Universidad de Alcalá

Programa de Doctorado en Ingeniería de la Información y del Conocimiento

Propuesta de aplicación de nuevos enfoques de análisis de competencias y perfiles profesionales digitales

Proposal for the application of new approaches to the analysis of digital competencies and professional profiles

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ABSTRACT

The main objective of this thesis is the proposal of a new approach to the analysis of competences and professional profiles in the field of Information and Communication Technologies (ICT). The review research methods of existing contributions in the area reveals limitations and opportunities for improvement of the results of analysis. The main problems detected, leading to low accuracy and representativeness in the results of professional profiles analysis, are: a) lack of homogeneous and well-defined terminology and concepts linked to standard or to widely accepted competence models or frameworks, b) limitations in the variety of information sources and in the size and representativeness of the datasets for analysis, c) limitations in the design and efficiency of data collection, mainly based on manual methods and d) limited basic analysis of the data collected with questionnaires.

Fortunately, especially in the European Union, the ESCO European Job Reference Framework and the EN16234 standard provide a homogeneous and well-defined terminology of competences, skills, knowledge, and attitudes for ICT professional profiles. The Skills Match model resulting from a European project provides a solid reference for soft skills. CEDEFOP's OVATE tool allows the analysis of millions of online job ads with ESCO terminology and the replication of the ESCO database allows sophisticated queries of its information for ICT profiles.

The application of these options and other methodological improvements has allowed the confirmation of the improvement of the analyses presented in three impact publications, showing better representativeness and larger size of the data, a close linkage to existing reference models and a generation of more sophisticated results in the shape of competency frameworks. This confirmation enables a research line to extend the scope and robustness of studies of ICT occupational profiles in the future.

RESUMEN

El objetivo principal de esta tesis es proponer un nuevo enfoque para el análisis de competencias y perfiles profesionales en el ámbito de las tecnologías de la Información y las Comunicaciones (TIC). La revisión de los métodos de investigación de las contribuciones existentes en el área revela limitaciones y oportunidades de mejora de los resultados del análisis de perfile TIC. Los principales problemas detectados que provocan baja precisión y representatividad en los resultados de análisis de perfiles profesionales son: a) ausencia de terminología y conceptos homogéneos y bien definidos vinculados a modelos o marcos competenciales estándar o ampliamente aceptados, b) limitaciones en la variedad de las fuentes de información y de tamaño y representatividad de los conjuntos de datos para el análisis, c) limitaciones en el diseño y la eficiencia de la recogida de datos, excesivamente basada en métodos manuales y d) análisis excesivamente básico de los datos recogidos con cuestionarios.

Por suerte, especialmente en la Unión Europea, el marco de referencia laboral europea ESCO y el estándar EN16234 permiten contar con una terminología homogénea y bien definida en cuanto a competencias, habilidades, conocimientos y actitudes para perfiles profesionales TIC. El modelo Skills Match resultante de un proyecto europeo ofrece una sólida referencia para soft skills. La herramienta OVATE de CEDEFOP permite el análisis de millones de ofertas de trabajo en línea con terminología ESCO y la replicación de la base de datos de ESCO permite consultas sofisticadas de la información de esta clasificación para los perfiles TIC.

La aplicación de estas opciones y de otras mejoras metodológicas ha permitido confirmar la mejora de los análisis presentados en tres publicaciones de impacto, con mayor representatividad y tamaño de los datos, una estrecha vinculación a los modelos de referencia existentes y una generación de resultados más sofisticados en forma de marcos competenciales. Gracias a esta confirmación se abre una línea de trabajo para ampliar el alcance y la solidez de los estudios de los perfiles profesionales TIC.

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ABREVIATIONS

CV: Curriculum Vitae

ICT: Information and Communication Technology

EU: European Union

ESCO: European Skills/Competences, Qualifications and Occupations

e-CF: e-Competence Framework

CEN/TC: European Committee for Standardization/Technical Committee

ISCO: International Standard Classification of Occupations

EURES: European cooperation network of employment services

EQF: European Qualifications Framework

LDA: Linear Discriminant Analysis

RACI: Responsibility assignment matrix

ISO: International Organization for Standardization

JCR: Journal Citation Report index

NCS: Non-Cognitive Skills

NCSF: Non-Cognitive Skills Framework

IoT: Internet of Things

MOOC: Massive Open Online Courses

1. INTRODUCTION

1.1 Description of context

The Information and Communication Technology (ICT) field is in a continuous growth. The ICT profession is present in all production and service sectors, and its importance is highly noticeable in most studies on the job market. The technological transition in all areas of economy pushes enterprises to focus on acquiring suitable skill sets to compete at global standards. As a consequence, ICT profession generates many job opportunities [1]. At the same time, studies confirm the scarcity of skilled professionals in the technology sector, a shortage of qualified workforce for the demand of developing new processes. Even European Union (EU) has reported that the skills gap in ICT specialists hinders growth in the EU countries, finding out that more than half of companies surveyed struggled to fill ICT vacancies according to a study published by Eurostat [2], [3].

The situation gets worse when the recruiting and talent management processes must deal with a deficit of trustable references in terminology of competences, skills, knowledge, recommended job profiles, qualifications, occupations, roles, etc. The fast evolution of technology and ICT market with brands make effort consuming and difficult to work with job descriptions, job ads and CVs [4]. Although the terms can be easily found in the text and documents, their lack of consistency and homogeneity hinders the management of information generated and used by stakeholders. However, ensuring that these terms are used consistently with a common language is essential for a correct matching of needs between employers, job applicants and training providers. This consistency can be assured with the usage of the relevant frameworks. When we consider global scenarios, where talent management must deal with transnationality (especially in the freedom of mobility of workers in EU), having common frameworks for all actors in ICT job market is key. Efficiency also demands the existence of recommended ICT role or occupation profiles to save efforts in recruiting, talent management and training, providing predefined references that could be adapted to each case. Job profiles can be used as a guide for companies, recruiters, and workers or even for ICT students for orientation to labour market [5].

Unfortunately, although some contributions in literature have tried to progress in this analysis of ICT labour market and professional profiles, as shown in section 1.2, the applied methods are far from being effective, with absence of modern techniques, good data samples and, especially, with a lack of consistent and widely accepted terminology for roles, occupations, skills, etc. If the general analysis of ICT labour market and professional profiles still experiences problems, the case of non-technical abilities, popularly called soft skills (that mostly refer to behavioural skills) is specifically severe. These skills are highly relevant for majority of recruiters [6] and for researchers in the field [7]. As shown by multiple studies [8]–[10], soft-skills are crucial for successful educational performance, employability, earnings and career development. There is a growing awareness that technical skills alone are insufficient for success in ICT [11]. In this case, the problem of terminology and solid analysis of data is even worse, given the absolute absence of trustable, standardized and widely accepted concepts and references.

The above-described situation has motivated the work of this thesis. This thesis is aimed at applying a new approach of analysis of ICT labour market and professional profiles based on consistent and more relevant datasets, previously linked to heterogeneous trustable sources of information to increase representation and variety of information. The goal is the improvement of accuracy on results extraction and analysis, providing more understandable references by linking data and results to existing accepted frameworks, especially in the EU. References such as ESCO (European Skills Competences and Occupations) [12] or the European standard EN16234 [9], known as e-Competence Framework (e-CF), published by CEN/CENELEC, will be used as the two main references. As part of this new approach, this thesis will present, in Sections 2, 3 and 4, three research publications generated as contributions resulting from the application of this new approach, focused on addressing the main hypothesis (see Section 1.3) and the corresponding research questions and objectives.

1.2 Literature review and problem description

The review of existing research literature reveals a moderate number of contributions on the analysis of ICT labour market and professional profiles. As described in this section, the contributions are far from the total coverage of this field and show relevant limitations in methods and results that will inspire the solution through the approach proposed in this thesis.

One of the relevant findings extracted from the analysis of literature is that surveys are a frequent method of information collection in the related works (e.g., [13], [14], or [15]). The application of this method in the analysed contributions offers unsatisfactory results because of the limitations in its implementation:

- limited size of samples: small samples such as 186 responses in [15] or 35 in [20],
- probable inaccuracy of the answers due to the design of questionnaire and the scarce homogeneity of terminology. Results are not linked to any known or completely defined terminology or classification: e.g., authors of [13] and [14] do not refer to any existing framework to present the results as they create an ad-hoc classification without any reference to accepted frameworks or models,
- limited representation with data linked to only one specific source of information or specific context: e.g., geographical limitation to one country or region and very specific types of stakeholder selected as target [13], [14], [15],
- poor response rate to questionnaires such as 37.1% in [15],
- very basic descriptive analysis, both caused by basic unprepared questionnaire design and by use of mere limited descriptive analysis.

Another group of contributions has worked with a usual option for estimation based on consensus like the Delphi method. That is the case of [16], where a set of 11 experienced Finnish software developers and 19 Finnish professors or lecturers evaluated the relevance of 42 usual subjects and skills in IT education, again without reference to homogeneous terminology, with some idea taken from [13] and from the Computing Curricula of 2001 [17].

While the studies mentioned in the previous paragraphs followed manual analysis using survey methods without any reference to framework, other contributions have followed an approach of analysis of the available information on skills in occupations from the job market. These studies have manually analysed job advertisements to identify the most demanded skills related to ICT profiles,

and personally classify these competences based on the authors' experience. The sample datasets are larger than in surveys, so the results are more reliable and consistent, but the sample size is still small to reach relevant conclusions. However, the methodology introduced in these studies help to set a basis to using large amount of data in nowadays. This is the case of the analysis in [18], [19], [20], [21] and [22]. All of them have manually analysed job advertisements to identify the most demanded skills related to software profiles with a personal classification based on authors' experience. The sample datasets are bigger than in surveys with more than 500 vacancies in general (400 in [21] only for testers). The results become more reliable and consistent, but the sample size remains insufficient to support relevant conclusions. Manual collection and analysis of job vacancies is time consuming and very limited to aspire to a proper coverage of reality. Moreover, the absence of a consistent framework for classification again obstructs the potential of aggregation of the different sources into a joint larger sample for a more solid analysis of data.

There is a special case of study with automatic data collection with more than 20000 online job ads from Stackoverflow website [23], analysing (not so automatically) both hard skills and soft skills (but only with 376 ads randomly selected and only providing a word cloud as result [24]. The problem of non-homogeneous terminology is also present in this bigger study and in [20] where authors explicitly admit the "the lack of a definitive taxonomy on non-technical skills". Sometimes, authors add interviews to stakeholders for the interpretation of results extracted from analysis of data from job market (as in [20] with 15 interviewees). [17] is another relevant case with almost 1400 jobs ads, treated with LDA, a generative topic modelling technique, to discover knowledge and skills required in text of ads. Again, the problems of terminology for skills and occupations hinder the comparability of results with other contributions.

Other authors [10] contributed to the analysis of soft skills in ICT. Of course, it is possible to identify the most used terminology coming from international organizations such as OECD [25], UNECO [26], WEF [27], P21 [28] as well as from results from international projects under Erasmus+ program and many references from literature. However, no common model or framework has emerged from this great effort because there is very little consistency and uniformity in the existing models and contributions.

As a conclusion, the contributions in the literature have not developed satisfactory results in the analysis of ICT labour market and professional problems because they have been hindered by the following problems:

- **Lack of a commonly accepted or standardized terminology and/or frameworks** to ensure understandability and comparability of results.
- **Deficit in variety of sources** of information **and limitations in size of dataset** or samples.
- **Poor efficiency and effectiveness of compilation methods**, still based on effort consuming manual procedures.
- **Basic analysis of data** collected with surveys, leading to limited conclusions.

However, it is possible to adopt a new approach for alleviating these problems as there exist options for all of them. In the case of terminology and reference models, the EU has promoted several competences frameworks to enable better coordination of European labour market and promote transnationality for the people around Europe. The two most important reference frameworks for ICT are the e-CF framework [29] and the ESCO Labour Classification [12]. In the case of ESCO, it contains a description for near to 14.000 skills and competences and more than 3.000 occupations

when writing this document, in version 1.1. This framework also describes the recommended skill set for each occupation, which helps all stakeholders (recruiters, candidates, employers, etc.) to understand the most frequently demanded for good performance in each occupation. ESCO is the result of a process longer than 4 years, with the work of more than 200 experts from relevant stakeholders in the education and training sector and from the labour market from all the productive sectors and from national authorities. The use of ESCO is compulsory for all Member States of EU from 2021 onwards. The following numbers summarize the information available for ICT occupations [41]: 111 profiles/occupations with a total of 631 essential skills/knowledge items and 467 optional ones with 4 occupation groups and 15 occupation subgroups. ESCO uses a hierarchy of relationships between the skills and occupations, mapped these last to the International Standard Classification of Occupations (ISCO) to structure the catalogue of occupations. ESCO has been mapped to other reference frameworks for European countries (national classification), known as EURES countries mapping tables [30]. Another mapping with ESCO has been done at non-European level, in this case for United States of America reference framework, known as O*NET [31]. Some other important reference frameworks as for example SFIA [32] is pendent to be mapped with ESCO. The use of ESCO is mandatory for all EU member states from 2021.

The European Standard EN 16234-1 provides an e-Competence Framework [26][33] referencing 41 competences and their relation to ICT area, distinguishing five proficiency levels. The framework responds to the need of supporting mutual understanding and provide transparency of language through the articulation of competences required and deployed by ICT professionals, including both practitioners and managers. It includes relations to ICT qualification context (e.g., by the EQF) and familiar frameworks (e.g., DigComp, ESCO, European ICT Professional Role Profiles, behavioral skills, SFIA, ISO and further ICT industry standards). The emphasis is more on competences rather than on job profiles. This framework considers 41 different competences categorized into five competence areas (Plan, Build, Run, Enable and Manage) and with up to 5 proficiency levels which are reference level specifications on competences. It adopts a competence-based approach where the competences are characterized by a specific set of knowledge items and skills, useful to achieve observable results in the context where the competences are acted. Similarly, CWA 16458-1 [34] provided the description of 30 ICT profiles in terms of the e-CF competences and a framework to create new description for others. The e-CF universe also include an End User Guide EN16234-2 [35] where it is suggested a list of deliverables linked to each competence while [34] shows a RACI matrix for linking deliverables and profiles and describes 30 examples of ICT role profiles based on e-competences of EN 16234-1. The e-CF framework became a standard for the ICT competences in Europe in 2016 [36]. This framework is structured in four dimensions with five competence areas (dimension 1: Plan, Build, Run, Enable and Manage) with a set of e-Competences for each area (dimension 2: 41 in total with a generic description for each one). There are five possible proficiency levels e-1 to e-5 (dimension 3) for each e-competence, although not every competence needs to define its configuration in all these five levels as some of them could not be meaningful for it. The standard also includes limited samples of knowledge and skills (dimension 4) which add value and context, although the list of these items is not intended to be exhaustive.

Despite the importance of these reference frameworks in ICT field, these models have some limitations. Regarding the soft skills, both frameworks not fully address them, despite of being considered very important by recruiters, and has been attracting the attention of many researchers and professionals in the area. In case of e-CF, the information presented in this framework is not exhaustive, and regarding the skills and knowledges, the framework presents examples of usage

rather than the specific skill of knowledge associated to the area presented in the framework. ESCO framework, however, contains good amount of information, but fails in some cases to relate this information between different sources. For example, ESCO contains transversal competences, but these competences are not linked to the ESCO occupations. Additional problem is that despite these both frameworks are referenced frameworks in Europe, there were very limited efforts to match the information between them [37]. To address some of the soft skills gaps, only one European project (Skills Match) developed a soft skills framework directly linked to the information contained in ESCO. Prior this work another European project e-Skills Match [37] worked with different competences standards and models for ICT occupations considering these two reference frameworks, ESCO and e-CF with the main purpose of creating the mapping between these two frameworks for the future works. Also, in the literature review for the soft skills specific relation, only one study [38] presented a comparison between the 11 dispositions of ACM/IEEE Computing Curricula 2020 (CC2020) [39] with the 24 responsibility characteristics expected of new hires of the SFIA framework [40].

Referred to the possibility of using automatic methods for enhancing size and variety of datasets, there is one big data tool developed by Cedefop that collects millions of job advertisements from thousands of job portals. The Ovate tool [41] collects and analyse open data from online job advertisements, and links this data to ESCO skills and occupations. Thanks to the usage of big data, this tool contributes to obtain consistent results referred to the job advertisements, although it has some limitations. As example, one of the limitations this tool has, is that the scrapped job offers are only linked to the third ISCO level in ESCO, not being possible to analyse the lowest levels of occupations. However, the usage of this tool thanks to the job advertisements information linked to a reference framework, helps to obtain relevant results, being a preference to be used over the manual analysis still performed nowadays by some authors in the ICT field.

Another option is the use of the ESCO database out of the common web interface of the portal. Reconstructing and exploiting the data from ESCO database enables extra information through sophisticated queries focused on skills or on occupations, thus expressing the opinion of hundreds of experts who developed the model. The combination of the opinion of expert with data from job market from OVATE provides a much more solid basis for the analysis of ICT professional profiles than the results presented in the existing contributions in literature. Together with more precise and sophisticated analysis of correctly design surveys and questionnaires, it is possible to configure a new approach that serves as basis for the main hypothesis of this thesis.

1.3 Main hypothesis

Based on the problem description and the existing possibilities of improving the analysis activities, this doctoral thesis will focus on the following research hypothesis as main objective:

> **It is possible to improve the accuracy and the representativeness of the analysis of professional profiles (and their competences, skills, knowledge items, and attitudes) recommended for a good performance in ICT roles and occupations by modernizing the data collection methods and analysis.**

The main hypothesis is connected to three detailed research questions that help to define detailed objectives for the different research contributions in this thesis which, in the end, would help to confirm the main hypothesis stated before.

Research questions and detailed objectives

The following research questions related to the main hypothesis are posed:

1. Research Question 1 (RQ1): is it possible to conduct studies on the professional profiles and the competencies, skills, knowledge, and attitudes demanded for a good performance in the ICT roles with more precision and better data support than in the existing studies?
2. Research Question 2 (RQ2): can the analysis of professional ICT profiles be benefited from the integration of European frameworks of competencies and job classification such as ESCO and EN16234?
3. Research Question 3 (RQ3): can the relationships between professional profiles and their competences, skills, knowledge, and attitudes be explored in real context scenarios to lead to more sophisticated results such as specialised competence frameworks?

Answering the three research questions require addressing more detailed and specific objectives during the development of research activities. These objectives are the following ones:

1. Objective 1 (OBJ1): analysis of the weaknesses and the limitations of existing methods for the study of professional profiles and the competencies, skills, knowledge, and attitudes recommended for a good performance in ICT roles and occupations.
2. Objective 2 (OBJ2): exploration of the integration of widely accepted reference frameworks and models with different data sources on ICT professional roles and occupations.
3. Objective 3 (OBJ3): use of more modern and solid techniques such as large open datasets, natural language processing, taxonomies, etc. for the collection, management, and analysis of information on ICT professional profiles overcoming the limitations in effectiveness and efficiency of traditional and manual methods.
4. Objective 4 (OBJ4): a proposal for the study of professional profiles and the competences, skills, knowledges, and attitudes demanded for a good performance in the ICT roles demonstrating an improvement of accuracy and representativeness of the results.

