document attached.

START TIME: END TIME:

Thank you for your collaboration.

Problem II. Forno dos Mouros: data analysis tasks

The Forno dos Mouros case study emerges during the archaeological works performed in the Serra de Bocelos (Spain) between June of 1999 and July of 1999. The archaeological team documented and studied (The site was discovered previously in past campaigns) the Forno dos Mouros archaeological site. The following data that you can explore through Excel spreadsheets or through the iOS prototype of the software-assisted knowledge generation framework belongs to the Forno dos Mouros excavation remains and research results obtained. Please, explore the data following the method I or II and ask the questions annotating your start and end time:

TASK A: Please, enter here the total number of fragments found in the Forno dos Mouros site in function of the material associated to them. In addition, enter also the the total number of fragments found in the site in function of the decoration characteristics of them.

START TIME:	END TIME:

TASK B: Please, enter here the average fragmentation percentage of the ceramic objects found in the Forno dos Mouros site and extract by manual excavation method

START TIME:	END TIME:

TASK C: Please, enter here the different temporal values assigned to the ceramic fragments found in the Forno dos Mouros site. In addition, think about the temporal value of the ceramic object composes by these fragments: Is it possible to associate a temporal value for each ceramic object? Indicate the temporal value associated to PZ01 object and PZ06 object:

START TIME:	END TIME:

TASK D: Please, enter here the stratigraphic units defined in the Forno dos Mouros site and the criterion used to group these stratigraphic units. In addition, enter also what stratigraphic units belong to the “First megalithic zone” group and the “Chamber access: pit” group.

START TIME:	END TIME:

TASK E: Please, enter here the attributes (important features documented by the archaeological team) of the stratigraphic unit defined in the Forno dos Mouros site.

START TIME:	END TIME:

TASK F: Please, enter here the temporal intervals associated to the Forno dos Mouros site at a general level, having into account all data presented about the stratigraphic study and the objects and fragment found in the site. In addition, indicate the name of the tumular phase associated to Initial Neolithic stage: What's happened in Forno dos Mouros in that period?

START TIME:	END TIME:

TASK G: Please, ask the following question through a textual abstract (300-500 words): What are the Cultural Heritage conclusions that you can obtain after exploring the Fornos dos Mouros data?

START TIME:	END TIME:

TASK H: Please, enter here the mistakes and inconsistencies that you can identify in the abstract provided to you for evaluation, following the guidelines document attached.

START TIME:	END TIME:

Thank you for your collaboration.

Questionnaire Data-Analysis Method I: Spreadsheets in Microsoft Excel®

The questionnaire gives you the possibility to express your opinion about the use of Excel spreadsheets to perform data analysis tasks during the knowledge generation process. Note that a data analysis task is one that is carried out to examine raw data in order to extract knowledge and achieve some conclusions. Please read each sentence carefully and give a score according to the following values: 1 = Totally Disagree, 2 = Moderately Disagree, 3 = Neutral, 4 = Moderately Agree, 5 = Totally Agree

SENTENCES	1	2	3	4	5
1. I think the procedure for data analysis using Excel spreadsheets k is simple and easy to follow.	O	O	O	O	O
2. I think Excel spreadsheets reduce the effort I need to do to perform the required data analysis tasks.	O	O	O	O	O
3. Excel spreadsheets allow the grouping of the data following different criteria in an agile and intuitive manner.	O	O	O	O	O
4. Using Excel spreadsheets I can efficiently perform data grouping following my own criteria.	O	O	O	O	O
5. Excel spreadsheets allow me to combine data values in order to extract conclusions in an agile and intuitive manner.	O	O	O	O	O
6. Using Excel spreadsheets I can efficiently perform exploratory data analysis tasks that relate different dimensions (geographical, temporal and provenance), and test different hypotheses.	O	O	O	O	O
7. Excel spreadsheets allow me to explore contextual dimensions (geographical, temporal or provenance) of my data in an agile and intuitive manner.	O	O	O	O	O
8. Using Excel spreadsheets I can know more about the contextual dimensions (geographical, temporal or provenance) of my data, which allows me to answer questions about their structure.	O	O	O	O	O
9. Excel spreadsheets allow me to know more about the internal structure of my data (i.e. the underlying schema) in an agile and intuitive manner.	O	O	O	O	O