1.4 Research publications

Three research publications have been the channel for the presentation and the independent validation of the results of the work linked to the hypothesis and research questions of this thesis. This way of presentation of research results is aligned to the option of doctoral thesis as a compendium of articles by the PhD student in publications of recognised prestige, existing in Universidad de Alcalá as expressed in art. 5 of the Regulations for the Preparation, Authorisation and Defence of Doctoral Theses of Universidad de Alcalá[1]. According to the standards of the Doctoral

[1] Reglamento de Elaboración, Autorización y Defensa de la Tesis Doctoral https://www.uah.es/export/sites/uah/es/conoce-la-uah/organizacion-y-gobierno/.galleries/Galeria-Secretaria-General/reglamento-elaboracion-autorizacion-defensa-tesis-doctoral.pdf

Program Information and Knowledge Engineering (D442) of Universidad de Alcalá[2], these publications must have been published in impact journals indexed in Journal Citation Report (JCR) index or in proceedings of international conferences in the area with relevant rank (A or higher) in relevant conference rankings like Computer Research and Education (CORE)[3]. The publications are the following ones in chronological order:

- Vera Pospelova, Inés López Baldominos, Luis Fernández Sanz. "**Big data and skills frameworks to determine recommended profiled of soft skills for is development**". *Information Systems Development: Crossing Boundaries between Development and Operations (DevOps) in Information Systems (ISD2021) 8–10 September, 2021*, Proceedings AIS eLibrary, ISBN: 978-1-908358-98-1. 2021.
    - Quality indicators:
        - CORE Conference Ranking: A (2018).
        - Citations Google Scholar: 3
        - Downloads: 96
- Vera Pospelova, Inés López-Baldominos, Luis Fernández-Sanz, Ana Castillo-Martínez, Sanjay Misra. "**User and Professional Aspects for Sustainable Computing Based on the Internet of Things in Europe".** *Sensors*. 23 (1), 529. January 2023. https://doi.org/10.3390/s23010529.
    - Quality indicators:
        - Main index: Journal Citation Reports (JCR) Science Citation Index Expanded (SCIE), CATEGORY ENGINEERING, ELECTRICAL & ELECTRONIC, position 95/276, Q2, Impact factor: 3.847 (2021).
        - Other indexes: SJR H-INDEX 196, Computer Science Information Systems Q2, Engineering Electrical and Electronic Engineering Q2. 2023.
        - Citations Web Of Science: 2
        - Citations Google Scholar: 3
        - Citations Scopus: 2
        - Citations AltMetric: 1
- Vera Pospelova, M. Teresa Villalba, Ana Castillo-Martinez, Inés López-Baldominos, Luis Fernández-Sanz, Sanjay Misra. **"Mobile application development skills set aligned with the e-CF framework and industry needs"**. *Technical Gazette (Tehnički vjesnik).* 30(4). Pages: 1326-1335. July 2023. DOI: https://doi.org/10.17559/TV-20221008125905.
    - Quality indicators:
        - Main index: Journal Citation Reports (JCR) Science Citation Index Expanded (SCIE), CATEGORY Engineering, Multidisciplinary, position 82/90, Q4, Impact factor: 0.9 (2022).
        - Other indexes. SJR H-INDEX 34, Engineering (miscellaneous) Q3. 2023.
        - Citations Web Of Science, Google Scholar and Scopus: NA

These publications are detailed in the following sections of this document.

[2] Ingeniería de la Información y del Conocimiento (D442): https://www.uah.es/es/estudios/Ingenieria-de-la-Informacion-y-del-Conocimiento-D442/
[3] http://portal.core.edu.au/conf-ranks/

1.5 Document structure

This document is organised in eight sections. Section 1 provides an overview of the context of the thesis, with a review of related literature and a description of the problem with a catalogue of existing options to improve results in research. In addition, the section states the main hypothesis and the objectives together with the corresponding research questions. Section 1 also lists the three impact publications that present the results of the research and officially considered to fulfil the requirements established in regulations of Universidad de Alcalá to accept a thesis as compendium of publications.

Section 2 presents a summary of each of the three publications clearly explaining their relation to the research questions and the main hypothesis. The publications are replicated in chronological order in the next three sections (3, 4 and 5), each of them together with an analysis of its impact as well as its main conclusions.

The sixth section discusses the results presented in each of the publications and describes their relationship with the research objectives and questions of this thesis. After that, the section 7 presents a list of the complementary results developed during the doctoral work leading to this thesis, outside the main three publications presented for the compendium. Those results include additional publications published as book chapters, communications in international conferences, participation in projects and research contracts and two research stays.

The eight and last section presents the main conclusions derived from the thesis and some proposals for the future work following the research line started with this doctoral work. Finally, this thesis includes the list of bibliographical references mentioned along the document.

2. PROPOSAL FOR THE APPLICATION OF NEW APPROACHES TO THE ANALYSIS OF DIGITAL COMPETENCIES AND PROFESSIONAL PROFILES

2.1 Introduction

The publications developed during this thesis not only present the results of the doctoral work; they also represent a logical path with steps connected to the different research questions and objectives related to the main hypothesis stated above. These steps are summarized in the Figure 1 and described in this introduction.

The first evident step was literature review for detecting the limitations of the existing contributions, especially confirming the limitations in representation, variety and accuracy of datasets and the problems with terminology and the absence of links to reference models and frameworks. At the same time, it was possible to identify a catalogue of appropriate data sources and terminology that improve the results. This step also enables the identification of other points for improvement like the design of mechanisms like surveys or the use of more sophisticated analysis of results.

The second step was to study the identified data sources limitations, as well as the information presented in the professional profiles in the ICT domain, by working on case studies for selected profiles and groups of occupations. This work focused on comparing the available and collected data with studies and checking if the quality of the results is appropriate for the research objectives and questions.

The third step insisted in the development of methods involved in the new approach of data analysis for ICT professional profiles. Different techniques were explored: big datasets analysis, natural language processing, tools for the analysis of data sources on ICT professional profiles, replication of the ESCO database to enable more sophisticated queries and analysis of the information, using the terminology of the reference frameworks, web scraping techniques, and some others. This step was very important to set-up and refine the analysis methods to link terminology and concepts to the European frameworks (EN16234 and ESCO) and to integrate tools for big datasets on job market such as OVATE. The results were presented in the first publication of the compendium of this thesis.

The fourth step was focused on testing the new approach in real context scenario of a project (focused on Smart Cities and the associated profiles, as part of the project SMACITE) and refining the analysis of the professional profiles. The approach required a careful design of all the steps and actions, focused on the information extraction and analysis to derive relevant conclusions, and guarantee the adequacy, accuracy, and representativeness of the results. The whole process enabled the validation of the underlying methodology of the proposed approach, while also helping to refine the analysis of limitations. The results were presented in the second publication of the compendium of this thesis.

The fifth and final step was the application of the proposed approach and the lessons learnt on methodology to an additional real case scenario, also linking to a project. The work was focused on the ICT occupations and roles involved in mobile application development. The main result was a specific new framework with competencies, skills, knowledges, and attitudes required for a good performance in the ICT positions in the area. All the items were linked to the reference models EN16234 and ESCO, also addressing the aspect of soft skills. This was possible because the data analysis was more sophisticated than the basic descriptive level and allowed a solid treatment of multiple variables with solid statistical foundations.

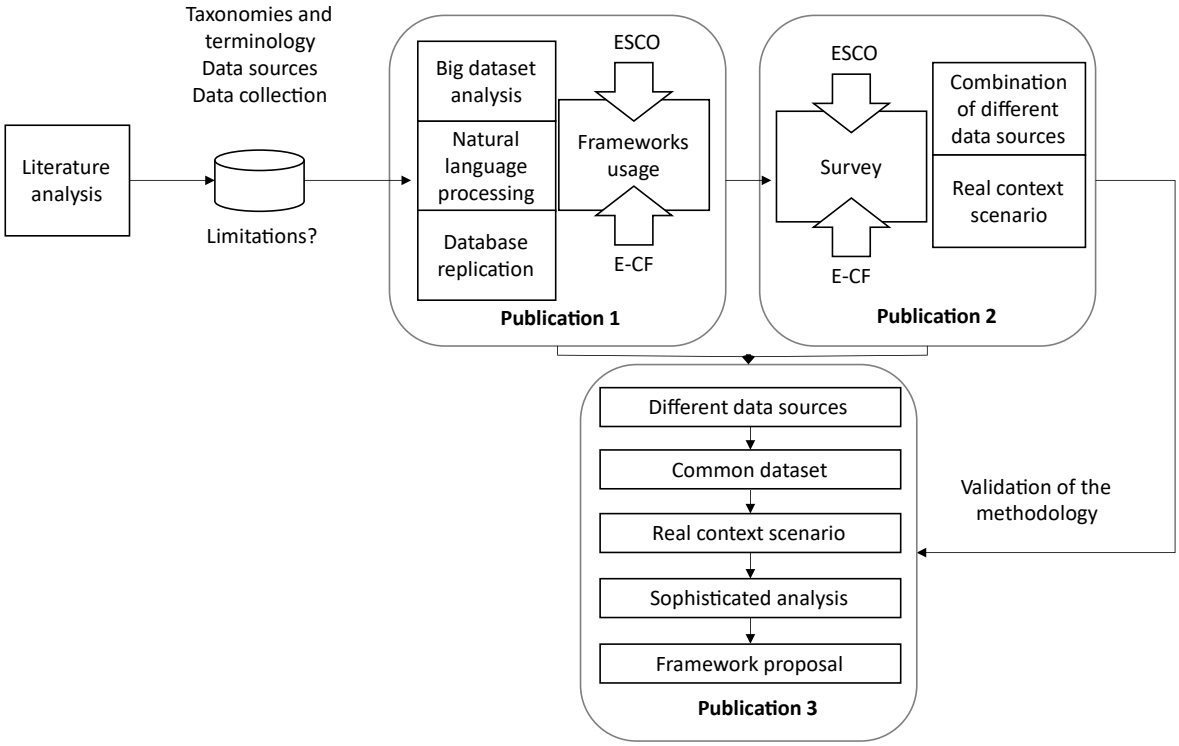

Figure 1. Relation among publications as a line of progress in research.

2.2 Relation between results in each publication and the research questions and objectives

Table 1 shows the relation between the three research questions (RQ) and the three publications that present the results of the doctoral work.

Publication	RQ1	RQ2	RQ3
Big data and skills frameworks to determine recommended profiled of soft skills for is development	X	X	X
User and Professional Aspects for Sustainable Computing Based on the Internet of Things in Europe		X	
Mobile application development skills set aligned with the e-CF framework and industry needs		X	X

Table 1. Link between research questions and publications

Table 2 shows the relation of the four research objectives (OBJ) and the three publications that present the results of the doctoral work.

Publication	OBJ1	OBJ2	OBJ3	OBJ4
Big data and skills frameworks to determine recommended profiled of soft skills for is development	X	X	X	X
User and Professional Aspects for Sustainable Computing Based on the Internet of Things in Europe		X		X
Mobile application development skills set aligned with the e-CF framework and industry needs		X	X	X

Table 2. Link between research objectives and publications

The following table shows the proposed objectives in relation to the research questions. These objectives will help to answer to the proposed research questions and the main hypothesis.

Objective	RQ 1	RQ 2	RQ 3
Analyse the weaknesses and limitations of existing methods for the study of professional profiles and the competencies, skills, knowledges, and attitudes required for a good performance in the ICT roles	X	X	
Explore the possibilities of integrating using reference frameworks different data sources on profiles and competencies, skills, knowledges, and attitudes in ICT professional roles following different techniques such as large open datasets, natural language processing, taxonomies, etc. for the collection, management, and analysis of information		X	
Present a proposal for the study of professional profiles and the competences, skills, knowledges, and attitudes demanded for a good performance in the ICT roles demonstrating an improvement of accuracy and representativeness of the obtained results			X

Table 3. Link between objectives and publications.

2.3 Summary of the three publications

Publication 1

Title	Big data and skills frameworks to determine recommended profiled of soft skills for IS development
Abstract	Information systems development (ISD) is a social activity where non-cognitive skills (NCS), frequently known as soft skills, are a key factor. Previous efforts to determine the recommended NCS for the ISD professional roles got limited results due to the use of manual procedures, absence of reference frameworks and small size of samples. This work presents a new approach which exploits existing reference models like ESCO, e-CF and NCSF (NCS Framework) as basis to analyse big datasets offered by tools like the ESCO database with thousands of relations between occupations and skills and the Ovate tool with millions of online vacancies. The combination of information from job market with the opinion of

	experts from ESCO provides a stronger basis for recommended NCS profiles for ISD professional roles, a promising option for an aspect not extensively explored.
Impact	This paper was accepted and published in the proceedings of the 29th International Conference on Information Systems Development (Valencia, Spain, September 8-10, 2021). The last CORE Conference ranking indicator for this conference published in 2018 was A.

Table 4. Summary of publication 1.

Publication 2

Title	User and Professional Aspects for Sustainable Computing Based on the Internet of Things in Europe
Abstract	The commonly accepted definition of sustainability considers the availability of relevant resources to make an activity feasible and durable while also recognizing users' support as an essential part of the social side of sustainability. IoT represents a disruption in the general scenario of computing for both users and professionals. The real expansion and integration of applications based on IoT depend on our capacity of exploring the necessary skills and professional profiles that are essential for the implementation of IoT projects, but also on the perception of relevant aspects for users, e.g., privacy, legal, IPR, and security issues. Our participation in several EU-funded projects with a focus on this area has enabled the collection of information on both sides of IoT sustainability through surveys but also by collecting data from a variety of sources. Thanks to these varied and complementary sources of information, this article will explore the user and professional aspects of the sustainability of the Internet of Things in practice.
Impact	This paper has been published in Sensors. Sensors is a peer-reviewed open-access scientific journal published by Multidisciplinary Digital Publishing Institute (MDPI), indexed in the category Engineering, Electrical & Electronic. In the Science Citation Index Expanded (SCIE) of the Journal Citation Report (JCR), the position within the category was 100/275 (Q2) with an impact factor of 3.9 (2022). In the Scimago Scientific Journal Ranking (SJR) this journal is placed in the H-INDEX 196 being the categories Computer Science Information Systems (Q2) and Engineering Electrical and Electronic Engineering (Q2). This paper was accepted in 2022 and published in January of 2023.

Table 5. Summary of publication 2.

Publication 3

Title	Mobile Application Development Skills Set Aligned with the E-Cf Framework and Industry Needs
Abstract	The number of mobile apps is continuously growing but development organisations are not sure of the good alignment of the skills of application developers with what the industry needs. A precise definition of the professional profile of the Mobile Application Developer (MAD) can help to better understand

	the needs of software development teams. This cooperation of several European organisations for analysing professional profile of MAD has led to a study of skills and competences resulting in a conceptual model with relevant characteristics: a) based on literature review, b) framed within the European standard e-Competence Framework, e-CF (EN16234) and the ESCO official labour classification and c) empirically validated with qualitative and quantitative data from many stakeholders in the field. This analysis might help to add homogeneity to talent management overcoming possible barriers for international mobility within EU as the concepts are taken from the EU reference models.
Impact	This paper has been published in Technical Gazette (Tehnički vjesnik). This is a peer-reviewed open-access scientific journal. In the Science Citation Index Expanded (SCIE) of the Journal Citation Report (JCR), it is indexed in the category Engineering, Multidisciplinary in the 82/90 (Q4) position and an impact factor of 0.9 (2022). In the Scimago Scientific Journal Ranking (SJR) this journal is placed in the H-INDEX 34 being the category Engineering (miscellaneous) (Q3). This paper was published in July of 2023.

Table 6. Summary of publication 3.

3. PUBLICATION 1: BIG DATA AND SKILLS FRAMEWORKS TO DETERMINE RECOMMENDED PROFILED OF SOFT SKILLS FOR IS DEVELOPMENT

3.1 Detailed contribution and relation to the objectives

The soft skills have become very important for employability and for professional development in general. However, there is a huge variety of proposals and contributions related to soft skills in literature studies, projects, reports, and international organisations as shown specially in the catalogue compiled by Lippman et al. [10], representing an invaluable source for analysing which are the most important and the commonest soft skills. Despite this key reference in the area, there is not a solid and commonly accepted framework that could serve as classification or taxonomy of these terms: almost all the references and models were created by consultation to experts and key stakeholders. The considerations coming from real data from labour market have been very frequently neglected or directly ignored thus losing the ability of ranking the skills by their relevance for employment and career development. This is unfortunate as defining requested soft skills and their relevance for job performance is crucial according to the study of Newton et al. [6] that shows that a high percentage of the employers are demanding more soft skills rather than technical skills, as they consider these last ones trainable.

Other initiatives in this area have emerged, with special focus on solving the absence of a reference framework focused on soft skills. This is the case of the Skills Match, an EU-funded project. This project analysed many sources of information on soft skills including 66 models, 403 publications, 527 European projects, and 5 other reference soft skills frameworks, totalling more than 2700 mentions to possible candidate skills. This analysis contributed to generate a framework of 36 soft skills, or as the consortium named them, non-cognitive skills (NCS). The mapping of those skills with ESCO items totalled 3138 at different levels (among the total set of skills of ESCO with more than 13.800 items), thus allowing the identification of groups of different soft skills across the ESCO occupations. This was possible thanks to the replication of the ESCO database to perform complex queries, not possible through the public website interface. The key point of the Skills Match project is the development of a standardised soft skills framework specifically totally linked to the ESCO classification names.

Due the importance of the soft skills in the labour market, many other authors tried to identify which of the soft skills are the most demanded for ICT profiles. The problem is that the methodology followed by these authors was very limited, merely using surveys with many limitations: inaccuracy of responses, small sample size, limited variety of geographical and stakeholder representation (normally one single country or area and one type of target respondent). In addition, most of these studies did not use a referenced framework to present their results so it is almost impossible to compare or combine results or even properly understand the used terms (e.g., skills and occupation names) as they did not have any definition or a clear one for of each of them. Given this situation, the literature analysis revealed the need of proposing a new approach to overcome the current problems in accuracy and representativeness that can be mitigated by using reference frameworks and models and bigger dataset for the data analysis from a variety of sources.

This publication is connected to the research results from the Skills Match European project [42] EU4DIGITAL – DG CONNECT [43] – LC-00822001 where the author of this thesis participated as researcher.

3.2 Full publication

Big data and skills frameworks to determine recommended profiled of soft skills for IS development

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Abstract

Information systems development (ISD) is a social activity where non-cognitive skills (NCS), frequently known as soft skills, are a key factor. Previous efforts to determine the recommended NCS for the ISD professional roles got limited results due to the use of manual procedures, absence of reference frameworks and small size of samples. This work presents a new approach which exploits existing reference models like ESCO, e-CF and NCSF (NCS Framework) as basis to analyse big datasets offered by tools like the ESCO database with thousands of relations between occupations and skills and the Ovate tool with millions of online vacancies. The combination of information from job market with the opinion of experts from ESCO provides a stronger basis for recommended NCS profiles for ISD professional roles, a promising option for an aspect not extensively explored.

Keywords: non-cognitive skills, soft skills, ESCO, e-CF, role profiles.

1. Introduction

The topic of soft skills and its relevance in information systems (IS) has attracted the attention of researchers and practitioners in recent years [16]. Current IS development (ISD) must respond to an environment where technologies are the drivers of digital transformation. This approach significantly influences business strategies, processes, products, and services by enabling new ways of working. This can only be achieved if IT professionals are equipped with technical skills but also with "non-cognitive skills" (NCS). The term NCS has been used by different authors [2], [11] to distinguish them from cognitive skills commonly measured by academic evaluation. However, other authors [6, 7], [14] prefer the term soft-skills over the one of NCS. We will use the term NCS in our research as it is the preferred term in documents of the European Commission [10].

As shown by multiple studies (e.g. [3], [13, 14]), the so-called non-cognitive skills are crucial in the success of educational performance, employability, income and professional development or career. There is a growing awareness that technical skills alone are insufficient for success in IT, particularly in today's dynamic, distributed and complex workplace [8]. At present time employers are less demanding technical skills to job candidates, because they are considering them trainable so they are prioritizing those who exhibit employability and NCS as positive attributes according to Newton et al. [17].

Albeit the evidence of the importance of NCS, researchers are finding several obstacles which hinder the progress in this field: absence of a common accepted terminology ranging from skills name to descriptions and lack of standardized or widely-accepted catalogue or model of skills. It is not strange to find many contributions both from literature (e.g. [14] compile up to 443 references) and from international reputed organisations (such as OECD, UNECO, WEF, P21, etc.) or from international projects given the relevance of the NCS. However, no solid common model has arisen from this big effort as, for example, there is very little consistency and uniformity in the existing models. Even more, many have not even explained in detail the rationale and methodology behind their development. Having a stable framework as reference and common language for NCS is a prerequisite to study the impact of these skills in professionals in IS development and operation. Such a framework would enable the analysis of information from different sources to determine the NCS profile demanded and recommended for IS profiles.

The everyday practice of ISD is very diverse as we can realise looking into ESCO, the European multilingual classification of Skills, Competences, Qualifications, and Occupations [9]. It describes, identifies, and classifies professional occupations (almost 3,000 for all sectors and around 100 for IT services). It also presents the recommended skills for them, selected from a global catalogue of more than 13,000. In the case of It profession, the European standard EN16234, known as e-CF [4], has also enabled the development of examples of role profiles for ICT professionals identifying area, competences and level of proficiency [5], a different point of view from ESCO. Other open data sources from job market (e.g. https://www.cedefop.europa.eu/en/data-visualisations/skills-online-vacancies) have shown a dynamic context characterized by fast evolution and big variety of professional profiles as well as they have confirmed the increasing demand of the IS related occupations. However, there is no clear results on the requested NCS in IS profiles neither strong agreement between the sources despite the existence of these references and the different studies mentioned in this research. Our contribution is aimed at providing a new approach to study the recommended NCS for IS profiles with stronger evidence than the previous contributions.

The structure of the paper starts with Section 2, which analyses existing contributions and summarises the findings and their limitations. Section 3 presents the different reference frameworks, which serve as basis for the analysis of NCS. Section 4 analyses a demand of NCS for IS profiles using open big data and data mining from different sources, discussing results and comparing them with conclusions from previous research works. The data for analysis is extracted from online vacancies (representing the present demand of NCS) as well as from models created by large groups of experts (representing trends and more prospective recommendations for profiles). The last Section summarizes conclusions and depicts further lines of work.

2. Traditional analysis of NCS in IS profiles

There has been little contribution from research on recommendations of NCS for ISD profiles in recent years. The existing studies clearly illustrate the strengths and weaknesses of the approaches adopted by the authors. The survey is a common method for collecting information in contributions like [12], [16] or [24]. The main problem of the survey method is the limitation in working with relevant samples and the possible inaccuracy of responses. In general, samples are limited in size and diversity of contexts: small samples such as 186 responses in [12] or 35 in [16], also combined with low responses rate such as 37.1% in [24] and data usually limited to one country. Moreover, authors of [12] and [16] do not refer to any existing framework to present the results as they create an ad-hoc classification. This is an additional weakness as there is not homogeneity in presentation of results, impeding the comparison with other studies or their use to populate a repository of comparable research results. However, one strong point is that personal experience of respondents can help to detect trends, but this is also possible by using big datasets.

Other contributions have followed another approach based on the analysis of the available from the job market. This is the case of the analysis in [20], [15] and [1]. All of them have manually analysed job advertisements to identify the most demanded NCS

related to ISD profiles with a personal classification based on authors' experience. The sample datasets are bigger than in surveys with more than 500 vacancies in each study. The results become more reliable and consistent, but the sample size remains insufficient to support relevant conclusions. Manual collection and analysis of job vacancies is time consuming and very limited to aspire to a proper coverage of reality. Moreover, the absence of a consistent framework for classification again obstructs the potential of aggregation of the different sources into a joint larger sample for a more solid analysis of data.

Our work is aimed at overcoming these limitations by adopting a new approach with two pillars: a reference framework for NCS based on accepted labour classifications like ESCO [9] and the exploitation of large datasets created by different initiatives of the European Union (EU). Our analysis will exploit the analysis of huge samples of job vacancies (millions of data, not a few hundreds) and the opinion of large numbers of experts devoting long dedication (hundreds during years).

3. Reference frameworks for analysis of NCS in IS development and operations

During the past decade EU has promoted several competence frameworks which could be applied to ICT profiles to enable a better coordination of the analysis of the job market. ESCO is a classification of occupations and their recommended profile of skills and knowledge. It uses a hierarchy of relationships between them as well as metadata and mappings to the International Standard Classification of Occupations (ISCO) to structure the occupations. Although they consider NCS in a way or another, they do not offer a specific framework structure by themselves. So, we will complement them with the NCS framework (NCSF) from the Skills Match project [19], which maps skills to the ESCO Classification and was developed after an exhaustive analysis of sources on NCS.

3.1. ESCO

ESCO is the European classification of skills and occupations. The aim of ESCO is to support job mobility across Europe and therefore a more integrated and efficient labour market, by offering a "common language" on occupations and skills that can be used by different stakeholders on employment and education and training topics. It provides descriptions for 2942 occupations and 13.485 skills linked to these occupations, translated into 27 languages. ESCO groups the occupations into ISCO-08 code groups with 4 digits classifying the different occupational profiles and showing the relationships between occupations, skills, competences. The ESCO classification was created in a process longer than 4 years by more than 200 experts from all the productive sectors, reviewed and refined by main stakeholders from education and training to labour market and authorities. According to implementation acts, the use of ESCO is compulsory for all Member States of EU from 2021 onwards.

3.2. Skills Match Framework

Skills Match was a project funded by European Commission (DG CONNECT) which developed and demonstrated a European-wide assessment and learning and guiding platform to help users to adapt their NCS to the demands of the labour market. The Skills Match project created a comprehensive and solid NCSF as the basis for its work [19]. The team analysed information from academic literature, reviewing 66 models and 403 publications with 2928 mentions to skills as well as 527 European Projects and other NCS existing frameworks and referenced models as OECD [18], P21 [21], UNESCO [22], WEF [23], among others. Skills Match uses ESCO as main reference and its 36 NCS of NCSF are mapped to ESCO skills generating 3138 connections at different levels. More than 700 buzzwords associated to each of the 36 NCS complement the description and help to identify mentions to NCS in other models and references. The visualization of the framework shows seven clusters for its 36 NCS, which group those ones most related among them (see Fig. 1).

Fig. 1. NCSF

4. New approach for analysis of NCS in IS professional profiles

Our approach for the analysis of IS profiles covers two points of view: job market and opinion of experts. The market perspective extracts data from the analysis of job ads giving us a vision of recruiters who demand NCS to candidates. The expert perspective integrates their recommendation of NCS for each profile. Both visions can be combined to check differences and get stronger evidence of common elements. Although traditional analysis already used these two options, we have opted to dramatically increase the volume of information by exploiting open big data for the Skills-Ovate developed by CEDEFOP an agency of EU. Ovate extracts detailed information mapped to ESCO through natural language processing and machine learning on jobs and skills that employers demand in online job vacancies. This tool has collected data from July 2018 to September 2020 (and keep doing it) totalling more than 105 million of vacancies from thousands of sources (private job portals, public employment service portals, recruitment agencies, online newspapers, and employer websites) when writing this paper.

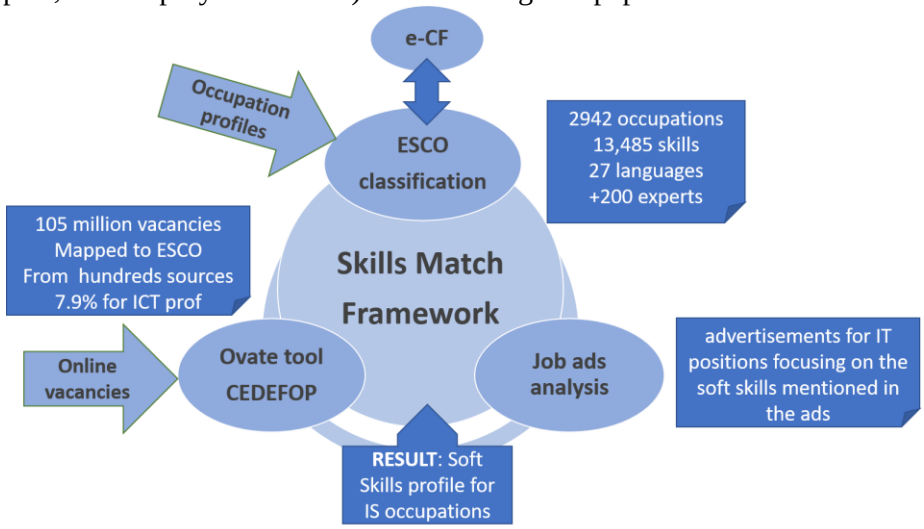

Fig. 2. Diagram for NCS demand analysis.

Fig. 2 shows our approach, which combines the sources of information with NCSF as central reference. The analysis in ESCO was possible because the authors created a local replica of ESCO database through the data downloading functions offered by the ESCO portal. It also shows a link to the standard EN16234-1 (e-CF) on IT professional e-

competences [4].

As an example of the potential of this approach, we have worked with the mentioned data sources for occupations of groups Software developers (subgroup 2512) and Systems analysts (subgroup 2511). These occupation roles were also manually analysed in [1] and [15]. Due to space reasons, we do not show results for other IS groups (e.g., 13 Technical managers and 35 ICT Technicians). In 2020, OVATE processed data for group of occupations 251 (Software and applications developers and analysts: 18 specialised occupations) included 2,804,416 OJA (Online Job Advertisements) in 27 European countries, 6.2% of OJA in all sectors. There is a clear difference with the 500 vacancies in [1] (which only detected 9 NCS), with 534 in [20] and with the 679 in [19] (which detected 17 NCS), all of them heterogeneous without reference to a NCS model. Thanks to the connection of ESCO to the NCSF, we can determine which the most mentioned NCS in OJA are along 2020, capturing big trends by recruiters and employers.

However, that one is not the only source of information with big amount of data. As commented, the ESCO database concentrates the work of hundreds of experts in linking almost 3,000 occupations to more than 13,000 skills and knowledge items with more than 114.000 relations. There are more than 100 occupations in the ICT services sector and, obviously, ESCO has recommended skills profiles for them. If we analyse the group 2511, there are 111 relations between NCS and the 18 occupations of the group while group 2512 has 18 relations for four occupations. We can compare this number of data with the 35 interviews of the study in [16], again with no reference to any NCS model. Table 1 shows the combined results of the NCS mentioned in job ads (as percentage of total ads where the NCS is mentioned) and recommended by ESCO experts for group 2511 and 2512 (percentage of occupations in the group which recommend the NCS).

Table 1. NCS recommended by ESCO experts and mentioned in OVATE's OJA for groups 2511 and 2512

	ESCO		OVATE			ESCO		OVATE	
NCS Name	**2511**	**2512**	**2511**	**2512**	**NCS Name**	**2511**	**2512**	**2511**	**2512**
accountability			4,0%	4,7%	motivate others	44,4%	50,0%	3,9%	0,9%
adaptability	16,7%	25,0%	3,7%	4,0%	networking	5,6%			
coaching	38,9%	50,0%	4,2%	8,0%	organisation			7,5%	8,5%
communication	72,2%	75,0%	19,8%	18,2%	personal development	27,8%	50,0%	1,6%	0,5%
conflict resolution	5,6%				problem-solving	50,0%	50,0%	8,9%	10,2%
critical thinking	22,2%		4,9%	1,0%	reliability	5,6%	25,0%	3,9%	3,8%
customer focus	55,6%	25,0%	1,6%		respect the environment	5,6%			
diligence			0,2%	4,5%	self-management	22,2%			
leadership	16,7%	25,0%	10,9%	16,3%	strategic thinking	5,6%		0,4%	
manage quality	44,4%		6,7%	1,4%	teamwork			14,0%	15,6%

5. Conclusions

Our approach shows how exploiting existing tools and sources with big volume of data (millions of vacancies in Ovate and thousands of relations between skills and occupations in ESCO) combining the expert view from ESCO and the market facts from OVATE provides solid results to the identification of recommended NCS for IS occupations. This approach is possible because there is a solid framework like NCSF linked to the ESCO classification. There is a big difference in using tens or hundreds of data in one single country in traditional manual studies to hundreds of thousands of records in Ovate or thousands of relations between skills and occupations in ESCO. We think that the exploitation of this amount of data with our approach provides more solid conclusions to the analysis of professional profiles in ISD. We have shown an example of the potential of analysis of NCS for specific IS profiles.

Adding the e-Competence Framework (e-CF) [4] with already 30 sample profiles based on e-CF competences [6] could strength our approach as it also represents a connection to

a standard adopted by big companies like Tata Steel, Airbus, Poste Italiane, etc. As ESCO and e-CF are also especially addressing technical skills and knowledge, it is also possible to work with them. However, we would need a previous non-trivial phase for correctly cataloguing specific skills within other more general concepts like competences in e-CF.

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3.3 Summary of the results of Publication 1

This contribution proposes a new approach to the research area of ICT professional profiles based on the usage of reference framework and bigger and varied samples of data. The results presented in the publication are focused on the soft skills classification, linked to the Non-Cognitive Skills Framework (NCSF) developed by the Skills Match Project Consortium [42] [44, p. 2]. The most relevant aspects of this framework in comparison to other previous soft skills models are:

- Transparent and comprehensive process of development, showing its solid foundations compared to most of the other models with total absence of explanation of their basis.
- Totally mapped to the ESCO classification so the sources of information from all EU countries (from 2021, onglide to refer to ESCO as reference for labour market) can be exploited for collecting more representative and larger datasets.
- Complete definition of each of the soft skills, not only with a description but also with a set of representative buzzwords linked to each of them, with a total of more than 770 terms with 21 words for each skill. These terms represent a useful guide for identifying the presence of a skill in descriptions and document, either in manual analysis or by automatic language processing.

Thanks to the mapping to ESCO, it was possible to extract the list of ESCO occupation where each soft skills is recommended in the professional profile. Furthermore, thanks to the OVATE tool, which compiles the information expressed in millions of online job ads, with results also linked to ESCO, it is possible to know which are the groups of occupations demanding each soft skill and which soft skills are the most demanded for the employers for the ICT occupations. This is the reason why the NCSF is considered a very important and referenced framework in this area.

The approach presented in this publication has been focused on two different points of view of available data, combining them together: job market as expressed in job ads on one hand and the opinion of experts as expressed in the ESCO recommended profiles in the other hand. This variety of perspectives enable more solid results than the approaches in previous literature thus confirming the improvement in representation and accuracy of the conclusions.

4. PUBLICATION 2: USER AND PROFESSIONAL ASPECTS FOR SUSTAINABLE COMPUTING BASED ON THE INTERNET OF THINGS IN EUROPE

4.1 Detailed contribution and relation to the objectives

This publication presents the results of the analysis of different data sources in the field of Internet of Things (IoT) and Smart Cities. In this case, data come from two European Projects and helped to acquire a European level vision in the area. This publication is connected to the activities developed in the work package 2 of the SMACITE European Project [45], EACEA – 101052513.

The new approach depicted in publication 1 is now applied to a real case scenario: sustainability in Smart Cities projects in terms of qualification of professional profiles involved in them, especially in the area of IoT, which is key in those projects. The focus was on the qualification profile of the Smart Cities technicians and engineers. The study combined data from two surveys: the first one was designed for IoT project proposal finally not funded, while the second survey was directly designed for the SMACITE project. The design of the surveys was aligned to ESCO, using the individual items connected to the area and enable a direct connection of results with ESCO and e-CF terms. Thanks to this link, other researchers in the field, thus benefiting stakeholders who use to work with both frameworks to analyse ICT profiles, can expand the dataset.

The first survey helped to analyse the most influential factors in IoT implementation from the point of view of non-technical professionals. Results confirmed the concerns of different non-technical stakeholders regarding IoT implementation, such as privacy and security, already identified by other studies referenced in the publication.

The second survey collected the opinion of different experts in the Smart Cities area to determine the skills and knowledge recommended for the profiles of Smart Cities technicians and engineers. The design of the survey was fully based in and linked to ESCO and e-CF (EN16234); in fact, survey statements were directly the result of the text extraction previously performed on both frameworks.

This publication shows the combination of a survey analysis method and the extensive use of the references of ESCO and e-CF, leading to more consistent results and increasing understandability of questions and results.

4.2 Full publication

sensors

MDPI

Article

User and Professional Aspects for Sustainable Computing Based on the Internet of Things in Europe

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Abstract: The commonly accepted definition of sustainability considers the availability of relevant resources to make an activity feasible and durable while also recognizing users' support as an essential part of the social side of sustainability. IoT represents a disruption in the general scenario of computing for both users and professionals. The real expansion and integration of applications based on IoT depend on our capacity of exploring the necessary skills and professional profiles that are essential for the implementation of IoT projects, but also on the perception of relevant aspects for users, e.g., privacy, legal, IPR, and security issues. Our participation in several EU-funded projects with a focus on this area has enabled the collection of information on both sides of IoT sustainability through surveys but also by collecting data from a variety of sources. Thanks to these varied and complementary sources of information, this article will explore the user and professional aspects of the sustainability of the Internet of Things in practice.

Keywords: IoT; implementation; human factors; Europe; survey

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1. Introduction

Sustainability is a paradigm for thinking about a future in which environmental, societal, and economic considerations are balanced in the pursuit of an improved quality of life: "meeting the needs of the present without compromising the ability of future generations to meet their own needs" [1,2]. Sustainable development is a core principle of the European Union and a priority objective for the Union's internal and external policies [3]. The objectives of the EU are aligned with the ones of the United Nations expressed in the set of 17 sustainable development goals [4]. The Internet of Things (IoT), understood as "a network of things, with clear element identification, embedded with software intelligence, sensors, and ubiquitous connectivity to the Internet" [5] has been identified as a contributor to sustainability in general, but more specifically to some of the SDGs: e.g., SDG 11 for sustainable cities [6,7] or SGD 7 for clean energy [8,9]. Sometimes, the contribution of IoT to the goal of saving energy is seen as controversial as it generates large amounts of data to be processed and the corresponding energy consumption (which could always be optimized [10]) but the abundance of data also contributes to other sustainability goals such as one of sustainable cities. Undoubtedly, these debates on the balance of sustainable computing with IoT are linked to the general idea of Green IT that emerged many years ago [11]. However, our focus is on the contribution of IoT as an enabler of disruptive innovations that promote safe, secure, and environmentally friendly lives to people, trying to find additional empirical insights on how the true impacts of IoT on sustainability can be ensured through a successful implementation [12]. As some research works have highlighted the importance of IoT with smart cities (SCs) [13–16], we will focus a good part of our work on the study of IoT in the context of SC projects.

The studies mentioned above show the potential contribution of IoT to sustainability, but its successful implementation may be hindered by different factors. Sometimes, the pressure of the market for the adoption of IoT technologies poses serious challenges for the involved organizations. For example, computing projects for innovation and sustainable growth, especially in SMEs, are highly dependent on having educated human resources to effectively address the specific internal and external activities through the IoT [17]. These challenges require constant technological and managerial support and improvement of contextual conditions for projects. While information security and privacy are rather apparent points of concern [18], there are many more IoT-specific factors that need to be addressed for the successful implementation and actual generation of value. The analysis of the factors that are essential for success in IoT projects, environments, and initiatives is a prolific area in the literature. The related work has tried to formalize the impact of factors in IoT projects in the shape of maturity models [19]. These models have been found effective for, firstly, the assessment and, secondly, the improvement in this process by breaking it down into highly detailed steps [20]. These models help to analyze or even predict the success of initiatives by assessing the possible set of all or the most relevant influential factors. They also guide the efforts of organizations to reach the best conditions for success in IoT initiatives.

The number of maturity frameworks related to the different possible contexts of projects linked to IoT is high in the existing literature, frequently linked to the concept of Industry 4.0 [21]. As we want to explore both the side of users and that of professionals within solution providers, we will focus on the B2C context. The work by Klisenko and Serral [20] has analyzed 16 different models applicable to readiness for IoT in B2C, although considering different aspects of the area. As a result of the compilation and analysis of those models, two main human factors are identified, apart from other technical and organizational factors:

- The connection with customers for IoT adoption considering their attitude and fears toward this technology is also complemented by the culture of users: employees that will apply IoT solutions in their daily work. This aspect has been also identified, sometimes embedded in the culture of the organization, in additional studies such as [22–24];
- The capabilities of the IoT implementation support team, as this is an essential resource for success, are also identified in specific projects [22,25].

Another research work conducted by Brandstetter [26] demonstrated how new business models can be successfully implemented thanks to a transnational approach, which leads to close cooperation between different partners. Furthermore, a high number of EU projects are carried out transnationally to fulfill one of the European pillars: inclusiveness and cooperation [27].