SENTENCES	1	2	3	4	5
10. Using Excel spreadsheets I can know more about the internal structure of my data (i.e. the underlying schema), which allows me to answer questions about it.	O	O	O	O	O
11. In general, I find Excel spreadsheets easy to use.	O	O	O	O	O
12. I think I could easily explain how to perform data analysis tasks using Excel spreadsheets to others.	O	O	O	O	O
13. In general, I find Excel spreadsheets helpful.	O	O	O	O	O
14. In general, Excel spreadsheets could be a practical method to perform data analysis tasks and obtain conclusions.	O	O	O	O	O
15. In my opinion, it is easy to use Excel spreadsheets to perform the data analysis tasks required in the specific case study that was analysed.	O	O	O	O	O
16. I would use Excel spreadsheets if it was available to group my data according to my own criteria.	O	O	O	O	O
17. I would use Excel spreadsheets if it was available to combine data values and extract some conclusions.	O	O	O	O	O
18. I would use Excel spreadsheets if it was available to explore contextual dimensions (geographical, temporal or provenance) of my data.	O	O	O	O	O
19. I would use Excel spreadsheets if it was available to know more about the internal structure (i.e. the underlying schema) of my data	O	O	O	O	O
20. I feel I have the necessary skills to perform data analysis tasks with Excel spreadsheets.	O	O	O	O	O
21. In general, I think Excel spreadsheets offers significant improvements over other methods to perform data analysis tasks in research and knowledge-generation.	O	O	O	O	O

SENTENCES	1	2	3	4	5
22. I will try to use Excel spreadsheets if I had to perform data analysis tasks in research and knowledge-generation in the future.	O	O	O	O	O

Questionnaire Data-Analysis Method II: Software-Assisted Knowledge Generation Framework

The questionnaire gives you the possibility to express your opinion about the use of our software-assisted knowledge generation framework to perform data analysis tasks during the knowledge generation process. Note that a data analysis task is one that is carried out to examine raw data in order to extract knowledge and achieve some conclusions. Please read each sentence carefully and give a score according to the following values: 1 = Totally Disagree, 2 = Moderately Disagree, 3 = Neutral, 4 = Moderately Agree, 5 = Totally Agree.

SENTENCES	1	2	3	4	5
1. I think the procedure for data analysis using the software-assisted knowledge generation framework is simple and easy to follow.	O	O	O	O	O
2. I think the software-assisted knowledge generation framework reduces the effort I need to do to perform the required data analysis tasks.	O	O	O	O	O
3. The software-assisted knowledge generation framework allows the grouping of the data following different criteria in an agile and intuitive manner.	O	O	O	O	O
4. Using the software-assisted knowledge generation framework I can efficiently perform data grouping following my own criteria.	O	O	O	O	O
5. The software-assisted knowledge generation framework allows me to combine data values in order to extract conclusions in an agile and intuitive manner.	O	O	O	O	O
6. Using the software-assisted knowledge generation framework I can efficiently perform exploratory data analysis tasks that relate different dimensions (geographical, temporal and provenance), and test different hypotheses.	O	O	O	O	O
7. The software-assisted knowledge generation framework allows me to explore contextual dimensions (geographical, temporal or provenance) of my data in an agile and intuitive manner.	O	O	O	O	O

SENTENCES	1	2	3	4	5
8. Using the software-assisted knowledge generation framework I can know more about the contextual dimensions (geographical, temporal or provenance) of my data, which allows me to answer questions about their structure.	O	O	O	O	O
9. The software-assisted knowledge generation framework allows me to know more about the internal structure of my data (i.e. the underlying schema) in an agile and intuitive manner.	O	O	O	O	O
10. Using the software-assisted knowledge generation framework I can know more about the internal structure of my data (i.e. the underlying schema), which allows me to answer questions about it.	O	O	O	O	O
11. In general, I find the software-assisted knowledge generation framework easy to use.	O	O	O	O	O
12. I think I could easily explain how to perform data analysis tasks using the software-assisted knowledge generation framework to others.	O	O	O	O	O
13. In general, I find the software-assisted knowledge generation framework helpful.	O	O	O	O	O
14. In general, the software-assisted knowledge generation framework could be a practical method to perform data analysis tasks and obtain conclusions.	O	O	O	O	O
15. In my opinion, it is easy to use the software-assisted knowledge generation framework to perform the data analysis tasks required in the specific case study that was analysed.	O	O	O	O	O
16. I would use the software-assisted knowledge generation framework if it was available to group my data according to my own criteria.	O	O	O	O	O
17. I would use the software-assisted knowledge generation framework if it was available to combine data values and extract some conclusions.	O	O	O	O	O

SENTENCES	1	2	3	4	5
18. I would use the software-assisted knowledge generation framework if it was available to explore contextual dimensions (geographical, temporal or provenance) of my data.	O	O	O	O	O
19. I would use the software-assisted knowledge generation framework if it was available to know more about the internal structure (i.e. the underlying schema) of my data.	O	O	O	O	O
20. I feel I have the necessary skills to perform data analysis tasks with the software-assisted knowledge generation framework.	O	O	O	O	O
21. In general, I think the software-assisted knowledge generation framework offers significant improvements over other methods to perform data analysis tasks in research and knowledge-generation.	O	O	O	O	O
22. I will try to use the software-assisted knowledge generation framework if I had to perform data analysis tasks in research and knowledge-generation in the future.	O	O	O	O	O