This research is aimed at studying the two above-mentioned main human factors for IoT success: a) the attitude and culture of customers and users toward this technology and b) the qualification profile of the professional support team. Therefore, this study worked with two different surveys: the first one measures the impact of IoT on users and their attitude toward IoT projects and solutions, while the second one explores the recommended professional profile for a successful implementation of IoT in one specific context: smart cities (SCs) projects. Although restricting the IoT context to SCs would represent a relevant limitation, the process of this study has included additional sources of information to determine whether the results are applicable to most contexts where IoT is implemented. In the end, this second part of the research will explore the experts' opinions to study the influence of new professional profiles on existing frameworks and models of project work.

This article is structured as follows: Section 2 presents the research questions of our study and the methodology for answering them, briefly defining the motivation and goals of the two surveys developed for the study. Section 3 presents and discusses the results of the survey on the impact factors for the implementation of IoT solutions according to users'

perceptions. Section 4 describes and discusses the results of the recommended profiles for a successful IoT implementation. Section 5 proposes conclusions and future research lines.

2. Methodology

The process starts with the following research questions as an expression of our research goals:

- RQ1: what are the key factors perceived by users and customers in Europe, within their scope of action, for effective IoT deployment?
- RQ2: which is the most recommended qualification profile for ICT professionals in Europe for an effective IoT implementation?

Our main method for answering RQ1 was the development of a specific survey on the factors that influence the success of the implementation of IoT solutions from the point of view of users and customers, also analyzing the possible implications for their professional or business activity. The answer to RQ2 required the exploitation of another survey, this time within the frame of an EU-funded project on SCs that explores the recommended professional profiles for the projects in this area. IoT plays a very relevant role in SC projects, so we analyzed the specific questions on the qualification of the technical team in this part of IoT. Both surveys are complementary and enabled the coverage of the two human-related factors identified in our analysis in Section 1. The next subsections will describe the design of both surveys.

2.1. Survey on Factors That Influence IoT Implementation from the Point of View of Non-Technical Professionals

IoT is bringing relevant and even disrupting transformations to very different productive and professional areas. Different works have confirmed the power of IoT for the transformation of business models and organizational models [28,29]. The impact of IoT not only reaches the professional and business side: several authors [30,31] have analyzed the impacts of IoT as a social transformer. Others [32] consider this topic as one with the highest priority. As a social transformer, IoT is frequently conditioned by legislation, which may differ from one country to another, so studies must adopt the multinational approach to be effective while analyzing both the effects in business and in society.

Losavio et al. [33] analyze data management laws protecting the rights of people in terms of privacy and security as well as the rights of personality and personal autonomy in different nations, relating IoT aspects to SC projects. The analysis shows how we need clear legislation on what can and cannot be done, balancing public security with individual freedoms across different countries. Not only is the evident case of legislation dependent on the country where IoT acts: research conducted by Zallio [34] collected information of users as feedback comments to increase the usability of IoT devices. The results demonstrated the importance of IoT-based devices in daily activities and relevant variations depending on the countries, cultures, and personalities of individuals. All these findings suggest that the analysis of the user side in IoT implementations should cover different countries (in our case, in the European Union) and should also explicitly inquire on the possible commonalities and differences among countries.

In general, transformations linked to solutions based on IoT tend to encourage social concerns and worries about safety and rights. Several works [16,17,20] have analyzed the challenges of privacy and security produced by IoT and proposed approaches to mitigate some of these fears that influence user' and customer behaviors. Other authors have studied the users' concerns regarding data privacy and security when they decide to purchase IoT solutions [22]: these worries impacted almost all the users surveyed. Therefore, we explicitly included a question on these aspects in our survey.

Regarding the educational approach, a research [35] analyzes the impact of IoT in different educational approaches. The study shows the effectiveness of establishing IoT-based learning frameworks, generating new paradigms of learning. Despite its importance, the study also determines several challenges for the inclusion of IoT in the curricula

and highlights the importance of training all types of professionals, not only the ICT professionals. In fact, various studies have identified the impact of IoT on changes and challenges in the qualification of non-ICT professionals [36,37]. This is the reason why we also explore this aspect in our survey.

Motivated by the goal of exploring the above-mentioned aspects detected in previous studies, we surveyed to examine the impact of IoT on users and other relevant stakeholders involved in the implementation of solutions. We avoided addressing people with IT backgrounds, as the objective was the perception of those without specialization in IT. One additional goal was determining the need for training to help these people to adapt their business models and their daily work to a new context with IoT, while also examining the general social impact. This survey was designed to explore the best approach for engaging, training, or re-skilling all types of non-technical professionals to be prepared for a forthcoming massive implementation of IoT in their activity sectors and all aspects of life.

Design of the Survey

The first part of the survey was designed to identify the profile of the respondent. Age, years of working experience, and familiarity with IoT helps to identify the confidence of the user in the topic, while the sector and size of the working organization will allow for measuring the challenges of IoT for the organizations. The age of the respondents was measured in a group of 5 years starting from 25 until 64 years old, being less than 25 or more than 64 in a different group. The years of working experience, however, were measured in groups of 10. Regarding the familiarity with IoT topic, four possible options were presented, as none, basic, advanced, or professional experience. We also added the country to control the geographical variety of the sample. Free space for comments was also provided to the user to gather other relevant opinions (e.g., about the survey).

The objective of the next section of the survey was the exploration of the relevant impact factors in practical IoT implementation from the perspective of non-technical professionals. It was implemented as statements linked to the different areas above-mentioned in the previous section:

- Business models, marketing, and customer service: the transformation of business processes and new business models;
- Security, data privacy and protection, and IPR: the types, amount, and specificity of data gathered by billions of devices create concerns among individuals about their privacy and among organizations about the confidentiality and integrity of their data;
- Employment and qualifications: IoT would imply the need for upskilling and reskilling non-ICT professionals after a careful analysis of profiles and the requested hard and soft skills;
- Social and environmental aspects: IoT opens an opportunity to decrease the environmental impact of activities by avoiding physical presence and trips, reducing carbon footprint, and fostering more social balance.

The participants were asked to mark their level of agreement with 8 statements linked to the mentioned factors, expressed in a 5-level Likert scale: totally disagree, disagree, neither agree nor disagree, agree, totally agree.

- (S1) The adaptation to the impact and changes which IoT may bring to people, society, and businesses deserve the highest priority in all European countries;
- (S2) The impact and the implementation of IoT may differ from one to another country due to specific market conditions, legislation, etc.;
- (S3) Study and training of the adaptation to the impact of IoT recommend an international perspective for addressing different national views;
- (S4) Training all types of professionals in IoT literacy is essential for a successful and beneficial implementation of IoT in all sectors.

For a successful and beneficial implementation of IoT, the information and training on its changes and challenges are very important:

- (S5) In business models and market competition;
- (S6) In employment, occupation profiles, skills, and qualifications;
- (S7) In privacy, security, and legal consequences;
- (S8) In social aspects and transformations.

2.2. Survey on the Qualification of the Technical Team for the Successful Implementation of IoT

As detected in previous research on the SCs sector [38], with an intensive presence of IoT solutions, there is a deficit in the analysis and development of qualification profiles for the technical team responsible for solution implementations. In fact, the study of the SmartDevops project [38] finally determined three initial job profiles ("smart city planner", "smart city IT manager", and "smart city IT officer") but mainly focused on the contribution of DevOps to the SC projects. Given the wide set of contexts where IoT implementation may happen, we have also exploited the SMACITE EU-funded project, also focused on SCs, [39] to more deeply explore what technical professionals need in terms of qualification referred to the implementation of IoT and in other complementary aspects such as security, data management, etc. The project reviewed the main educational references on SCs (degrees, masters, and non-official postgraduate programs) as well as five case studies provided by partners from Spain, Bulgaria, Belgium, and Greece. This information helped to detect the consideration of different groups of skills and knowledge that are vital for a qualified technical workforce for SC implementation. Thanks to this analysis, it was possible to identify different technical categories. Some of these categories (such as enabling technologies, management, and business, or green and soft skills) were similar to the ones determined by the above-mentioned research in contexts where IoT plays a prominent role. We exploited this context of SCs for IoT implementation to explore, with a survey, the most recommended qualification profile for ICT professionals in Europe for an effective IoT implementation (RQ2).

2.2.1. Survey on Qualification Profile for Professionals Who Implement IoT Solutions

As part of the SMACITE project [39], we designed a survey to collect the opinion of a broad base of stakeholders to determine the recommended skills and knowledge profile for ICT professionals working in the context of SC projects, both at the engineer and technician level. Our interest was determining the recommended qualification profile for ICT professionals, mapping it to the two most relevant frameworks for technical occupations and job roles: ESCO [40], which is the European multilingual classification of skills, competences, qualifications, and occupations, and EN16234 [41], the European standard on e-competences for ICT professionals. The nature of e-CF is different from the one of ESCO:

- The normative part of EN16234 is focused on the description of the 41 e-competences in terms of the main functions and activities developed in each one;
- It also includes descriptions of levels of proficiency and examples of skills and knowledge items, but they are only illustrative.

Our analysis focused on the requirements of qualification in the field of IoT and other key aspects such as privacy, legal, IPR, security issues and data analytics, and machine learning. The survey was designed, as usual, with a first general part for collecting the basic profile of the respondent (country, age, years of experience, etc.). Then, follows a set of statements on functions and responsibilities in SC at the engineer and technician level plus a set of questions on the relevance of categories identified in previous research on technical skills (enabling technologies, management and business, green and soft skills). The next section of the survey also explored the recommended skills and knowledge items, taken from ESCO, for smart city technicians and engineers: their descriptions were presented as a compilation of the most relevant existing in the skills pillar of the classification connected to each category, to each enabling technology, or to similar occupations. The final shape of the statements was reviewed and selected by a focus group of seven experts from the partners participating in the project.

The last section focused on the recommended soft skills (non-technical skills) as they are very linked to success in effectiveness, professional performance and career [42,43]: this is confirmed by employers as they consider that soft skills are less trainable than technical skills, while the performance of a hard skill is often dependent upon soft-skill capacity [44]. As there is no widely accepted model of soft skills, we adopted one of the Skills Match projects [45,46] with a framework of 36 soft skills, also directly matched to ESCO [40].

3. Analysis of Results and Discussion on Users' Perception of Factors for IoT Implementation

As commented in Section 2.1, the survey on users' perception of IoT implementation was aimed at answering RQ1. The participation was targeted at non-technical professionals, especially those in SMEs, as these types of organizations have fewer resources to adapt their business models and daily activities to new paradigms. The survey was also addressed to those involved in the education and training of future professionals in non-IT fields.

3.1. Sample

Most of the 48 respondents to the survey were from European countries and other associated countries. The rate of participation was 37.5%, as there was finally a total of 128 clicks on the link. The participants who answered this survey were in majority from Ireland and Spain, followed by eastern countries such as Latvia and Bulgaria. The age of the participants was diverse and balanced: the highest proportion of age was 25–29 (17.6%), followed by 35–39 (15.7%), and 45–49 (13.7%). Regarding the years of working experience, respondents in the range of 1–9 years (33.3%) had the highest percentage, followed by those in the range of 20–29 (23.5%).

The working sector of the participants was diverse (up to 12 different ones), although the most frequent was IT (but respondents were not ICT professionals, only non-technical employees and managers) with 29% of responses and the second one was the education sector (25%). Other sectors such as marketing, engineering, management, etc., completed the sample, all under 9%. Regarding the size of the organization, most of the participants were working for SMEs (33%) with less than 250 employees, micro-SMEs (21%) with less than 10, and public education (21%). The rest of the participants worked for medium and big companies and the public sector of government.

Participants in the survey also self-rated their familiarity with IoT. Most of the users declared to have only basic concepts (54%), while one-third of them claimed to have advanced knowledge (31%). Only 11% had some professional experience in the area, while 6% had neither experience nor knowledge.

3.2. Analysis of Survey Results

This section presents the results expressed as respondents' agreement level for the statements S1–S8 presented in Section 2.1. The end of this section contains a chart summarizing the results. Respondents showed the following levels of agreement (see Figure 1):

- S1—IoT impact and changes in people, society, and businesses: most of the respondents agree (51%), while 31.4% totally agree, and 11.8% neither agree nor disagree;
- S2—Differences among countries in conditions for IoT implementation: 56.9% agreed and 33.3% showed total agreement, while the other available options were below 6%;
- S3—Transnational approach when analyzing IoT implementation: almost half of the respondents totally agree (49%) and another 45.1% also agree;
- S4—Training of all types of professionals in IoT literacy is essential: again, half of the respondents totally agree (49%), another 43.1% agree, and only 3.9% disagree;
- S5—IoT changes and challenges in business models and market competition: 39.2% totally agree and 47.1% agree but only 3.9% disagree;
- S6—IoT impact on employment, occupation profiles, skills, and qualifications: 47.1% totally agree and 43.1% agree. Neither agree nor disagree represented 9.8% of respondents;

- S7—IoT impact on privacy, security, and legal consequences: total agreement 47.1%, agreement 39.2%, and the rest of the options represented less than 6%;
- S8—IoT impact in social aspects: total agreement reached 51%, agreement 35.3%, while the option of neither agree nor disagree obtained 11.8%.

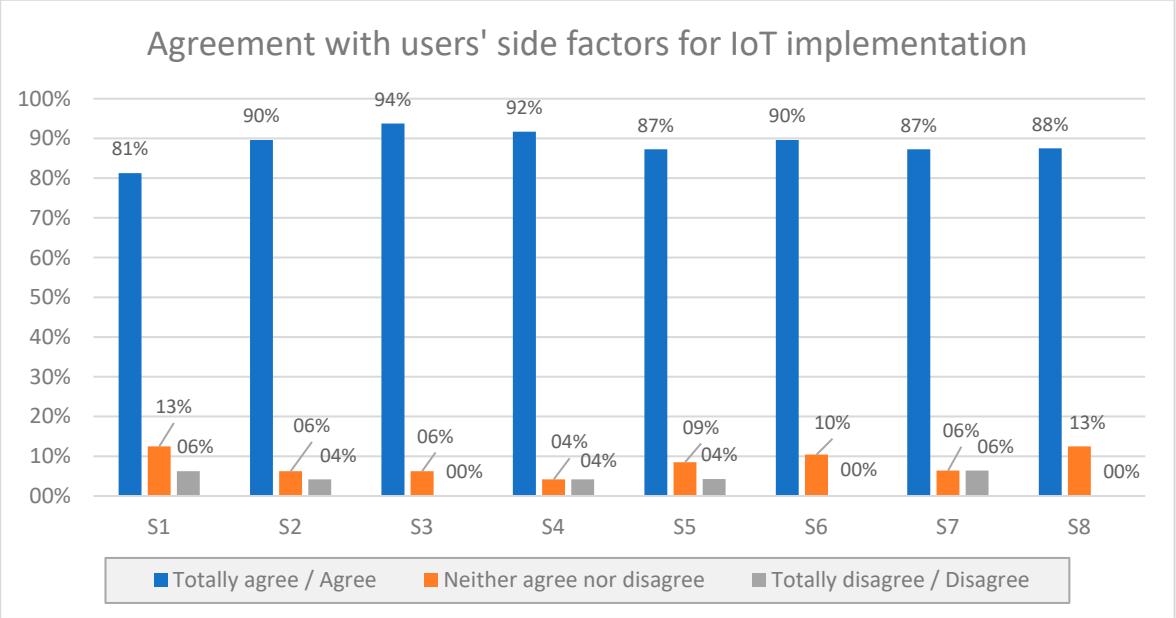

Figure 1. Summary of agreement of users with statements on impact factors for IoT success.

The free space left for comments in the survey only attracted three comments without relevance to the analysis.

The first conclusion is the high level of agreement of participants to the statements, something that surprised us. This means that our study confirms the findings from the preliminary review of the literature, although logically there are evident limitations in the size and the composition of the sample. There are no relevant and meaningful differences in percentages of agreement or total agreement when segmented by country, age, or experience. However, the size/type of organization shows some differences regarding the average percentage of agreement in the eight questions: micro-SMEs and education organizations are less convinced than the rest, while medium-size (although with a small sample) organizations show the highest values. In contrast, there are no relevant differences in the opinion of participants regarding the self-declared level of familiarity with IoT: only those with some professional experience with IoT (again, a small sample) show a slightly lower level of agreement.

However, the results suggest that the sample of EU non-technical professionals confirms that their adaptation to changes caused by IoT is key to success. It is also essential to their awareness of possible differences among countries due to non-homogeneous conditions or legislation in the different national contexts. In general, they also agree on the importance of training in two aspects: (1) adaptation to new contexts created by IoT implementation and (2) acquisition of basic IoT literacy skills. According to the results, the support should also be complemented with information and specific training in (a) changes and adaptation of business models, (b) occupation profiles, skills, and qualifications, (c) challenges in privacy, security, and legal consequences, and (d) changes and challenges in social aspects such as environmental effects and inclusion.

The survey has enabled a detailed answer to RQ1, generating a list of more specific points than the mere general description of the human factor described as "connection with customers for IoT adoption considering their culture and their attitude and fears towards this technology" mentioned by the literature (See Section 1). These details may help to

adopt more effective actions for a successful and more sustainable implementation of IoT in the future.

4. Analysis of Results and Discussion on Recommended Profiles of the Technical Team for Successful IoT Implementation

As commented in Section 2.2, the second survey focused on the qualification of the technical team for IoT as part of the SMACITE project [39] and it provides information to answer RQ2. The participation in the survey was targeted to three different categories of stakeholders linked to SC projects: (a) the customer side, with municipal authorities, managers, and technicians, (b) the provider side, with managers and professionals from solution development companies, and (c) the user side, with representatives of citizens' associations and independent experts. Although disseminated across Europe in English, some partners of the project translated it into local languages to facilitate participation in their countries: Spain, Italy, and Greece.

4.1. Sample

Project partners disseminated the online survey through different networks, specifically targeting contacts belonging to any of the categories of stakeholders. The rate of participation was 34%, as there finally were 134 contributions from a total of 394 clicks on the link.

The first section of the survey collected the basic profile of the country and gender from each of the contributors. The nationality of the respondents was diverse, with 11 European countries identified. The highest number of contributions came from Spain (34.07%), Greece (16.30%), Bulgaria (27.41%), and Italy (13.33%). Gender representation was unbalanced: 71.1% male, 26.6% female, and 2.2% preferred not to say their gender.

The stakeholder category included three main options with different sub-options as job roles: public sector and authorities (client side), business sector and providers (supply side), and civil society (user side). The sample contained 18.52% of participants from the group of public sector and authorities, 54.81% from solution providers, and 26.67% from civil society, user representation, and independent experts. Table 1 shows the distribution among roles of the three categories, showing the variety of roles (except for the case of "Municipal city planner or urbanism expert" without representation).

Table 1. Distribution among roles of different categories.

Main Sector (in Bold) and Subsectors	%
Public sector and authorities (client side)	**18.52%**
Policy authority or decision maker	5.19%
Municipal city planner or urbanism expert	0%
Municipal technical manager	3.70%
Municipal technician	1.48%
Other	8.15%
Business sector and providers (supply side)	**54.81%**
Business manager in IT solutions provider	20%
ICT project manager in solutions provider	14.81%
ICT engineer in solutions provider	9.63%
ICT technician in solutions provider	2.96%
Other	7.41%
Civil society (user side)	**26.67%**
Expert in smart cities (academia, research, education, etc.: out-of-solution providers)	13.33%
Representative of citizens' association	2.96%
Sociologists or similar specialists in urban life	1.48%
Other	8.89

The years of professional experience are also important for analyzing the results: the answer options appeared in groups of five, with options for less than five years, steps of

five between 5 and 20, and more than 20. The contributors mostly concentrated in more than 20 years (48.15%) and less than 5 years (15.56%), while all the rest of the options were under 11.11%. However, the general experience is not the only factor that may have an impact on opinions. We also requested participants to self-declare their familiarity with SC concepts and solutions on a scale with five options. The distribution of the sample was: none (5.19%), basic knowledge (30.37%), application of concepts out of professional practice (25.19%), professional experience in the area (28.15%), and highly qualified and experienced in the area (11.11%).

4.2. Analysis of Results on Qualification of the Technical Team

The main section of the survey collected the opinion of the participants on the set of functions, skills, and knowledge based on ESCO and e-CF [41] determined by our preliminary analysis (see Section 2.2.1). Participants were asked to rate each item according to their understanding of the relevance for recommending it for the qualification profile, for both engineer and technician roles. The questions adopted a 5-option Likert scale (essential, relevant, useful, marginal, worthless) plus a "not sure" option. The design of the description for each item was concise and synthetic, thus avoiding excessive time and effort: a focus group with experts from project partners generated descriptive phrases as a compilation of items inspired and extracted from specific ESCO occupations, selecting the ones with the highest conceptual similarity, and their skills and knowledge items.

An expert group with representatives of project partners performed an analysis of information through several methods for the identification of relevant skills and knowledge items in ESCO: on one hand, a direct search on the ESCO website using various keywords to obtain results related to SCs; on the other hand, a local replica of the whole database of the ESCO website allowed for a deeper search on skills and knowledge through specific sophisticated queries not possible on the website. This led to the identification of 15 ESCO occupations with relevance in the SCs context: "Smart home engineer", "Smart home installer", "Civil engineer", "Civil engineering technician", "Cloud engineer", "ICT security engineer", "ICT security technician", "Data analyst", "Data scientist", "3D modeler", "3D printing technician", "Blockchain architect", "Blockchain developer", "Project Manager", and "ICT Project manager". Then, the expert group extracted 89 knowledge and skills from the descriptions of these occupations as the most relevant related set of items for the qualifications of technical professionals in SC projects.

Regarding the reference to the e-CF (EN16234) framework [41], the first analysis focused on the set of 30 examples of description of professional roles with their e-competences. However, none of these roles exhibit a reasonable degree of similarity in terms of functions or responsibilities to the target smart cities profiles. Moreover, these descriptions are also mere examples, not exhaustive descriptions, as the number of e-competences mentioned in each of them is limited to five on purpose. Therefore, the final approach with e-CF was working with the mapping of the resulting set of functions from ESCO occupations to link them to the equivalent e-competences and proficiency levels in the standard. The final set of e-competences comprised nine of them (B.6, E.2, A.6., B.4, E.8, D.7, B.3, B.1, and C.1) and different levels ranging from level 1 to 4.

4.2.1. Functions for Engineers and Technicians

The proposed functions for the SCs engineer and the SCs technician came from the description of the different similar ESCO occupations as mentioned above (see Tables 2 and 3 for details).

Table 2. Functions for engineers.

Category	ESCO Reference for Inspiration and Extraction of Items	Description for Survey
IoT	Smart home engineer (2151.2)	FE1. Design, integration, and acceptance testing of automation systems integrating connected devices and smart appliances within residential facilities. Work with key stakeholders to ensure the desired project outcome including wire design, layout, appearance, and component programming.
Cybersecurity	ICT security engineer (252.9)	FE2. Advise and implement solutions to control access to data and programs and ensure the protection of processes. Responsible for the protection and security of systems and networks and design, plan, and execute the system's security architecture, with models and security policies and procedures.
Data analytics	Data analyst (2511.3) and data scientist (2511.4)	FE3. Collect and interpret rich data sources, manage large amounts of data, merge sources, ensure consistency, and create visualizations to aid in understanding data using mathematical models and communicate insights and findings to the team and, if required, to non-experts, as well as recommend ways to apply data.
Machine learning and Big Data	No reference occupations: selection of skills and knowledge	Not included in the survey. Preliminary analysis from case studies considers this area as optional in terms of responsibilities.

Table 3. Functions for technicians.

Category	ESCO Reference for Inspiration and Extraction of Items	Description for Survey
IoT	Smart home installer (7421.7)	FT1. Install and maintain automation systems, connected devices, and smart appliances at customer sites. Also, act as a user educator and resource for product and service recommendations for customers' needs for comfort, convenience, security, and safety.
Cybersecurity	ICT security technician (3512.3)	FT2. Propose and implement necessary security updates and measures whenever required. In addition, advice, support, inform, and provide training and security awareness.
Data analytics	Data analyst (2511.3) and data scientist (2511.4)	FT3. Import, clean, validate, model, or interpret collections of data for business goals and given criteria. Also, ensure consistent and reliable data from sources and repositories and prepare reports with visualizations such as graphs, charts, and dashboards.
Machine learning and Big Data	No reference occupations: selection of skills and knowledge	Not included in the survey. Preliminary analysis from case studies considers this area as optional in terms of responsibilities.

The results from the survey show the relevance of functions and responsibilities allocated by participants for the determination of the recommended profile of SC engineers and SC technicians (see Figures 2 and 3). As we can see, the work in SC projects for engineers and technicians is intensive in IoT as well as security and data management. This confirms that the study of the data from our survey can be representative of the analysis of qualification for the implementation of IoT solutions in general, combined with the aspects of security and data management.

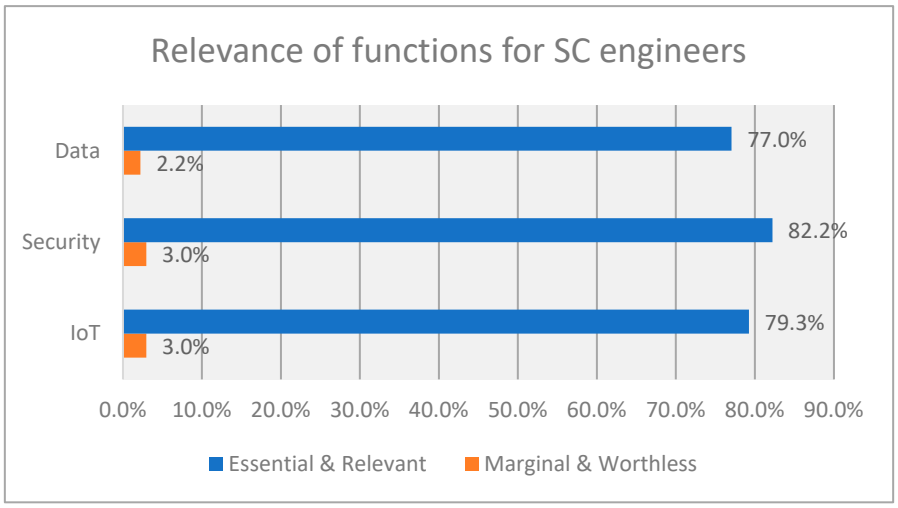

Figure 2. Summary of relevance of functions for SC engineers.

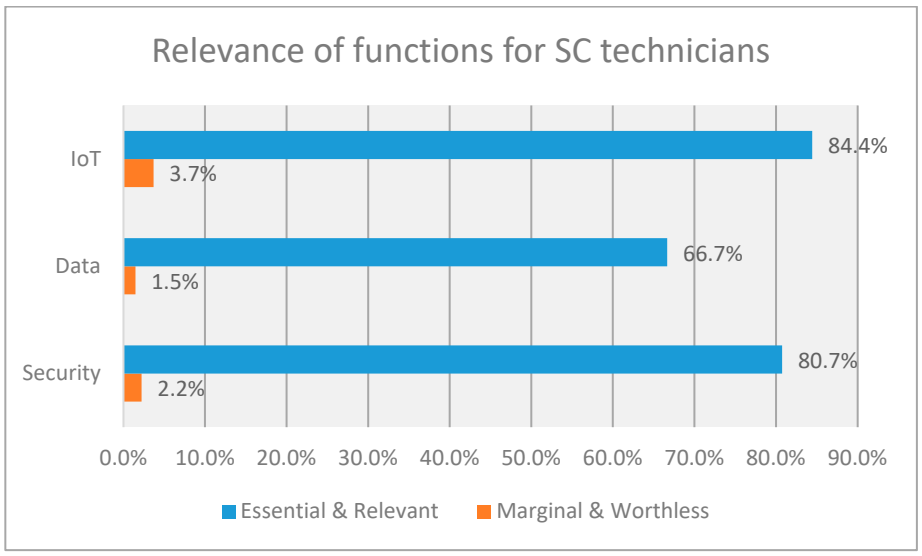

Figure 3. Summary of relevance of functions for SC technicians.

Once the profile of functions was determined, the development of the mapping to the EN16234 framework [41] mainly considered the equivalence of those functions with responsibilities and activities described in dimension two of the standard. The detected relations were very direct: only a small number of functions needed to be linked to two e-competences to ensure a correct representation of the activities. The final mapping developed by the expert group after analyzing the survey is shown in Table 4.

4.2.2. Knowledge, Skills, and Soft Skills

In the case of skills and knowledge, the expert group of the project identified the most relevant skills in ESCO for the occupations already used for the functions (see Section 4.2.1). Tables 5 and 6 show the selected ones, the most relevant for SC engineers and for technicians. The participants in the survey had to answer the question: "According to your experience, up to what extent is this skill/knowledge important for SC engineers/technicians?". Table 5 shows the specific descriptions of skills and knowledge for an SC engineer, together with their inspirational basis from ESCO; Table 6 shows the one for an SCs technician. The description is a summary of the most meaningful features of the corresponding skills or knowledge items identified in ESCO.

Table 4. Mapping of functions to the e-competence of EN16234.

Role	e-Competence	Level
Engineer	B.6 (ICT systems engineering)	4
Engineer	E.2 (project and portfolio management)	4
Engineer	A.6 (application design)	3
Engineer	B.4 (solution deployment)	3
Engineer	E.8 (information security management)	4
Engineer	D.7 (data science and analytics)	3
Engineer	B.3 (testing)	3
Technician	E.2 (project and portfolio management)	2
Technician	B.1 (application development)	2
Technician	B.4 (solution deployment)	2
Technician	E.8 (information security management)	3
Technician	D.7 (data science and analytics)	2
Technician	B.4 (solution deployment)	1
Technician	C.1 (user support)	1

Table 5. ESCO descriptions for engineers.

Category	ESCO Reference for Inspiration and Extraction of Items	Description for Survey
IoT skills	ESCO skill: "design smart grids"	SE1. Design and calculate smart systems, based on grid load, duration curves, energy simulations, etc.
IoT knowledge	Three ESCO knowledge items: skills "internet of things", "smart grids systems", and "building automation"	KE1. Principles, requirements, limitations, and vulnerabilities of smart connected devices and automatic control systems for digital control, distribution saving, and use of energy and information management.
Cybersecurity skills	Nine ESCO skills: "verify formal ICT specifications", "analyze ICT system", "identify ICT security risks", "develop information security strategy", "ensure information security", "perform risk analysis", "define security policies", "manage disaster recovery plans", and "implement ICT risk management"	SE2. Create a strategy for safety and security, with a set of rules and policies. Analyze systems to identify risks and implement procedures for identifying, assessing, and mitigating them and prepare recovery plans.
Cybersecurity knowledge	Four ESCO knowledge items: "cyber security", "ICT security standards", "risk management", and "cloud security and compliance"	KE2. Methods and standards to protect ICT systems, resources, and users against illegal or unauthorized use, identifying, assessing, and dealing with all types of risks, including from cloud computing.
Data analytics skills	Five ESCO skills: "Interpret current data", "apply statistical analysis techniques", "manage data", "define data quality criteria", and "perform data analysis"	SE 3. Define data quality criteria and perform data analysis with statistical techniques to interpret data to assess development and innovation.
Data analytics knowledge	Five ESCO knowledge items: "manage cloud data and storage", "statistics", "data models", "visual presentation techniques", "unstructured data"	SE4. Statistical methods, practices, and data techniques for collection, organization, the structure of data elements, analysis, interpretation, and presentation of data (local and cloud) to reinforce human understanding.
Machine learning and Big Data skills	Two ESCO skills: "perform data mining" and "analyze big data"	SE4. Explore large datasets to reveal patterns using statistics, databases, or AI and present information in a comprehensible way.

Table 5. *Cont.*

Category	ESCO Reference for Inspiration and Extraction of Items	Description for Survey
Machine learning and Big Data knowledge	Three ESCO knowledge items: "machine learning", "data mining", and "smart city features"	KE4. Big Data technologies (machine learning, data mining, etc.) for smart cities to develop novel software ecosystems upon which advanced mobility functionalities emerge.

Table 6. ESCO descriptions for technicians.

Category	ESCO Reference for Inspiration and Extraction of Items	Description for Survey
IoT skills	ESCO skill: "install smart devices"	ST1. Install connected devices, (sensors, light switches, plugs, energy meters, cameras, etc.) and interconnect these devices to the system and to relevant sensors.
IoT knowledge	Three ESCO knowledge items: skills "internet of things", "smart grids systems", and "building automation" (same as in KE1)	KT1. Categories, requirements, limitations, and vulnerabilities of smart connected devices and automatic control systems for digital control, distribution, saving, and use of energy and information management (adapted to the technician role).
Cybersecurity skills	Four ESCO skills: "analyze ICT system", "identify ICT system weaknesses", "solve ICT system problems", and "define firewall rules"	ST2. Analyze the functioning and performance of systems to identify and categorize weaknesses and vulnerabilities to intrusions or attacks. Deploy diagnostic tools and resources to solve them, including firewall configuration.
Cybersecurity knowledge	Three ESCO knowledge items: "cyber-attack counter-measures", "attack vectors", and "cyber security" (this is common to KE2)	KT2. Methods or pathways deployed by hackers to penetrate or target systems illegally and techniques and tools to detect and avert malicious attacks and protect ICT systems, resources, and users.
Data analytics skills	Four ESCO skills: "perform data cleansing", "collect ICT data", "normalize data", and "manage data" (this is common to SE3)	SE 3. Collect data from connected devices, detect and correct corrupt records from datasets (according to defined quality criteria), and normalize data to minimize dependency, eliminate redundancy, and increase consistency.
Data analytics knowledge	Five ESCO knowledge items: "manage cloud data and storage", "statistics", "data models", "visual presentation techniques", and "unstructured data" (all the same as in KE3)	KE3. Understanding statistical methods, practices, and data techniques for collection, organization, structuring data elements, analysis, interpretation, and presentation of data (local and cloud) to reinforce the human understanding of information (adapted to the technician role).
Machine learning and Big Data skills	Two ESCO skills: "perform data mining" and "analyze big data" (the same as in SE4)	SE4. Explore large datasets identifying patterns according to predefined methods with statistics, databases, or AI and generate reports of information in a comprehensible way (adapted to the technician role).
Machine learning and Big Data knowledge	Three ESCO knowledge items: "machine learning", "data mining", and "smart city features" (the same as in ST4)	KE4. Principles, methods, and algorithms of machine learning, statistics, and data mining (adapted to the technician role).

In the case of soft skills, the statements for the survey were almost the same for engineers and technicians. The reference model was one of the Skills Match projects [45,46].

The model has 36 soft skills, but it also identified clusters of skills intimately linked among them. For the sake of simplicity, the survey referred to the relevance of the clusters for the profiles. The list of clusters of soft skills is the following one:

- Accountability (customer focus, diligence, reliability, efficiency);
- Communication (networking, negotiation, teamwork);
- Creativity (critical thinking, problem-solving, decision-making, initiative);
- Ethical behavior (respect diversity, respect environment, respect privacy);
- Leadership (coaching, conflict resolution, entrepreneurship, strategic thinking, motivating others, managing quality);
- Self-management (adaptability, organization, positive attitude, self-control, personal development);
- Tenacity (goal orientation, patience, motivation, resilience).

Figure 4 summarizes the opinion of the participants regarding the main categories of skills and knowledge. Both IoT knowledge and skills are the most recommended categories for the qualification of SC engineers and technicians. This represents another confirmation that our analysis focused on SC projects is practically equivalent to the one for the general implementation of IoT, suggesting that our conclusions can mostly be applicable to general IoT projects.

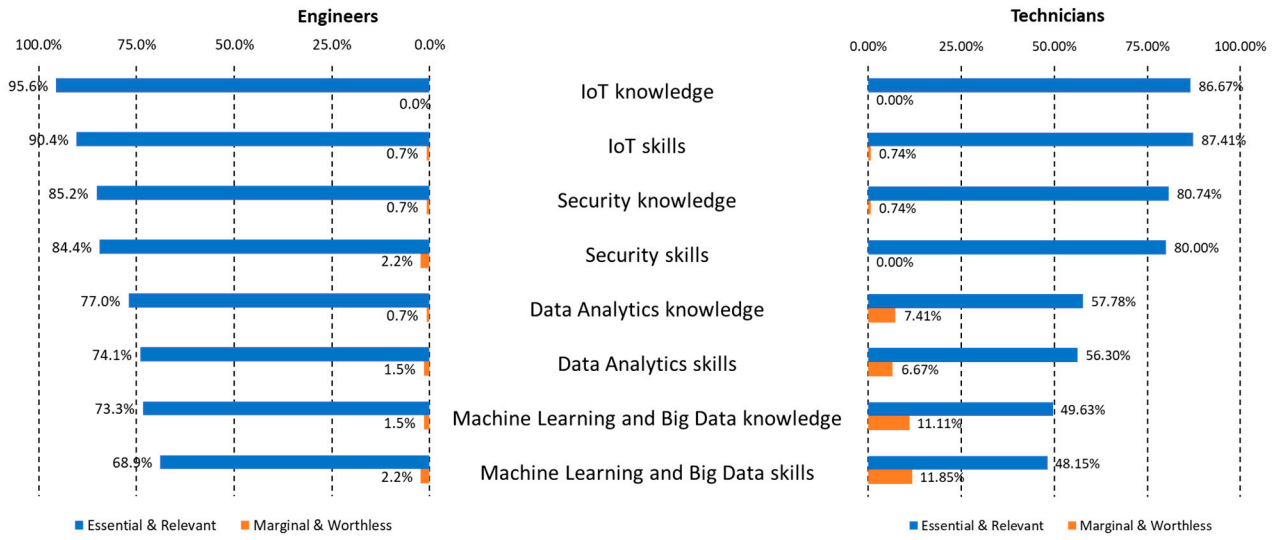

Figure 4. Summary of perceived relevance for skills and knowledge.

Cybersecurity is considered slightly less relevant than IoT but has equivalent high levels of agreement both for engineers and technicians. Data analytics skills and knowledge are the area in the third position but, in this case, while it is essential or relevant for engineers (74.1% in skills and 77% in knowledge), the values are considerably lower for technicians (around 57%). In this category, it is also possible to find a relevant proportion of disagreement, especially for the technician profile.

The area of Machine Learning and Big Data skills and knowledge represents the last relevant option in the ranking. Again, while it is most essential or relevant for engineers (around 70% for skills and knowledge), for technicians that consideration hardly reaches 50%. Clearly, this area is not considered a key factor for the qualification profile of SC technicians.

Apart from the evident descriptive results showing percentages of relevance, the data in Figures 3 and 4 suggest a clear trend: the importance of skills over knowledge for the qualification of technicians, while knowledge is at the same level or even higher than skills in the different areas for engineers. The participants in the survey considered that the role of technician should be mainly focused on practical aspects while the engineers need more knowledge for their activities. The analysis of mapping to e-CF in Table 4 is also consistent

with this idea of differences between technicians and engineers: functions for engineers exclusively relate to proficiency levels 3 and 4 of the standard, with high levels of influence within the organization, context complexity, and autonomy. Technicians are mainly linked to levels 1 and 2 (only the competence E.8, Information Security Management, reaches level 3), more connected to following instructions or applying and adapting procedures in structured and predictable contexts with limited independence or under general guidance.

Finally, regarding soft skills, every cluster was considered essential or important for engineers by at least 77% of the participants in the survey, with insignificant percentages for the options marginal and worthless (see Figure 5). In the case of technicians, there is a greater disparity of values. However, more than 50% of the participants considered all the proposed clusters of soft skills to be relevant, except for leadership with only 48% and creativity with a relatively high value of importance (65%). The results for these two clusters are consistent with the results for the e-CF mapping mentioned above, as low proficiency levels are linked to limited autonomy and work under guidance, mainly following instructions and procedures.