Guidelines for evaluating textual abstracts: possible mistakes

This document presents a set of guidelines for evaluating the textual abstract created in the context of the current empirical validation. The guidelines attend to the main mistakes and inconsistencies that the abstract could contain. Please, read the abstract carefully and identify the following mistakes and inconsistencies, by answering these questions:

- Explicit references to numeric data values presented in the case study analysed. For instance, "30 ceramic fragments are recovered which only 3 of them correspond to vessel's rims".
    - How many similar references appears in the abstract? ___________________________________
    - How many similar references presented in the abstract are mistakes? _______________________
- Sentences containing references to processes performed by the author to obtain conclusions from the data, for instance, use of verbs such as compare, classify, identify, categorize, etc. or causalities, exemplifications and generalizations.
    - How many similar references appears in the abstract? _____________________________________
    - How many of them you think are well-founded by the author based on the data of the case study that you analysed? ____
    - How many of them you think you would obtain the same conclusion than the author? ____
- References with redundancies referring to a specific aspect in the abstract, such as repetition of argumentation, same references to numerical data of the case or repetition of examples.
    - How many similar references appears in the abstract? _____________________________________
- Sentences containing references to conclusions of the author about the case study:
    - How many similar references appears in the abstract? _____________________________________
    - How many of them you think are well-founded by the author based on the data of the case study that you analysed? ____

- How many of them you think you would obtain the same conclusion than the author? ____

Thank you for your collaboration.

Evaluation Questionnaire: Satisfaction Degree about Knowledge Generation Quality

The questionnaire gives you the possibility to express your opinion about the quality of the textual abstracts generated throughout the empirical validation process. These memories are generated after performing data analysis tasks with Excel spreadsheets and the software-assisted knowledge generation framework. Please read the textual abstract carefully and give a score according to the following values: 1 = Totally Disagree, 2 = Moderately Disagree, 3 = Neutral, 4 = Moderately Agree, 5 = Totally Agree.

Sentences	1	2	3	4	5
1. In general, the abstract presents a structured and clear discourse organization.	O	O	O	O	O
2. In general, I think the abstract summarizes the case study data analysed.	O	O	O	O	O
3. The abstract presents redundancies in data references and motivation reasoning.	O	O	O	O	O
4. I can clearly identify the research conclusion specified in the abstract.	O	O	O	O	O
5. I think the conclusion expressed in the abstract —explicitly or implicitly— is well-founded based on the data.	O	O	O	O	O
6. The abstract contains references to the raw data used as a basis for reasoning.	O	O	O	O	O
7. The abstract contains references to the relation between the raw data analysed and the research conclusion achieved.	O	O	O	O	O
8. In my opinion, the abstract contains inconsistencies or contradictions.	O	O	O	O	O
9. After reading the abstract, I know what kinds of data have been analysed and its internal structure.	O	O	O	O	O
10. I think there is a lack of references to important data of the case study in the abstract, which should be referenced for the complete understanding of it.	O	O	O	O	O
11. The abstract contains references to what processes have been performed to analyse the data: grouping, comparing, etc.	O	O	O	O	O
12. After reading the abstract, I can give a better answer to the question: What are the conclusions achieved for the authors from the data?	O	O	O	O	O
13. After reading the abstract, I can give a better answer to the question: How the conclusions have been generated?	O	O	O	O	O
14. After reading the abstract, I know how the author is reasoning about the data of the case study.	O	O	O	O	O
15. I think the abstract is a good synopsis about the research performed based on the case study analysed.	O	O	O	O	O

Sentences	1	2	3	4	5
16. I think the abstract allows me having an overview of the case study analysed.	O	O	O	O	O
17. I think the abstract allows me creating new research questions and elaborating hypotheses about the data if the case study and the conclusions achieved by the author.	O	O	O	O	O
18. I think if I read the abstract without knowing the case study, I can understand the main ideas and research conclusion.	O	O	O	O	O
19. In general, I understand the content of the abstract.	O	O	O	O	O

Thank you for your collaboration.

RESULTS OBTAINED

Accuracy: Raw data obtained

Subject	Method	Problem	Accuracy Task A	Accuracy Task B	Accuracy Task C	Accuracy Task D	Accuracy Task E	Accuracy Task F	Total Accuracy All Nothing	Total Accuracy Weighted
1	1,00	1,00	0,00	100,00	100,00	66,00	0,00	0,00	50,00	44,33
1	2,00	2,00	50,00	0,00	100,00	100,00	100,00	100,00	66,67	75,00
2	1,00	2,00	50,00	0,00	100,00	100,00	50,00	50,00	50,00	58,33
2	2,00	1,00	100,00	0,00	100,00	100,00	100,00	100,00	66,67	83,33
3	1,00	1,00	100,00	100,00	100,00	66,00	0,00	100,00	66,67	77,67
3	2,00	2,00	100,00	100,00	100,00	100,00	100,00	50,00	83,33	91,67
4	1,00	2,00	50,00	0,00	100,00	33,00	100,00	0,00	33,33	47,17
4	2,00	1,00	50,00	0,00	100,00	100,00	100,00	100,00	66,67	75,00
5	1,00	2,00	50,00	0,00	100,00	100,00	100,00	0,00	50,00	58,33
5	2,00	1,00	50,00	0,00	100,00	100,00	100,00	50,00	50,00	66,67