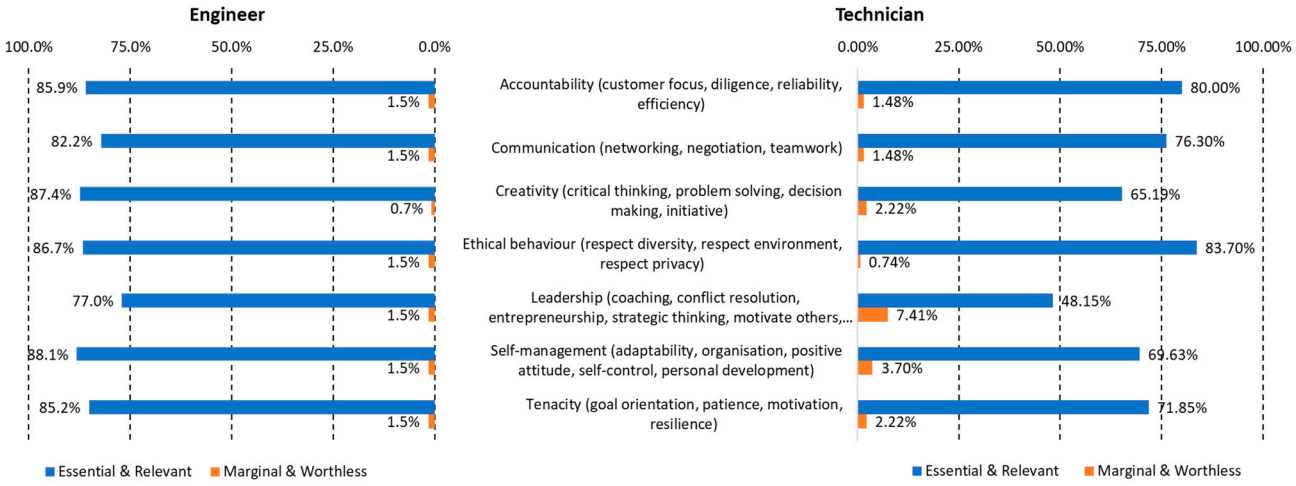

Figure 5. Summary of responses to the agreement on soft skill clusters.

It is worth mentioning that the effort of developing the survey for RQ2 and the final mapping of the profiles to both ESCO and EN16234 has involved a considerable number of references to items from these models:

- Development of survey:
  - A total of 15 reference occupations selected from the 3008 existing in the version 1.1 of ESCO;
  - A total of 89 skills and knowledge items, connected to the 15 occupations, were selected from the total catalog of 13,890 in ESCO;
  - A total of nine e-competences from EN16234 linked to 11 functions for the profiles through 14 pairs of competencies and proficiency levels.
- Recommended profiles:
  - Engineer profile: linked to 28 knowledge items and 35 skills from ESCO and seven e-competences from EN16234;
  - Technician Profile: linked to 20 knowledge items and 19 skills from ESCO and seven e-competences from EN16234.

5. Conclusions and Future Lines

This article has explored in more detail two of the aspects linked to human factors, identified as key factors for IoT implementation by the maturity models in the literature: user attitude toward IoT and qualification of the technical implementation team. Our work has focused on the opinion of involved stakeholders in each case:

- In the case of the users' side, we addressed a specific survey to non-technical managers and professionals in SMEs (as these organizations have fewer resources to work with disrupting technology such as IoT) and educators of future non-technical professionals;
- In the case of the qualification of ICT professionals for IoT solutions, we preferred to have a broad spectrum of opinions, covering the clients' side (municipality managers and professionals), the providers' side (technical managers and professionals), and the users' side. The survey explored the specific details of the recommended qualifications for professionals working in teams where the implementation of IoT (and connected aspects of security and data management) are intensive such as in SC projects. We have shown that SC projects could be representative of the case of general IoT implementations.

Thanks to the analysis of the results of both surveys, we have provided the answer to the two research questions RQ1 and RQ2, adding details to the two human factors linked to them and identified by maturity models for the implementation of IoT. In the case of RQ1, the models already identified that the attitude and culture of IoT users was a key factor for a successful implementation of IoT solutions. In our case, we have confirmed their importance and provided more specific indications: users in Europe consider it essential to address their adaptation to changes caused by IoT with special care regarding possible differences among countries (market conditions, legislation, etc.). They have also listed the set of topics recommended for training and information prior to the implementation of IoT: the adaptation to new contexts created by IoT, the acquisition of basic IoT literacy, changes in business models and in occupation profiles, skills and qualifications, challenges in privacy, security, and legal consequences, and challenges in social aspects.

In the case of RQ2, we have seen how the answer to RQ2 resulted in a specific description of the functions, skills, and knowledge recommended for a good qualification of the technical implementation team, both for the role of engineer and for one of the technicians. Going beyond the mere indication of maturity models regarding "the capabilities of the IoT implementation support team", the results depict a detailed set of skills and descriptions which can help to better prepare the technical teams for the successful implementation of IoT. The mapping to ESCO will ensure a better understanding and improved alignment with terminology and a classification that it is compulsory in all member states of the European Union since 2021, thus facilitating the adoption across the continent. The mapping to EN16234 also ensures an enhanced connection to ICT industry practices adopted by all types of organizations in Europe, promoting a good understanding of the recommended profiles.

The results have an evident geographical limitation as the samples for surveys were focused on Europe. Although we think that possible differences for developed countries would be minimal, we are planning an additional collection of data from stakeholders in the rest of the world, then allowing for a deeper study of the two human factors involved in our research questions. Possibly, the factor of differences among countries in conditions for IoT already confirmed in the European scenario may possibly be much more relevant with this wider sample.

In the case of RQ2, we approached the study through the context of SC projects, although we have confirmed through different results of our study that stakeholders consider this context as representative of IoT implementations. We are also planning to address additional contexts in our study of the recommended qualification of the technical team for IoT solutions through two actions: expanding the collection of data with a survey to other types of IoT projects and by a compilation of data from the future training activities of technical professionals planned by the project SMACITE after the description of the qualification profiles. New data could help us to verify and refine the qualification guidelines for successful IoT projects.

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Data Availability Statement: The data presented in this study are openly available in Zenodo at 10.5281/zenodo.7492255.

Conflicts of Interest: The authors declare no conflict of interest.

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4.3 Summary of the results of Publication 2

This publication presents an analysis in a specific ICT field (Smart Cities) partially using the approach already proposed in the publication 1. This allowed to test the new approach presented in this thesis in a real case scenario, with a multinational environment where the consistency and the coordination is not always easy to ensure. As explained before, the data from two surveys previously mapped to ESCO and e-CF frameworks were the basis for the analysis. Text extraction techniques from the description of related occupations in ESCO and from role and level descriptions in e-CF enable the mapping of the survey statements to both frameworks and, therefore, direct link of the results to them.

Thanks to the survey design to be aligned to ESCO framework information, it was also possible to extract the information regarding soft skills, which helps to analyse the human factors as attitude and culture. The design process of the main survey followed a strict process to guarantee the validity of results: a) extensive analysis of existing information, b) a focus group with collection of local experiences in different countries to promote a coordinated view on the target profiles, c) external review of survey design, d) pre-test of survey with additional partners of the project, e) strict descriptive analysis, and f) a set of interviews with reputed experts to aid in the interpretation of conclusions.

5. PUBLICATION 3: MOBILE APPLICATION DEVELOPMENT SKILLS SET ALIGNED WITH THE E-CF FRAMEWORK AND INDUSTRY NEEDS

5.1 Detailed contribution and relation to the objectives

The mobile application development attracts a good percentage of the job market in the ICT profession but research studies like [46] have detected problems of time and cost in projects. Other studies analysed, mainly using surveys, a possible mix of skills in software development, project management and soft skills recommended [47]. This work was part of an EU-funded project aimed at defining a framework with the recommended skills for mobile application development, ensuring alignment with the industry needs. This project was the European ICT Sector Skills Alliance - VET open course for mobile apps creators, 554271-EPP-1-2014-1-UK-EPPKA2-SSA, 2015-2017, Erasmus+, Cooperation for innovation and the exchange of good practices, Sector Skills Alliances in vocational education and training [48].

The work combined the analysis of information from the reference frameworks (ESCO and e-CF) with the direct opinion of stakeholders (industry needs) for the professional profiles involved in mobile application development. Although the frameworks ESCO and e-CF already suggested recommendations for the profile, it was partial and far from being enough. The stakeholders provided information on skills (including soft skills) to be demanded for the roles as well as on their perception on the presence of those skills in their employees.

The second part of this work was focused on combining the information and extracting a specific framework, in reality a customisation of e-CF for mobile application development (as it referred to the e-CF competences recommended for profiles). All the surveys were previously validated using different statistical methods to analyse consistency and robustness of data. After that, other techniques, and tests like Exploratory Factorial Analysis (EFA) were used to clean repeated and remove non-valid items, and to group the different elements in categories.

The usage of the references of ESCO and e-CF enabled the cooperation and consistency to work with a valid multinational sample, with different types of stakeholders, complex design, and multiple steps. Moreover, thanks to the links ESCO and e-CF frameworks as previous work, it was possible to express results in uniform and universally understandable terms.

5.2 Full publication

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Subject review

Mobile Application Development Skills Set Aligned with the E-Cf Framework and Industry Needs

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Abstract: The number of mobile apps is continuously growing but development organisations are not sure of the good alignment of the skills of application developers with what the industry needs. A precise definition of the professional profile of the Mobile Application Developer (MAD) can help to better understand the needs of software development teams. This cooperation of several European organisations for analysing professional profile of MAD has led to a study of skills and competences resulting in a conceptual model with relevant characteristics: a) based on literature review, b) framed within the European standard e-Competence Framework, e-CF (EN16234) and the ESCO official labour classification and c) empirically validated with qualitative and quantitative data from many stakeholders in the field. This analysis might help to add homogeneity to talent management overcoming possible barriers for international mobility within EU as the concepts are taken from the EU reference models.

Keywords: app development; IT professionalism; mobile apps; skills

1 INTRODUCTION

The rapid evolution of technology and subsequent changes in businesses continuously increases complexity and dynamism in the IT sector. Constant emergence of new roles and occupations within IT profession stresses the fight for talent and the need of adapting training of engineers to the skills demanded by job market. The development of mobile apps is one of the most productive professional areas as the number of apps has massively grown during recent years, reaching over 230 billion of downloads by 2021 [1]. In this scenario, the quality of apps, as well as the need to be developed quickly and with low costs, play an important role in surviving in such a competitive market [2].

The development of mobile applications has specific characteristics (e.g., varied network speeds, network dependency, limited platform performance, varying screen size and resolution, etc.) so app development is considered a different discipline from the development of web/desktop applications [3, 4]. Those differences hinder the respect to software engineering principles which is farther from what one might expect [5]. The development of apps for mobile devices has challenged the development departments, which needed to change and update their practices as projects increasingly involve innovation and have become more challenging: e.g., beyond completely different interface and usability features, apps have shorter life cycles [6] when compared to the one of software for desktop/laptop or websites. They also use a different way of distribution with preinstallation on the device or download from an appstore [2]. Besides, the development life cycle of a mobile application moves much faster than the one of a traditional Web application imposing adjustments in the associated life cycle management [7]. Clear differences between mobile and conventional development in budget or development time require adaptations of the work with this type of devices [8]. In addition, the testing process of these applications is different from the traditional one, mainly due to differences in the user interaction with the device [9].

A survey conducted on the Enterprise Mobility Study [10], where more than 340 respondents from leading global brands participated, highlighted the importance for development teams to focus on business strategy to improve the quality of mobile applications and avoid costly project delays and inefficiencies. Moreover, the same study also considered the lack of marketing and business say as important point to get the best possible chance of succeeding in app stores. Other relevant barriers for good results include the deficit of skills of developers [11], secure ty issues [11, 12] and compatibility issues [13, 14].

The analysis of information from different job portals, as Monster or Indeed, shows that companies clearly differentiate the vacancies for MAD from the rest for typical desktop or web application development: this indicates that the companies' needs for MAD positions are different. A study performed by Jia et al. [15] identifies specific differences on the soft skills requested for traditional software and for MAD in job ads. The differences in requirements for app development do not only involve those personal skills but also technical competence in specific and different software development processes, project management or testing skills, even including aspects not strictly confined to the traditional field of software development such as, e.g., product and project management, and communication skills with people from different cultures to develop distributed systems [15]. These findings suggest that the professionals in MAD could benefit from a specific mix of some business and application marketing skills as well as specific security-related skills, among others.

However, there is a need of determining more precisely the professional profile of competences, skills and attitudes recommended to successfully develop mobile apps. Even the IT professionalism frameworks and reference models such as e-CF EN16234 [16] have not specifically defined competence profile for the role of app developer, they only consider the one of general software developer [17]. When looking at ESCO, the official EU labour classification has a profile of MAD [18] among the total of more than 3000 of all sectors. Although this is a very relevant reference, this profile has two limitations: a) it has not been compared with the opinion of a wide sample of stakeholders of the IT job market, b) it is extremely focused on the mere programmer/coder role, while market tends to require

profiles with broader spectrum of skills and responsibilities, assuming the full range of activities involved in MAD.

The absence of a complete profile motivated the joint effort of a wide set of organisations to determine it in a solid way, specifically collecting information from relevant stakeholders from different countries as well as from other relevant sources. The goal of the study was improving the precision and completeness of the description of the professional profile for MAD. This profile will enable a better adjustment of training programs, aligning them to job market needs. At the same time, it will be a basic reference for the general identification and assessment of capacities in candidates and professionals in MAD, specifically focused on EU job market but possibly applicable globally. This article presents the results of such study and the APP-CF framework for MAD resulting from it.

The article is structured as follows. Section 2 reviews the previous related works in literature. Section 3 shows the methodology followed in the study while Section 4 shows the previous work to explore the candidate skills for mobile apps developers. Section 5 shows the results from the survey that are analysed and discussed in Section 6. Finally, Section 7 presents the conclusions.

2 RELATED WORK

A solid specific study on competences for app development requires a prior analysis of existing literature and reference models to determine the candidate skills and the catalogue of profiles demanded by the labour market in the EU. One relevant point to develop a solid professional profile is to ensure homogeneity in the terminology to avoid problems in the analysis of information. Fortunately, the EU has developed two main European references for the ICT labour market which provide consistency in concepts and terminology: ESCO and e-CF.

The European ESCO labour classification [19] is a multilingual classification that identifies and categorises three inter-related pillars (skills-competences, qualifications and occupations) relevant for the EU labour market and education. The profiles of more than 3000 occupations of its catalogue were created through debate and analysis of data by a group of more than 200 experts during four years. According to ESCO, a Mobile App Developer implements application software for mobile devices, based on the designs provided, using general or specific development tools for device operating systems. There is a wide set of skills and knowledge items allocated to the description of the qualification for this position, some catalogued as essential items and others as optional, for example:

- Knowledge items like computer programming, mobile operating systems, integrated development environments or mobile operating systems.
- Skills like analyse software specifications, debug software, develop software prototype or use software design patterns.

The other relevant and available main reference as a sector-specific implementation of the European Qualifications Framework (EQF) is the last version of e-Competence Framework (e-CF)(popularly known as version 4.0) described by the Standard EN16234-1 [16]. This framework represents a common language for competences, skills and proficiency levels and job profiles for ICT professionals. It is the result of many years of work with the contributions of ten experts firstly at the Workshop on ICT Skills of CEN and then by Committee TC428. e-CF became a European standard and was published officially as the standard EN 16234-1 for the first time in 2016. The last version EN16234-1 [16] is the fourth version of the framework including a set of 41 e-competences that enable the description of any role in ICT profession. e-CF is complemented by a set of 30 examples of role profiles described in an additional document [17] published in 2018 (based on the version 2016 of the standard) and then updated as Annex in the standard of 2021. Among those ICT role profiles, we can find the general one of Developer whose main purpose is designing and/or coding components to meet specifications of solutions. This profile requires the e-competences (from e-CF) B.1. Application Development (level 3). B.2. Component integration (level 2). B.3. Testing. B.5 (level 2). Documentation Production (level 3) and C.4. Problem Management (level 3). The matching between ESCO and e-CF has been already explored in [20] and has served as a reference for contrasting the opinions gathered from experts and stakeholders to help categorize them within these models.

Apart from these two main models, other references, standards and bodies of knowledge delve more deeply into the specific competences needed for MAD. The National Competency Standards for Mobile Application Developers [21] are written specifications of skills and knowledge competencies for their successful performance at work. United Nations Industrial Development Organization (UNIDO), GIZ and National Vocational & Technical Training Commission (NAVTTC) have collaborated to create these standards. They include a competency map with fourunits: Design Screen Layout, Perform Coding, Perform Testing and, Perform Written/Verbal Communication. Although useful for industry, the map is not aligned with the e-CF and does not provide a direct process to inferlearning outcomes.

The International Association of Web Professionals, IWA/HWG, recognized by the CEN (European Committee for Standardization) as the standardization body for Web skills [22], has defined the general third-generation European ICT professional profiles that are primarily relevant to the Web sector. It is mainly based on the document "European ICT Professional Profiles" (CWA 16458:2012)" [23] and the "E-Competence Framework 3.0" (eC-F 3.0, not the last version) [24-26]. One of the profiles included there is the one of Mobile Application Developer (WSP-G3-017). According to them, the role of Mobile App Developer is coincidental to an ICT developer that creates/codes application solutions for mobile peripherals and writes application specifications for them aligned to customer requirements. Under this classification and according to ESCO, Mobile App Developers only implement application software for mobile devices based on the designs provided by others, so excluding application design from their tasks. The same happens with architecture design (hardware architecture, mobile operating system, etc.) or business plans among other tasks. All of them are e-competencies from the area "PLAN" of e-CF. However, several works have highlighted the importance of e-business skills in ICT profession in general, and especially for mobile app creators [27]. Therefore, the profile WSP-G3-017 might

be useful for large companies but it is unclear the same value for SME where developers must contribute to multiple tasks. Since MAD is market-driven, competences related to business and marketing areas linked to apps development could help to understand the app requirements resulting from business goals or market opportunities. In small companies, these competencies could seem necessary to develop successful apps. Besides, the WSP-G3-017 profile only defines 11 competences and those competences are not aligned with the e-CF standard.

We can extract from our literature review several relevant conclusions:

- The two main European references are e-CF and ESCO: they are essential for guaranteeing consistency and homogeneity across EU for framing the role profile for MAD. They provide stable and common references for skills and competences within the huge and fast-evolving world of terms in the ICT labour market.
- There is not any definitive work, developed and validated with the help of industry and experts, describing this profile of MAD with the competences required for a professional quality performance.

Inspired by these two main ideas, we proceeded to launch our research to determine a MAD role profile, especially focused on SMEs, since these type of companies are the main developers of mobile apps [28, 29], as well as the ones that can gain the most business advantage with skilled workforce [30].

We carried out two subsequent phases of study to determine the skills and knowledge recommended for app developers. The first one was a preliminary study of the competencies of the workforce of app developers as detected by SMEs through an industry consultation process. Based on the results of this first phase, the second one was aimed at determining the skills recommended for the MAD professional role according to the opinion of the labour market stakeholders. The results from both phases were compared to identify the gap between the needed competencies and the ones detected in workforce at SMEs.

3 METHODOLOGY

The methodology of the study starts with the following research questions as expression of our goals:

- RQ1: Which skills are reporting MAD SMEs as the ones they demand to mobile application developers?
- RQ2: Which is the level of MAD skills of employees reported by SMEs?
- RQ3: Which is the set of e-competences recommended for MAD according to experts?
- RQ4: Is it possible to develop an empirically solid profile for the MAD role, aligned to ESCO and e-CF, based on a relevant number of references and data from labour market stakeholders?

As mentioned above, answering these questions requires a study with two main phases as shown in Fig. 1. The first one was a preliminary study to know the situation of MAD workforce in terms of competencies through an industry consultation process. The results of this study would be the basis for researching in a framework of competencies for the MAD role. The second study was aimed at the goal of determining what skills developers should have according to the opinion of the labour market stakeholders. Tab. 1 summarises the sample of participants in the two surveys.