Subject	Method	Problem	Accuracy Task A	Accuracy Task B	Accuracy Task C	Accuracy Task D	Accuracy Task E	Accuracy Task F	Total Accuracy All Nothing	Total Accuracy Weighted
6	1,00	1,00	50,00	0,00	100,00	66,00	0,00	50,00	16,67	44,33
6	2,00	2,00	100,00	100,00	100,00	33,00	50,00	100,00	66,67	80,50
7	1,00	2,00	50,00	0,00	100,00	33,00	0,00	50,00	16,67	38,83
7	2,00	1,00	100,00	0,00	100,00	100,00	100,00	50,00	66,67	75,00
8	1,00	1,00	0,00	50,00	100,00	33,00	100,00	0,00	33,33	47,17
8	2,00	2,00	100,00	0,00	100,00	100,00	0,00	100,00	66,67	66,67
9	1,00	1,00	50,00	100,00	100,00	100,00	100,00	0,00	66,67	75,00
9	2,00	2,00	100,00	0,00	100,00	100,00	100,00	100,00	83,33	83,33
10	1,00	2,00	100,00	0,00	100,00	100,00	50,00	50,00	50,00	66,67
10	2,00	1,00	100,00	50,00	100,00	66,00	100,00	50,00	50,00	77,67
11	1,00	2,00	0,00	0,00	100,00	33,00	100,00	100,00	50,00	55,50
11	2,00	1,00	100,00	0,00	100,00	100,00	100,00	100,00	83,33	83,33

Subject	Method	Problem	Accuracy Task A	Accuracy Task B	Accuracy Task C	Accuracy Task D	Accuracy Task E	Accuracy Task F	Total Accuracy All Nothing	Total Accuracy Weighted
12	1,00	1,00	50,00	100,00	100,00	66,00	50,00	50,00	33,33	69,33
12	2,00	2,00	100,00	0,00	100,00	100,00	50,00	100,00	66,67	75,00
13	1,00	1,00	0,00	0,00	100,00	100,00	50,00	100,00	50,00	58,33
13	2,00	2,00	100,00	50,00	100,00	100,00	100,00	100,00	83,33	91,67
14	1,00	2,00	50,00	0,00	100,00	33,00	0,00	50,00	16,67	38,83
14	2,00	1,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
15	1,00	2,00	100,00	0,00	100,00	66,00	,00	100,00	50,00	61,00
15	2,00	1,00	100,00	0,00	100,00	100,00	100,00	100,00	83,33	83,33
16	1,00	1,00	0,00	0,00	50,00	33,00	0,00	0,00	0,00	13,83
16	2,00	2,00	100,00	50,00	100,00	100,00	100,00	100,00	83,33	91,67

Efficiency: Raw data obtained

Subject	Method	Problem	Efficiency Task A	Efficiency Task B	Efficiency Task C	Efficiency Task D	Efficiency Task E	Efficiency Task F	Total Efficiency
1	1,00	1,00	10,00	3,00	3,00	5,00	3,00	2,00	26,00
1	2,00	2,00	1,00	4,00	3,00	6,00	1,00	1,00	16,00
2	1,00	2,00	2,00	2,00	4,00	4,00	1,00	3,00	16,00
2	2,00	1,00	3,00	4,00	1,00	1,00	1,00	1,00	11,00
3	1,00	1,00	5,00	2,00	2,00	5,00	2,00	2,00	18,00
3	2,00	2,00	3,00	1,00	4,00	2,00	1,00	1,00	12,00
4	1,00	2,00	2,00	1,00	2,00	5,00	1,00	4,00	15,00
4	2,00	1,00	5,00	1,00	1,00	1,00	1,00	2,00	11,00
5	1,00	2,00	8,00	2,00	2,00	4,00	1,00	4,00	21,00
5	2,00	1,00	3,00	2,00	1,00	6,00	1,00	3,00	16,00
6	1,00	1,00	8,00	3,00	1,00	4,00	2,00	3,00	21,00
6	2,00	2,00	2,00	2,00	1,00	4,00	1,00	1,00	11,00