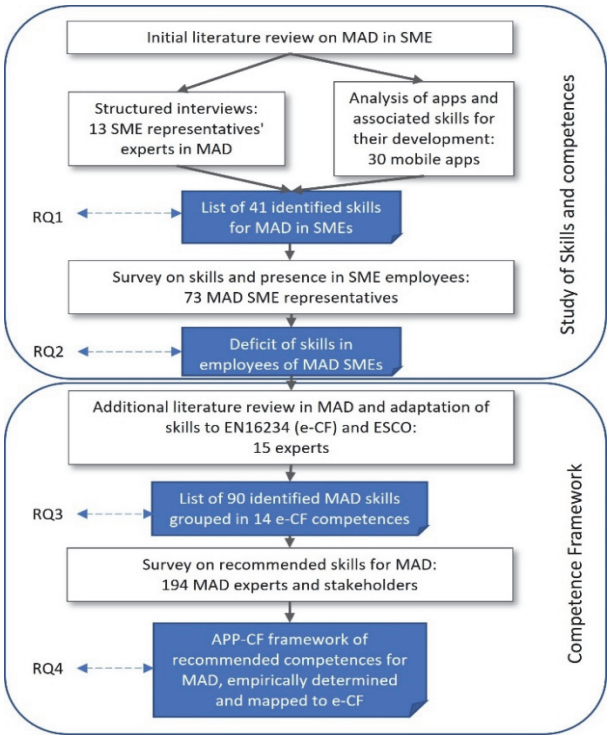

Figure 1 Steps of the methodology

Table1 Summary of samples of the two surveys of methodology

	Survey	#	Participants
1	Skills in MAD SME employees	73	SME representatives
2	Recommended skills	194	MAD experts

4 STUDY OF SKILLS AND COMPETENCES IN MAD WORKFORCE

4.1 Method

Answering question RQ1 and RQ2 requires the collection of information from stakeholders. The work had two main phases:

- Firstly, a preliminary review of industry practice through literature mentioning the most common skills in MAD.
- Then two actions in parallel:
- Structured interviews to 13 experts to main areas or domains of skills.
- Qualitative analysis by experts of 30 apps to determine skills needed for their development.
- A final survey addressed to ICT SMEs asking about the skills really present in their MAD workforce: the questionnaire was based on results from previous steps.

For the first step, the references [29, 31-34] provided a first set of most common skills present in the profile of MAD. In addition, we interviewed 13SME experts with more than 5 years of experience in MAD:

- Apps developer/designer: 3.
- MAD teacher/trainer: 2.
- Business/management profile: 2.
- Entrepreneur: 4.
- Mobile operating system/architecture expert: 1.
- Recruiter: 1.

All except one of the experts were male and their country origin was United Kingdom (40%), Italy (27%), Spain (27%) and Croatia (7%).These structured interviews aimed at identifying the areas or domains of skills as well as the most important ones in each of them: resulted in the creation of an initial matrix of skills. In parallel, the study included a qualitative analysis of 30 apps by 18 experienced professionals supported by 6 experts: this analysis helped to determine the skills required for their development.

After analysing, cleaning, and removing duplicates when needed, the final number of identified generic skills was 40. The list was initially divided into three general categories decided by the group of 6 experts who also allocated the skills to each category:

- Business skills: this miscellaneous category grouped 14 skills from different types:
- 3 soft skills like presentation or problem solving.
- 4 general management skills like project management or risk assessment.
- 2 legal and compliance skills like IPR (Intellectual property rights).
- 5 specific business skills like financial management or business development.
- Marketing skills: 5 skills from social media marketing to mobile app tracking.
- Technical skills for the different phases of development:
- 7 skills focused on languages and coding like Java or HTML5.
- 7 skills for app design like human interaction or architecture.
- 4 skills for testing and quality, e.g., user testing or bug fixing.
- 3 for maintenance like technical support and feedback management.

4.2 Survey Design and Sample

These results were an initial answer to RQ1. But the list of skills formed the basis of the online questionnaire to also answer RQ2. The questionnaire showed the competences classified according to the main areas that the experts identified in the interviews, to help respondents to properly understand the information: technical, and business and marketing skills. Respondents were asked to confirm the skills required for MAD and the level of those skills in their workforce.

The study team contacted SMEs specialised in MAD through several ICT associations in Spain (ATI) and Italy (AICA) and a Technology Educational Association in UK (NAACE). The sample accumulated 73 valid responses: 37 companies from the UK, 24 from Spain and 12 from Italy. The target market of the companies was uniformly distributed among Business-to-Business (44.44%), Business-to-Consumer (45.83%) with the rest (9.72%) participating in both, B2B and B2C. Most of the companies participating in the study had less than 50 employees and they work in the fields of business management (76.06%), marketing (80.28%) and business development (78.87%), all of them involved in MAD.

4.3 Survey Results

As the first step, we checked the reliability of the questionnaire using the Cronbach Alpha coefficient for the total scale and for each considered category of competences: technical and business and marketing. We also used descriptive analysis to know the competences most valued by companies as well as to detect data entry or collection errors. The Cronbach Alpha coefficient for the total scale gave a value of 0.967, while for each of the categories the values ranged between 0.805 and 0.896. The conventional minimum value adopted for Cronbach's alpha coefficient is 0.7 while values equal to or greater than 0.8 indicate good reliability [35], so the questionnaire shows good reliability.

Respondents confirmed the initial list of 40 skills used as basis thus confirming the answer to RQ1. Regarding technical skills, the results of this phase suggested that the mobile app developers showed a good level, with no less than 55% of companies reporting high or very high level for all the technical skills (average of 64.39% of companies) except only three cases: animation (16.6%), data analytics (37.5%) and IOS design (23.2%). In the categories of business and marketing-related skills, there were cases with high percentages of reported low or very low value of skills: e.g., 44.44% of companies reported deficit in legal issues skills and 34.73% in intellectual property rights (although data distribution was not skewed). Other cases of deficit of skills were the ones for financial management (26.39% of companies), sales channel distribution (22.85%), mobile app tracking (20.3%), social media marketing (20.3%) or risk assessment (20%). Fig. 2 shows the percentage for each skills category.

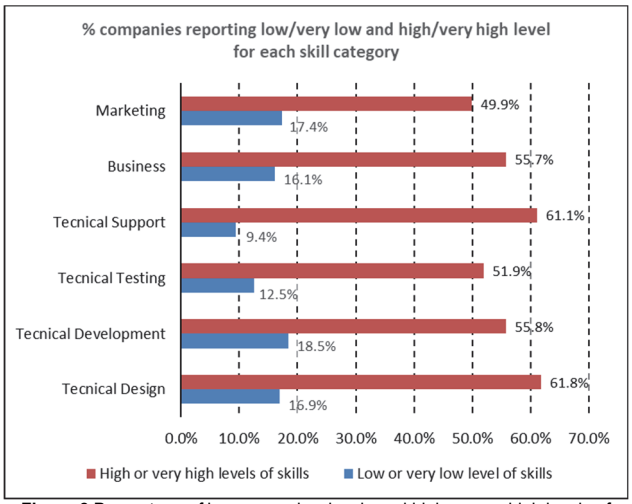

Figure 2 Percentage of low or very low levels and high or very high levels of skills for MAD to consulted SMEs

In summary, according to the consulted companies, their app developers have a good level of technical skills in general, but they detected a deficit in several business and marketing skills. Moreover, companies considered those skills as very important for mobile app developers according to the results of the interviews and other related works [36-38]. This could be explained by the fact that mobile app developers are expected to have all the necessary technical skills, but there is usually little supply of non-technical skill training or specific activities for developing them. These results represent an answer to question RQ1 and RQ2.

5 COMPETENCE FRAMEWORK FOR APP DEVELOPERS

Once completing the phase of analysis of the skills demanded by SMEs and their presence in MAD workforce, the study added a second phase focused on the skills for MAD recommended by a wide variety of stakeholders in the labour market: professionals, experts, recruiters and employers, educators and instructors, etc. The idea was offering a more complete framework supported in a wider sample of stakeholders, not limited to SMEs, which can guide all types of organisations by offering a recommended general MAD professional profile. So, the goal was collecting enough representative data to address RQ3 and RQ4.

5.1 Method

There are three main approaches in literature to identify and classify ICT competences [39]:

a) Using the theoretical foundations of ICT to identify the competence sets based on the relevance of the competences in an individual's career (and therefore not considering companies' perspective).

b) Including the view of practitioners by consulting them.

c) Grouping competences into familiar categories easily identifiable by respondents.

Similarly to other previous research which had empirically adapted the e-CF framework [40], we have followed a combined option to exploit the advantages of all approaches. Firstly, the ICT competences were collected and classified based on the literature review and on results from an industry consultation. Then a variety of industry stakeholders confirmed the skills and competences and indicated the most important ones to determine the relations among them by responding to an online survey. The method for confirming the initial classification was a statistical analysis, more specifically a factor analysis.

5.1.1 Preliminary Analysis of Catalogue of Skills and Knowledge

The first step was covered with a complementary literature review to determine the competences needed to develop mobile applications. The collected information served for building the instrument to be used for the validation by experts. Apart from the findings of the prior work about skills shown in Section 4, we added an additional varied set of information sources to determine the initial group of competences which captures the common view of all the stakeholders:

- Related literature, industry reports, analysis and sector studies addressing mobile app competences [16, 28, 29, 31, 32, 33, 41].
- Structured interviews with 50 experts from companies based in UK, Italy and Spain that created successful mobile apps to explore the most important skills according to their experience. Companies were contacted through the ICT and technology associations (AICA, ATI and NAACE).

The qualitative analysis of the whole set of collected data generated a list of 107 skills. A focus group of experts of the multinational research group of different industry and professional associations from Italy, Belgium, UK and Spain (AICA, ATI, NAACE and Agoria) sorted and cleaned them by removing duplicated items, when needed. The number of items was firstly reduced to 90 after adjusting the original list.

The group also worked in adjusting and grouping the selected skills within the approach of EN16234-1 (e-CF) [16] as official European standard for e-competences. Using this common language provides homogeneity to the work so it could be more easily used in all the countries involved in the study as well as across the rest of Europe. So, the skills were reformulated, grouped and simplified and mapped to e-CF: the initial list was reformulated as a set of 44 elementary items of skills and knowledge, specifically linked to MAD, mapped to 12 e-competences, out of the total of 41 of e-CF. The group mapped the initial list of competences to the e-CF framework adapting them, when possible; otherwise keeping the additional ones determined by the previous research separated. Attitudes and soft skills appear in e-CF as embedded items in the description of all competences, so this criterion was followed for our model too.

Subsequently, we conducted a content validation analysis (before launching the online survey) aimed at confirming the competences with the help of experts using a structured interview. The total number of participants was 15 from Spain, UK, and Italy. All of them with more than 10 years of experience, and with different profiles to ensure sample representativeness: 4 apps developers/designers, 2 mobile app teachers/trainers, 2 business/management professionals, 4 mobile apps focused entrepreneurs, 1 mobile operating system/architecture expert, and 1 IT specialist recruiter. Results confirmed the competences used as a reference in the questionnaire: 100% of interviewees agreed about the e-competences for business and technical areas as well as for marketing, but in this case, they suggested three more items connected to the e-competence D.6 Digital Marketing from e-CF.

5.1.2 Survey Design

After analysing the new items, we concluded that they were all either included in our initial model with a different name or embedded in other e-competences. Therefore, we decided to rename them to improve the customization to the field and consequently the understanding of the questionnaire. Once changed, we carried out the second round of interviews to confirm the changes to reach a consensus on the design. Experts added five soft skills too. Since we decided to follow the approach of e-CF of considering attitudes embedded as part of the competences, we did not specifically include them in the survey questionnaire. So, the solution was to add an open question in the survey design to confirm if respondents recommended more research on this aspect in the future. The analysis finally led to a survey design with 44 elementary skills and knowledge items adapted to e-CF through12 e-competences for grouping them. The survey did not directly show the reference to the e-CF e-competences as the standard is not widely known and using so specific terminology would have created confusion among respondents: as each item was mapped to e-CF competences, the subsequent analysis would enable the direct link of the final framework to e-CF.

The survey was addressed to experts working in the area as well as to all types of stakeholder representatives: e.g., developers, recruiters, and trainers/educators. The survey

was implemented online with the EU Survey tool of the European Commission and widely disseminated, especially through the ICT associations as well as public employment and learning services in the UK, Italy, and Spain. At this phase, we invited to participate not only the people in SMEs related to MAD, but also any other experts in the area to increase the sample (compared to the previous phase) as well as to consider all the possible relevant perspectives.

5.2 Analysis of Survey Results

The size of the sample was 194 valid responses leading to a margin of error of 7% with a confidence interval of 95%. The sample was not gender balanced as 81.96% were male respondents. This was expected due to the usual low representation of women in the ICT sector, especially in very technical fields like app development. Most respondents have tertiary education (87.63%) and more than 5 years of experience (69.59%). The sample was well dispersed across professional occupations with 43.81% of apps developers/designers and a good balance for the rest of the positions. We conducted an exploratory statistical analysis to detect data collection errors and to check the feasibility of factorial analysis. Subsequently, we examined descriptive statistics. The descriptive analysis did not provide enough evidence to eliminate any item without further study.

Once the descriptive analysis was concluded, we proceeded to check the feasibility of factorial analysis. Firstly, we analysed the item-total correlation coefficients to evaluate the extent to which each item is linked to the rest of the items of that dimension, i.e., if they measure the same concept. Additionally, the inter-item correlation was analysed too, to know the influence among the items belonging to the same category. As shown in Tab. 2, item-total correlations were above 0.3 suggesting that each item is related to the rest. Tab. 2 shows the results referring to the 44 elementary items of the survey but mentioning the corresponding skill or knowledge item of e-CF mapped to it for the sake of a short clear reference.

Moreover, validity and internal consistency or reliability of the questionnaire was calculated too. The reliability is the degree of consistency of the scale, and it confirms (or not) if the observed variable measures the real value and is free of error. Reliability is commonly calculated using Cronbach's alpha coefficient. Cronbach's alpha was calculated for the total questionnaire and each dimension. As shown in Tab. 2, the final Cronbach's alpha coefficient values for each dimension and total scale range from 0.779 to 0.925 (Cronbach's alpha > 0.7) showing that the scale is consistent [35]. None of the Cronbach's alpha coefficient values were increased by removing any item of the set.

Furthermore, construct validity is the degree to which the instrument measures the construct. Construct validity was tested by using Exploratory Factorial Analysis (EFA). The Exploratory Factorial Analysis (EFA) allows examining the relationships among the variables (in this case knowledge and skills) grouping them as components or dimensions (in this case competence areas) conceptually identified according to the weights of these variables on the component. This analysis will allow to confirm if the adjustment to the e-CF framework was well defined. Before executing EFA, we checked the conditions for applying it: both the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's Test of Sphericity.

Table 2 Summary of reliability and construct validation results

APP-CF area	D4 Skills/ knowledge[a]	Item-total correlation	α Cronbach	*KMO*	Bartlett's test	APP-CF area	D4 Skills/knowledge	Item-total correlation	α Cronbach	*KMO*	Bartlett's test
Apps Business plan	A.1.S7'	0.629	0.842	0.836	Sig 0.000 df 28 Chi.square 519.918	Mobile App Development	B.1.K5'	0.481	0.845	0.815	Sig 0.000 df 36 Chi.square 693.283
	A.1. S11	0.620					B.1.S3'	0.586			
	A.3. S6	0.583					B.1.S4'	0.669			
	A.3.S1'	0.456					B.1.S4'	0.649			
	A.3.S1"	0.572					B.1.S4"	0.620			
	A.3. 9	0.627					B.1.S4"'	0.742			
	A.4. K6	0.661					B.3.S6'	0.557			
	A.4. S3	0.549					B.2.K2'	0.389			
	A.6.K1	0.452					C.3.K6	0.356			
	A.6.K2'	0.508				Mobile app Deployment	B.4.S5'	0.600	0.854	0.795	Sig 0.000 df 10 Chi.square 425.428
	A.6.S2	0.489					B.4.K3	0.553			
	A.6.S5'	0.451					B.4.K1'	0.764			
	A.6.S5'	0.517					C.1.S1'	0.747			
	A.6.S6	0.642					C.1.S4	0.663			
	A.6.S7'	0.643				Channel management	D.6.S1	0.668	0.876	0.790	Sig 0.000 df 6 Chi.square 380.821
	A.6.S2'	0.632					D.6.S5'	0.797			
	A.6.S7"	0.549									
	A.6.S9'	0.545					D.6.S5"	0.733			
	A.6.K8'	0.482									
	A.6.K4	0.563					B.1.K5'	0.728			
	A.5.K1'	0.596									
	A.5.K2'	0.485									
	A.5.S1'	0.568									
	A.5.S2	0.588									
	A.5.K3'	0.510									

Note: [a] Sn'/Kn' are Sn/Kn from e-CF mode [16] (S for Skills and K for knowledge), i.e., faceted expression of Sn/Kn in the area of MAD

Tab. 2 shows the final underlying dimensions between measured variables as well as the coefficients for reliability and construct validity. As shown in Tab. 2, the analysis resulted in high KMO statistics ranging from 0.790 to 0.904 [35] and a significant probability level ($p < 0.001$) for Bartlett's test. Therefore, we can conclude the applicability of factor analysis is confirmed. Once we confirmed the applicability of EFA, we proceeded to apply it. Since the aim was to reduce the competences to the most important ones, we used Principal Components with Varimax rotation as an extraction method. Tab. 3 shows the final framework called APP-CF. The first column shows the competence areas validated by experts; the next columns correspond to areas, e- competences, and skills and knowledge adapted from e-CF or created according to the research carried out. Note that competence areas of APP-CF correspond with e-CF areas: App business plan with "A. PLAN", Mobile App Development and Mobile App Deployment with, "B. BUILD" and "C. RUN", and Channel Management with "D. ENABLE".

Table 3 APP-CF. Final framework for mobile app developers

Competence areas	D.1 areas	D.2. e-Competence	D4. Skills/knowledge
Apps Business planning	A. PLAN	A.1. IS and Business Strategy Alignment	S1 Choose the right Business Model for the app
			S1 Understand the legal & regulatory landscape
		A.3. Business Plan Development	K1 Risk and opportunity assessment techniques
			S1 Identify and analyse customer needs
			S2 Address and identify essential elements of the app
			S3 Understand the context in which app is used
		A.4. Product / Service Planning	K1 Structured Project Management Methodologies
			S1 Manage app development management lifecycle
			S2 Quality plans
		A.5. Architecture design	K1 Mobile HW Architecture
			K2 Mobile Operating Systems (MOS) concepts
			K3 Management of Security in Mobile Application
			S1 Provide expertise to help solve complex MOS problems
			S2 Use knowledge to build MOS enterprise architecture
		A.6. Application Design	K1 Data Modelling
			K2 Prototyping
			K3 Web Services standards
			K4 User interface design principles
			S1 Collect Requirements
			S2 Design user interface
			S3 Manage User Experience Factors
			S4 Design Data Model
			S5 Use Design Patterns
			S6 Manage Product Backlog
			S7 Mobilize existing application architectures
			S8 Maintain System Responsiveness
Mobile App Development	B. BUILD	B.1. Application Development	K1 Mobile Programming Languages
			S1 Manage Mobile SDK
			S2 Develop Mobile Native Apps
			S3 Develop Mobile Hybrid Apps
			S4 Develop Mobile Web Apps
			S5 Develop User Interface
		B.2. Integration	K1 Cross Platform issues
		B.3 Testing	S1 Test Mobile Application
	C. RUN	C.3. Service delivery	K1 Mobile App Analytics
Mobile App Deployment	B. BUILD	B.4. Solution Deployment	K1 Measurement of Users Experience
			K2 Software packaging and distribution: submit the app to store
			S1 Organize and manage trial days
	C. RUN	C.1. User support	S1 Managing feedbacks from clients
			S2 Communicate with end-users
Channel management	E. ENABLE	D.6. Digital marketing	S1 Choose the best sales channel according to features ofapp
			S2 Enhance App Visibility by digital marketing methods
			S3 Promote App applying digital marketing methods
			S4 Understand ASO (App Store Optimization)

6 DISCUSSION

The first phase of our study collected and analysed the information provided by MAD SMEs during the industry consultation process. The analysis of skills demanded by SMEs (RQ1) served to create a basis for analysing the perception of these companies regarding the presence of those skills in their employees (RQ2). Data analysis showed that there is a gap among the skills requested by SMEs according to literature, opinion and practice in app development and the ones shown by employees at the time of the study. The information reveals that app developers tend to have high technical knowledge and skills, but a deficit of competences related to marketing and business which are needed in this area. This pilot study has some limitations. It is an exploratory work what makes our results merely descriptive, so it needs to be confirmed by a larger sample. Also, the skill set used in the questionnaire is not based on standards, something that limits its transferability to different contexts and countries. Despite these limitations, the first phase of our study provides a general insight into the situation of MAD in SMEs confirming what other authors and reports had previously detected.