Subject	Method	Problem	Efficiency Task A	Efficiency Task B	Efficiency Task C	Efficiency Task D	Efficiency Task E	Efficiency Task F	Total Efficiency
7	1,00	2,00	1,00	1,00	2,00	2,00	1,00	2,00	9,00
7	2,00	1,00	4,00	1,00	1,00	2,00	1,00	2,00	11,00
8	1,00	1,00	3,00	2,00	1,00	4,00	1,00	6,00	17,00
8	2,00	2,00	1,00	2,00	3,00	4,00	2,00	2,00	14,00
9	1,00	1,00	3,00	2,00	1,00	3,00	1,00	1,00	11,00
9	2,00	2,00	1,00	2,00	2,00	3,00	1,00	1,00	10,00
10	1,00	2,00	3,00	1,00	1,00	3,00	1,00	2,00	11,00
10	2,00	1,00	2,00	1,00	1,00	2,00	1,00	1,00	8,00
11	1,00	2,00	1,00	1,00	1,00	5,00	1,00	2,00	11,00
11	2,00	1,00	1,00	2,00	1,00	3,00	1,00	1,00	9,00
12	1,00	1,00	6,00	3,00	1,00	5,00	1,00	2,00	18,00
12	2,00	2,00	2,00	1,00	4,00	2,00	1,00	1,00	11,00
13	1,00	1,00	9,00	2,00	1,00	3,00	2,00	2,00	19,00

Subject	Method	Problem	Efficiency Task A	Efficiency Task B	Efficiency Task C	Efficiency Task D	Efficiency Task E	Efficiency Task F	Total Efficiency
13	2,00	2,00	1,00	2,00	1,00	2,00	1,00	2,00	9,00
14	1,00	2,00	4,00	3,00	1,00	3,00	2,00	3,00	16,00
14	2,00	1,00	2,00	1,00	1,00	3,00	1,00	2,00	10,00
15	1,00	2,00	3,00	3,00	3,00	3,00	1,00	6,00	19,00
15	2,00	1,00	2,00	1,00	3,00	1,00	1,00	2,00	10,00
16	1,00	1,00	8,00	5,00	5,00	6,00	2,00	3,00	29,00
16	2,00	2,00	3,00	2,00	2,00	2,00	1,00	1,00	11,00

Productivity: Raw data obtained

Subject	Method	Problem	Productivity Task A	Productivity Task B	Productivity Task C	Productivity Task D	Productivity Task E	Productivity Task F	Total Productivity All Nothing	Total Productivity Weighted
1	1,00	1,00	0,00	33,33	33,33	13,20	0,00	0,00	1,92	1,71
1	2,00	2,00	50,00	0,00	33,33	16,67	100,00	100,00	4,17	4,69

Subject	Method	Problem	Productivity Task A	Productivity Task B	Productivity Task C	Productivity Task D	Productivity Task E	Productivity Task F	Total Productivity All Nothing	Total Productivity Weighted
2	1,00	2,00	25,00	0,00	25,00	25,00	50,00	16,67	3,13	3,65
2	2,00	1,00	33,33	0,00	100,00	100,00	100,00	100,00	6,06	7,58
3	1,00	1,00	20,00	50,00	50,00	13,20	0,00	50,00	3,70	4,31
3	2,00	2,00	33,33	100,00	25,00	50,00	100,00	50,00	6,94	7,64
4	1,00	2,00	25,00	0,00	50,00	6,60	100,00	0,00	2,22	3,14
4	2,00	1,00	10,00	0,00	100,00	100,00	100,00	50,00	6,06	6,82
5	1,00	2,00	6,25	0,00	50,00	25,00	100,00	0,00	2,38	2,78
5	2,00	1,00	16,67	0,00	100,00	16,67	100,00	16,67	3,13	4,17
6	1,00	1,00	6,25	0,00	100,00	16,50	0,00	16,67	,79	2,11
6	2,00	2,00	50,00	50,00	100,00	8,25	50,00	100,00	6,06	7,32
7	1,00	2,00	50,00	0,00	50,00	16,50	0,00	25,00	1,85	4,31
7	2,00	1,00	25,00	0,00	100,00	50,00	100,00	25,00	6,06	6,82

Subject	Method	Problem	Productivity Task A	Productivity Task B	Productivity Task C	Productivity Task D	Productivity Task E	Productivity Task F	Total Productivity All Nothing	Total Productivity Weighted
8	1,00	1,00	0,00	25,00	100,00	8,25	100,00	0,00	1,96	2,77
8	2,00	2,00	100,00	0,00	33,33	25,00	0,00	50,00	4,76	4,76
9	1,00	1,00	16,67	50,00	100,00	33,33	100,00	0,00	6,06	6,82
9	2,00	2,00	100,00	0,00	50,00	33,33	100,00	100,00	8,33	8,33
10	1,00	2,00	33,33	0,00	100,00	33,33	50,00	25,00	4,55	6,06
10	2,00	1,00	50,00	50,00	100,00	33,00	100,00	50,00	6,25	9,71
11	1,00	2,00	0,00	0,00	100,00	6,60	100,00	50,00	4,55	5,05
11	2,00	1,00	100,00	0,00	100,00	33,33	100,00	100,00	9,26	9,26
12	1,00	1,00	8,33	33,33	100,00	13,20	50,00	25,00	1,85	3,85
12	2,00	2,00	50,00	0,00	25,00	50,00	50,00	100,00	6,06	6,82
13	1,00	1,00	0,00	0,00	100,00	33,33	25,00	50,00	2,63	3,07
13	2,00	2,00	100,00	25,00	100,00	50,00	100,00	50,00	9,26	10,19

Subject	Method	Problem	Productivity Task A	Productivity Task B	Productivity Task C	Productivity Task D	Productivity Task E	Productivity Task F	Total Productivity All Nothing	Total Productivity Weighted
14	1,00	2,00	12,50	0,00	100,00	11,00	0,00	16,67	1,04	2,43
14	2,00	1,00	50,00	100,00	100,00	33,33	100,00	50,00	10,00	10,00
15	1,00	2,00	33,33	0,00	33,33	22,00	0,00	16,67	2,63	3,21
15	2,00	1,00	50,00	0,00	33,33	100,00	100,00	50,00	8,33	8,33
16	1,00	1,00	0,00	0,00	10,00	5,50	0,00	0,00	0,00	,48
16	2,00	2,00	33,33	25,00	50,00	50,00	100,00	100,00	7,58	8,33

Satisfaction: Raw data obtained

Subject	Method	Problem	PEOU —Perceived Ease Of Use—	PU —Perceived ease of Use—	ITU —Intention To Use—
1	1,00	1,00	22,00	17,00	19,00
1	2,00	2,00	42,00	37,00	24,00
2	1,00	2,00	34,00	28,00	12,00
2	2,00	1,00	37,00	33,00	21,00

Subject	Method	Problem	PEOU —Perceived Ease Of Use—	PU —Perceived ease of Use—	ITU —Intention To Use—
3	1,00	1,00	25,00	22,00	10,00
3	2,00	2,00	37,00	35,00	25,00
4	1,00	2,00	28,00	25,00	13,00
4	2,00	1,00	26,00	30,00	19,00
5	1,00	2,00	20,00	22,00	15,00
5	2,00	1,00	39,00	32,00	23,00
6	1,00	1,00	32,00	28,00	16,00
6	2,00	2,00	35,00	35,00	23,00
7	1,00	2,00	13,00	17,00	9,00
7	2,00	1,00	26,00	21,00	16,00
8	1,00	1,00	23,00	23,00	9,00
8	2,00	2,00	17,00	18,00	10,00
9	1,00	1,00	32,00	29,00	20,00
9	2,00	2,00	31,00	32,00	23,00

Subject	Method	Problem	PEOU —Perceived Ease Of Use—	PU —Perceived ease of Use—	ITU —Intention To Use—
10	1,00	2,00	30,00	26,00	10,00
10	2,00	1,00	30,00	29,00	12,00
11	1,00	2,00	13,00	14,00	5,00
11	2,00	1,00	29,00	29,00	19,00
12	1,00	1,00	25,00	26,00	16,00
12	2,00	2,00	28,00	29,00	15,00
13	1,00	1,00	15,00	12,00	6,00
13	2,00	2,00	39,00	37,00	22,00
14	1,00	2,00	16,00	21,00	13,00
14	2,00	1,00	42,00	39,00	24,00
15	1,00	2,00	26,00	34,00	22,00
15	2,00	1,00	42,00	36,00	25,00
16	1,00	1,00	17,00	22,00	12,00
16	2,00	2,00	32,00	32,00	21,00

Knowledge generated quality: Raw data obtained

Subject	Method	Problem	Errors Type 1	Errors Type 1	Errors Type 1	Errors Type 1	Total Errors	Knowledge Generated Satisfaction
1	1,00	1,00	0,00	2,00	0,00	0,00	2,00	28,00
1	2,00	2,00	0,00	0,00	0,00	0,00	0,00	43,00
2	1,00	2,00	0,00	1,00	1,00	2,00	4,00	36,00
2	2,00	1,00	0,00	1,00	0,00	3,00	4,00	36,00
3	1,00	1,00	0,00	0,00	1,00	1,00	2,00	47,00
3	2,00	2,00	1,00	0,00	0,00	0,00	1,00	47,00
4	1,00	2,00	0,00	0,00	1,00	1,00	2,00	38,00
4	2,00	1,00	0,00	0,00	1,00	0,00	1,00	49,00
5	1,00	2,00	0,00	0,00	0,00	0,00	0,00	45,00
5	2,00	1,00	0,00	0,00	0,00	0,00	0,00	44,00
6	1,00	1,00	1,00	0,00	0,00	1,00	2,00	50,00
6	2,00	2,00	0,00	0,00	0,00	0,00	0,00	53,00

Subject	Method	Problem	Errors Type 1	Errors Type 1	Errors Type 1	Errors Type 1	Total Errors	Knowledge Generated Satisfaction
7	1,00	2,00	0,00	0,00	0,00	1,00	1,00	38,00
7	2,00	1,00	0,00	0,00	0,00	0,00	0,00	42,00
8	1,00	1,00	1,00	0,00	0,00	1,00	2,00	35,00
8	2,00	2,00	0,00	0,00	0,00	1,00	1,00	35,00
9	1,00	1,00	0,00	0,00	0,00	1,00	1,00	47,00
9	2,00	2,00	0,00	0,00	1,00	2,00	3,00	51,00
10	1,00	2,00	0,00	0,00	1,00	2,00	3,00	25,00
10	2,00	1,00	0,00	0,00	0,00	1,00	1,00	34,00
11	1,00	2,00	0,00	0,00	0,00	0,00	0,00	35,00
11	2,00	1,00	0,00	0,00	0,00	0,00	0,00	44,00
12	1,00	1,00	0,00	1,00	1,00	0,00	2,00	27,00
12	2,00	2,00	0,00	1,00	0,00	0,00	1,00	42,00
13	1,00	1,00	0,00	0,00	1,00	0,00	1,00	37,00

Subject	Method	Problem	Errors Type 1	Errors Type 1	Errors Type 1	Errors Type 1	Total Errors	Knowledge Generated Satisfaction
13	2,00	2,00	0,00	0,00	0,00	0,00	0,00	44,00
14	1,00	2,00	1,00	0,00	1,00	2,00	4,00	28,00
14	2,00	1,00	1,00	0,00	0,00	0,00	1,00	43,00
15	1,00	2,00	0,00	2,00	0,00	0,00	2,00	27,00
15	2,00	1,00	0,00	0,00	0,00	0,00	0,00	42,00
16	1,00	1,00	0,00	0,00	1,00	0,00	1,00	25,00
16	2,00	2,00	0,00	0,00	0,00	0,00	0,00	34,00

APPLYING A LINEAR MIXED MODEL

Accuracy: Linear mixed model analysis

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14	148,770	,000
Problem	1	14,000	2,966	,107
Method	1	14,000	26,695	,000
Problem * Method	1	14	,724	,409

a. Dependent variable Accuracy_TaskA.

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14	26,372	,000
Problem	1	14	1,448	,249
Method	1	14	,000	1,000
Problem * Method	1	14	11,721	,004

a. Dependent variable: Accuracy_TaskB.

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	0	.	.	.
Problem	0	.	.	.
Method	0	.	.	.
Problem * Method	0	.	.	.

a. Dependent variable: Accuracy_TaskC: O confluence warning. The MIXED procedure continues. The subsequent results are based on the last iteration. The validity of the model fit is uncertain.

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14,000	382,526	,000
Problem	1	14	,188	,671
Method	1	14	9,866	,007
Problem * Method	1	14,000	,000	,994

a. Dependent variable: Accuracy_TaskD.

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14	134,217	,000
Problem	1	14	,179	,678
Method	1	14	8,795	,010
Problem * Method	1	14	2,739	,120

a. Dependent variable: Accuracy_TaskE.

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14	131,362	,000
Problem	1	14	1,098	,312
Method	1	14	13,451	,003
Problem * Method	1	14	,000	1,000

a. Dependent variable: Accuracy_TaskF.

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14	381,583	,000
Problem	1	14,000	,110	,745
Method	1	14,000	28,221	,000
Problem * Method	1	14	,131	,723

a. Dependent variable: Accuracy_Total_AllNothing.

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14,000	874,544	,000
Problem	1	14	,005	,943
Method	1	14	30,852	,000
Problem * Method	1	14,000	,051	,824

a. Dependent variable: AccuracyTotal_Weighted.

Marginal means by Method

	Media M1	Media M2	SD M1	SD M2
Accuracy_TaskA	43,750	90,625	35,93976	20,15564
Accuracy_TaskB	28,125	28,125	44,60475	40,69705
Accuracy_TaskC	96,875	100,00	12,50000	0,000000
Accuracy_TaskD	64,250	93,688	28,59487	18,27099
Accuracy_TaskE	43,750	87,500	44,25306	28,86751
Accuracy_TaskF	43,750	87,500	40,31129	22,36068
Accuracy_Total_AllNothing	39,584	72,917	19,12440	13,43534
Accuracy_TotalWeighted	53,417	81,240	16,02602	9,27162

Efficiency: Linear mixed model analysis

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14	106,563	,000
Problem	1	14	11,010	,005
Method	1	14	13,592	,002
Problem * Method	1	14	3,398	,087

a. Dependent variable: Time_TaskA.

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14	125,851	,000
Problem	1	14	,897	,360
Method	1	14	1,759	,206
Problem * Method	1	14	3,604	,078

a. Dependent variable: Time_TaskB.

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14	78,692	,000
Problem	1	14	3,375	,088
Method	1	14	,028	,870
Problem * Method	1	14	1,713	,212

a. Dependent variable: Time_TaskC.

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14	196,269	,000
Problem	1	14	,000	1,000
Method	1	14	7,143	,018
Problem * Method	1	14	2,423	,142

a. Dependent variable: Time_TaskD.

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14	373,333	,000
Problem	1	14,000	2,074	,172
Method	1	14,000	4,667	,049
Problem * Method	1	14	8,400	,012

a. Dependent variable: Time_TaskE.

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14	94,099	,000
Problem	1	14	,040	,844
Method	1	14	21,160	,000
Problem * Method	1	14	1,512	,239

a. Dependent variable: Time_TaskF.

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14	324,084	,000
Problem	1	14	3,625	,078
Method	1	14	31,319	,000
Problem * Method	1	14	3,726	,074

a. Dependent variable: Effort_T.

Marginal means by Method

	Media M1	**Media M2**	**SD M1**	**SD M2**
Time_TaskA	4,750	2,250	3,00000	1,18322
Time _TaskB	2,250	1,812	1,06458	0,98107
Time _TaskC	1,937	1,875	1,23659	1,14746
Time _TaskD	4,000	2,750	1,09545	1,57056
Time _TaskE	1,438	1,062	0,62915	0,25000
Time _TaskF	2,938	1,500	1,43614	0,63246
Effort_T	17,313	11,250	5,43714	2,29492

Productivity: Linear mixed model analysis

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14	93,910	,000
Problem	1	14	4,988	,042
Method	1	14	18,911	,001
Problem * Method	1	14	,179	,679

a. Dependent variable: Productivity_TaskA.

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14	11,612	,004
Problem	1	14	,825	,379
Method	1	14	1,031	,327
Problem * Method	1	14	2,311	,151

a. Dependent variable: Productivity_TaskB.

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14	120,184	,000
Problem	1	14	7,980	,014
Method	1	14	,116	,739
Problem * Method	1	14	1,272	,278

a. Dependent variable: Productivity_TaskC.

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14	76,660	,000
Problem	1	14	2,084	,171
Method	1	14	15,088	,002
Problem * Method	1	14	2,669	,125

a. Dependent variable: Productivity_TaskD.

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14	137,387	,000
Problem	1	14	,099	,758
Method	1	14	9,213	,009
Problem * Method	1	14	3,370	,088

a. Dependent variable: Productivity_TaskE.

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14,000	107,761	,000
Problem	1	14	2,387	,145
Method	1	14	32,549	,000
Problem * Method	1	14,000	2,253	,156

a. Dependent variable: Productivity_TaskF.

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14	184,468	,000
Problem	1	14	,024	,878
Method	1	14	53,310	,000
Problem * Method	1	14,000	,241	,631

a. Dependent variable: ProductivityAllN.

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14,000	245,557	,000
Problem	1	14	,011	,916
Method	1	14	59,574	,000
Problem * Method	1	14,000	,805	,385

a. Dependent variable: ProductivityWeighted.

Marginal means by Method

	Media M1	**Media M2**	**SD M1**	**SD M2**
Productivity_TaskA	14,792	53,229	15,17262	30,55335
Productivity _TaskB	11,979	21,875	19,23749	35,20772
Productivity _TaskC	68,854	71,875	33,75686	33,59274
Productivity _TaskD	17,659	46,849	9,83643	29,50000

	Media M1	Media M2	SD M1	SD M2
Productivity _TaskE	42,188	87,500	44,45855	28,86751
Productivity _TaskF	18,229	68,229	18,56389	30,46229
ProductivityAllN	2,579	6,769	1,54195	1,91947
ProductivityWeighted	3,484	7,547	1,59807	1,85204

Satisfaction: Linear mixed model analysis

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14	484,744	,000
Problem	1	14,000	,260	,618
Method	1	14,000	15,290	,002
Problem * Method	1	14	,001	,981

a. Dependent variable: PEOU.

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14,000	629,850	,000
Problem	1	14	,188	,671
Method	1	14	18,281	,001
Problem * Method	1	14,000	,003	,955

a. Dependent variable: PU.

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14	255,496	,000
Problem	1	14	,058	,814
Method	1	14	30,543	,000
Problem * Method	1	14	,154	,700

Marginal means by Method

	Media M1	Media M2	SD M1	SD M2
PEOU	23,188	33,250	6,98779	7,11337
PU	22,875	31,500	5,82952	5,64506
ITU	12,938	20,125	4,85069	4,63141

Knowledge generated quality: Linear mixed model analysis

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
Intersection	1	14	551,417	,000
Problem	1	14	,135	,718
Method	1	14	22,110	,000
Problem * Method	1	14	,536	,476

a. Dependent variable: Satisfaction_KnowledgeGen.

Fixed Effects type III[a]

Origen	gl numerator	gl denominator	F	Sig.
intersection	1	14	25,407	,000
Problem	1	14	,177	,680
Method	1	14	11,342	,005
Problem * Method	1	14	,230	,639

a. Dependent variable: ReportErrors_Total.

Marginal means by Method

	Media M1	Media M2	SD M1	SD M2
Satisfaction_KnowledgeGen	35,500	42,687	8,39841	5,74710
ReportErrors_Total	1,812	0,812	1,16726	1,16726

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