The second phase was aimed at researching the possibility of determining a common general set of

competences for mobile app developers. After collecting and analysing information from stakeholders, it was possible to confirm a high degree of consensus on the set of skills which are most recommendable for the effective and productive performance of MAD. The quantitative and qualitative analysis of data has confirmed a solid determination of the list of skills and knowledge which are recommended for a profile of app developer. This set of items represents an answer to RQ3. This idea is also applicable to other existing tools related to self-assessment of competences based on e-CF (e.g. [42]).

Moreover, the construction of the framework APP-CF, based on a sound statistical method which enables grouping of items together with the map to the e-CF standard [16], with the collaboration of the industry and validated by experts, allows an affirmative answer to RQ4. The value of this framework linked to a European standard resides in its capacity of enabling easier transferability to stakeholders across Europe as well as its value as basis for an easier matching to learning outcomes, which could be a relevant step for improving syllabus of education and training courses for MAD. Furthermore, the framework can also guide the management of HR in MAD, helping to configure recruitment, internal career paths and configuring organisational training oriented to skilling for specific positions.

The findings of the industrial research of this work underline the importance of non-technical skills related to marketing or business for the development of mobile applications. In particular, the greatest deficits are found in user support (managing feedback of clients and communicate with end-users about issues), elaborate quality plans, knowing the legal and regulatory landscape, knowing the risk and opportunity assessment techniques and security issues. Note that some of these deficits are consistent with those reported in other works, such as user support [43] or security [10, 12, 43, 44].

We are aware that our study has some limitations. Although the sample is varied and relevant both in profiles of experts and country origin, more information would be recommendable to confirm the details on competences, skills, and knowledge. Getting information from other European countries and performing a detailed analysis of a good sample of job ads to study how the recruiters express their requirements when trying to hire new professionals for app development would be a necessary additional step in the future. This could be possible through the tool OVATE from CEDEFOP [45] that collects information from millions of Online Job Ads (OJA) and maps them to occupations and skills and knowledge items of ESCO, the EU labour classification. In order to facilitate this work, we have been also working in the mapping of the elementary items of APP-CF to similar items in the catalogue of more than 13,000 skills and knowledge items of ESCO. As a first result, the 44 items of the framework have practically identical equivalent items in ESCO in 20 cases: e.g., there is exactly one "Design user interface" and another "Use software design patters" skills in ESCO. In fact, experts at the beginning of the process for the framework also get inspiration from ESCO when determining the first proposals of items for the MAD profile. Another 18 items have similar equivalents in ESCO, sometimes they refer to broader concepts and in others there are not big differences in description or approach: e.g., "Understand the legal & regulatory landscape" in APP-CF can be linked to "Comply with legal regulations" which is a broader skill, which includes understanding as first step. Finally, there are six items where we can find more or less equivalent items in ESCO, but sometimes they are skills instead of knowledge or vice versa or simply they have some differences: e.g., knowledge "measurement of users experience" in APP-CF has some link with the ESCO skill "measure software usability".

Additionally, our previous research [46] showed the importance of soft-skills and attitudes in the employability of engineers. In fact, the last version of EN 16234 has already added an annex with the first approach to behavioural skills. In the case of the ESCO classification, the section of cross-sectoral transversal skills directly includes a specific subsection on attitudes and values at work in its structure. So, as future work, we will explore this link while collecting more information from stakeholders for future refinement of the framework. The work for a model for matching and bridging ESCO and e-CF [20] should serve as a foundation for the integration coming from the different sources. The approach of combining extensive consultation to sectoral stakeholders with mapping to the relevant skills frameworks like ESCO or e-CF has already allowed the determination of other recommended professional profiles, e.g., for IoT implementation [47].

7 CONCLUSIONS AND FURTHER WORK

We have defined APP-CF, an e-competence framework for the field of MAD after a complete process of analysis of existing studies and references as well as after a detailed collection of information from a very relevant sample of stakeholders and experts. It is mapped to e-CF to ensure transferability and validity in the future. This framework can help to derive the learning outcomes of training programs to improve the competences of IT curricula in the field of MAD, but it also represents assistance to recruiters and HR managers in the personnel selection processes: of course, it can also guide developers who want to improve their professional profile or move to MAD specialization. Additionally, it would help students and professionals to choose training courses, official or not, to more efficiently improve their competences for MAD. The analysis of the information from candidates and recruiters would help to refine details of the framework to add an extra step of validation and fine-tuning. We are also planning an additional collection of information from experts from other European countries and with the presence of even a wider variety of profiles (e.g., more ICT recruiting experts and ICT managers like CIOs).

Finally, the process followed to get the evidence-based framework APP-CF herein described to also serve as a guide for determining the recommended competences for other professional profiles according to the needs of the industry. It is also valid to improve the employability and bridge the gap between the expectations of the industry and higher education graduate profiles.

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5.3 Summary of the results of Publication 3

This publication links the data collected from an extensive variety of stakeholders in different countries of the EU with several collaborative surveys that allowed an iterative confirmation of the representativeness of information. The first part of the analysis was related to the European frameworks, e-CF and ESCO. The first one has not a specific reference to the mobile app developer role, but only a general for the software developer role. In case of ESCO, there is only one reference to mobile application developer profile. The experts of the project consider that this information was partially useful as it was too much oriented to mere programming role, far from what was needed for the project, considering other roles with skills related to project management and soft skills. Obviously, the project decided to address the real scenario in industry adding the job market perspective to ensure relevant results.

During the literature analysis and the design of the surveys for collecting information, it was possible to extract two conclusions: a) e-CF and ESCO are important references to guarantee a consistent information extraction and b) the available information was not enough to create the expected framework for mobile application development. Furthermore, the work with survey data needed to increase complexity in design of questionnaires and in data analysis to be capable of managing tens of variables with suspected many cross-relationships. This type of complex analysis is one importance addition to the advances already considered in the approach while the results of this publication served as validation of the underlying methodology on the approach proposed in this thesis.

6. DISCUSSION AND RESULTS

The previous sections have shown the publications that present the results from the doctoral work for this thesis. This section offers a short discussion on how these publications and their results are related to the research question and objectives of the thesis.

6.1 Relation between publications and research questions and objectives

Research Question 1 (RQ1): is it possible to conduct studies on the professional profiles and the competencies, skills, knowledge, and attitudes demanded for a good performance in the ICT roles with more precision and better data support than in the existing studies?

The publication 1 shows the limitations of the works, found in literature, conducted to study the ICT professional profiles. The many contributions used surveys as main method. A survey could be a good method in some of the cases but only if the sample is representative enough, if it is carefully designed and if it avoids ambiguity and inconsistency in terminology and concepts. As seen in our literature review, all the studies using surveys did not follow this approach. But going further than the use of surveys, the results of contributions in literature are hindered by the lack of a commonly accepted or standardized terminology, the deficit in variety of sources of information and limitations in size of dataset or samples, poor efficiency and effectiveness of mainly manual, compilation methods and too basic analysis of data. This analysis confirms the achievement of **research objective 1 (OBJ 1):** analysis of the weaknesses and the limitations of existing methods for the study of professional profiles and the competencies, skills, knowledge, and attitudes recommended for a good performance in ICT roles and occupations.

This thesis devises a new approach to improve the study of ICT professional profiles. This was firstly experienced with soft skills in publication 1, for roles in information systems development. The exploitation of Ovate, a tool developed by Cedefop and directly linked to ESCO framework, enable the collection of data from millions of online job ads. Those data allowed a detailed analysis of soft skills requested by employers for the ICT roles (mainly the group 25 and 35 of occupations in ESCO). The information was linked to the soft skills NCS framework that is also linked to ESCO. Besides these data from job market, the approach wanted to ensure the exploitation of other sources to enhance the representativeness and accuracy of conclusions. Extracting information from the ESCO database to capture the opinion of more than 200 experts who participated in its development was a relevant complement to the analysis. As the ESCO website does not allow sophisticated queries, its information was extracted using web scraping techniques and ESCO API, creating a local database replica of the ESCO website. The queries to the database allowed an additional study of two main needs: competences demanded by recruiters and linking information to a reference framework, the NCS framework already linked to ESCO. This is also a first confirmation of achievement of the **research objective 2 (OBJ2):** exploration of the integration of widely accepted reference frameworks and models with different data sources on ICT professional roles and occupations.

The quality of results largely improved the ones achieved in all previous literature contributions. It was possible to positively answer the **research question 1 (RQ1).** Yes, it is possible to conduct studies of professional profiles and the competencies, skills, knowledge, and attitudes demanded for

a good performance in the ICT roles with more precision and better data support than in the existing studies.

Research Question 2 (RQ2): can the analysis of professional ICT profiles be benefited from the integration of European frameworks of competencies and job classification such as ESCO and EN16234?

The publications 1, 2 and 3 in this work have integrated the competences to reference frameworks ESCO and e-CF. The link to the reference sources enables consistency in results and ensures the full understandability of conclusions in the EU thanks to the use of known and common terminology and concepts. The integration of the information to the reference frameworks was already validated in the publication 1 (using ESCO as main link among the different sources) but it is also clearly confirmed in publications 2 and 3, as they both use ESCO and e-CF as basic feature for design of the collection of data and for the integration of information. The three publications confirmed the achievement of the **research objective 2 (OBJ2):** exploration of the integration of widely accepted reference frameworks and models with different data sources on ICT professional roles and occupations.

The publication 2 and 3 used different survey methodologies to combine different sources and increase the representativeness and size of samples to get solid conclusions. One key point in both publications is the rigour in survey design and the corresponding data analysis but especially also the use of statements directly linked to the ESCO and e-CF as reference. The results developed through these surveys have similar results concluded by other publications in the field thus validating this approach to get a more effective comparison of results among different sources. As a consequence, it is possible to confirm a positive answer to the **research question 2 (RQ2).** YES, the analysis of professional ICT profiles can be benefited from the integration of European frameworks of competencies and job classification such as ESCO and EN16234.

At the same time, together with the advances already validated in publication 1, there is a confirmation of the achievement of the **research objective 4 (RQ4)** as the combination of all the improved methods leads to a proposal for the study of professional profiles and the competences, skills, knowledge, and attitudes demanded for a good performance in the ICT roles demonstrating an improvement of accuracy and representativeness of the results.

Research Question 3: can the relationships between professional profiles and their competences, skills, knowledge, and attitudes be explored in real context scenarios to lead to more sophisticated results such as specialised competence frameworks?

The publications 1 and 3 compare data from the recruiters' perspective (expression of skills required for a specific position as expressed in job ads) and from the experts' perspective (recommended skills as expressed in occupation profiles in a reference framework). In the case of the publication 1, mainly focused on the demand in labour market and the recommendation of experts regarding soft skills for two ICT groups of occupations, some discrepancies arose: the experts' recommendations of soft skills for a specific occupation do not match to what was expressed by recruiters in job ads. These differences suggested the importance of exploring these relationships in real case scenario.

In case of the publication 2, specific research questions were proposed during the development of this publication, which were focused on study the demand of the skills for the specific profile, the

current skills level of the employees for the specific profile, and the set of competences which are recommended by experts for specific profiles in the frame of a real case scenario of a project. The publication 2 results show some agreements and disagreements with other studies conducted in the field and the opinion of different experts. The publication 3 also explores another specific area of occupations in a real case scenario with a wide variety of stakeholders as part of another project. The vision of the different types of stakeholders also offered commonalities and differences that, in the end, enriched the final conclusions. This was possible thanks to the approach adopted for the analysis, with extra soundness and complexity in publication 3. Therefore, it suggests a positive answer to the **research question 3 (RQ3)**. Yes, it is possible to explore the relationships between professional profiles and the recommended competences, skills, knowledge, and attitudes in real case scenarios.

It is also possible to see that whole combination of more modern and effective methods and techniques in the set of the three publications, as described before, contributes to the confirmation of **research objective 3 (OBJ3)**: use of more modern and solid techniques such as large open datasets, natural language processing, taxonomies, etc. for the collection, management, and analysis of information on ICT professional profiles overcoming the limitations in effectiveness and efficiency of traditional and manual methods.

6.2 Relation between publications and the main hypothesis

Figure 2 shows a summary of the main contributions of the three publications in this thesis. The key points in each case are the following ones:

- Publication 1: proposal of approach based on the usage of reference frameworks and analysis of larger datasets on job advertisements linked to the reference frameworks. As result it was possible to extract more reliable and representative data for the analysis of ICT professional profiles.
- Publication 2: analysis of the combination of different surveys with solid design and statements extracted from the reference frameworks within a real case scenario of a project. The process resulted in more consistent data for the analysis with more solid foundations in the use of surveys leading to reliability of the information source.
- Publication 3: combination of various sources as surveys, literature analysis, reference frameworks, more complex data analysis and conclusions on the demanded competences for specific ICT professional area. As result it was possible to propose a new framework of skills and knowledge based on solid and referenced information.

The publication 3, as the chronological final step in the logical path of presentation of results of the doctoral work, adds an additional value as the final validation of the approach adopted for this thesis: “Proposal for the application of new approaches to the analysis of digital competences and professional profiles”.

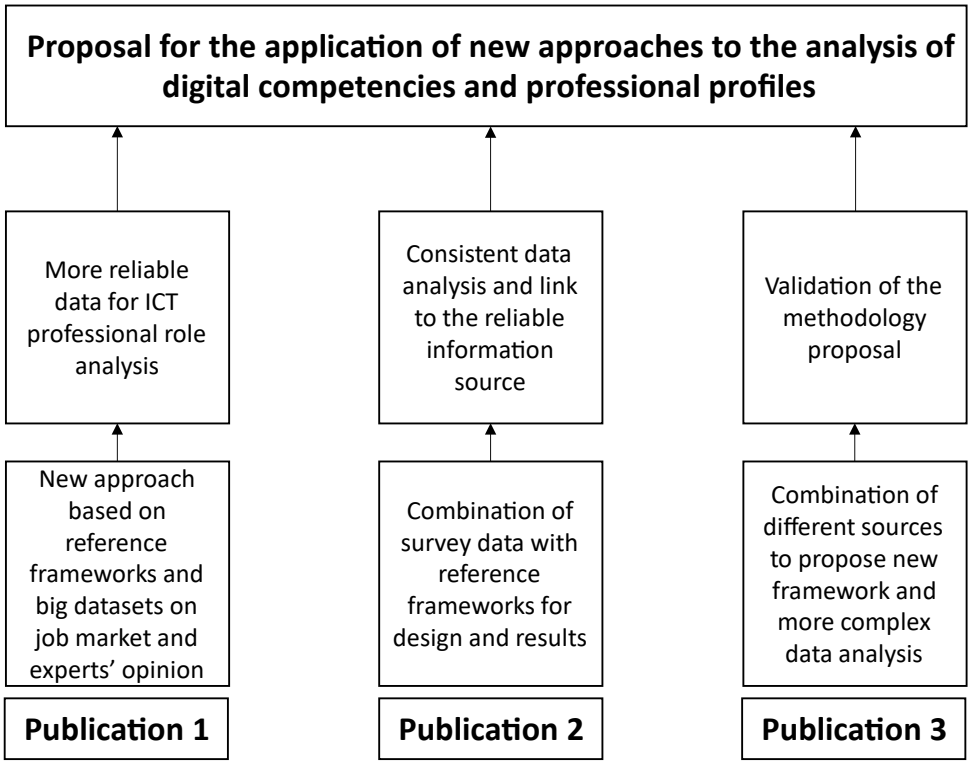

Figure 2. Main contributions of the results presented in each of the publications.

7. ADDITIONAL RELATED WORKS

This thesis has selected the impact publications with results aligned to the development of the doctoral work for the confirmation of the main hypothesis. However, other complementary results from the work are also present in other related publications and research projects that were linked to this same line of research on ICT professional profiles.

7.1 Book chapters

Publication: Skills for IT Project Management: The View From EU Frameworks

AUTHORS: Luis Fernández Sanz, Vera Pospelova, Ana Castillo-Martínez, María Teresa Villalba, Manuel de Buenaga, Marián Fernández de Sevilla
REFERENCE: ISBN13: 978179981279. Handbook of Research on the Role of Human Factors in IT Project Management
CHAPTER: 7
PAGES: 85-105
DATE: 2020
EDITORIAL: IGI Global

ABSTRACT: IT project management requires qualified staff capable of facing the rapidly changing conditions and even terminology of technology while managing large teams of people where main costs come from human work. A key factor for managing human side of IT is the understanding of the essential feature of people performance: skills. Capability to cope with this highly demanding field should firstly rely on clear and standardized frameworks for skills, not only the technical or hard ones but also the soft or behavioural ones, considered by employers as essential for employees' productivity. This chapter shows how the recent development of frameworks and standards in European Union (e.g., EN16234 or ESCO classification) is enabling the powerful exploitation of open big data from existing skills analysis systems for a more precise and solid determination of recommended skills for IT project management. The analysis will especially focus on the behavioural skills.

7.2 International Conferences

Communication: Skills Match: how open data enable analysis of demand of non-cognitive skills in the labour market

AUTHORS: : V. Pospelova, L. Fernández Sanz, M. de Buenaga, A. Castillo
REFERENCE: ISNN: 978-84-18254-52-9. Congreso Internacional sobre Aplicación de Tecnologías de la Información y Comunicaciones Avanzadas (ATICA 2019)
PAGES: 270-277
DATE: 2019

EDITORIAL: Universidad de Alcalá

ABSTRACT: Non cognitive skills (NCS) are considered a specific subset of the so called soft skills focused on behaviours and attitudes. Employers and HR experts agree on their importance for employability, prioritizing this type of skills versus specific knowledge or skills for an occupation. Albeit its importance, the present scenario is hindered by the lack of homogeneity in terminology and concepts as well as the absence of widely used standards. The Skills Match project has contributed to solve this situation, firstly creating a solid NCS framework which, in the end, enables a new approach to analyse the demand of skills in specific occupations with open data from big EU initiatives like ESCO or OVATE. This new approach and the results of data analysis are presented in this contribution.

Communication: Skills Match: how the sociology can impact in open data analysis of non-cognitive skills and why it should be considered

AUTHORS: V. Pospelova, L. Fernández Sanz, I. López Baldominos
REFERENCE: ISBN: 978-84-18254-84-0. ATICA2020: Aplicación de Tecnologías de la Información y Comunicaciones Avanzadas y Accesibilidad
PAGES: 408-415
DATE: 2020
EDITORIAL: Universidad de Alcalá

ABSTRACT: Non cognitive skills (NCS) are considered a specific subset of the so called soft skills focused on behaviours and attitudes. Stakeholders in labour market agree on their importance for employability, prioritizing this type of skills versus more specific knowledge or skills for an occupation. The open data collected from big EU sources (e.g., OVATE and ESCO) can help us to identify the NCS most demanded by employers and recommended by HR experts-. The Skills Match project has shown in practice the use of open big data to provide an accurate analysis of NCS demand to guide job seekers. As dominant country culture is considered a factor which impacts the disposition of nationals towards the development of NCS, the project has also analysed the relation of the six cultural indicators from Hofstede with the NCS of the project's framework. The combination of job market data and cultural background results in a very interesting analysis of NCS relevance as sometimes most demanded skills are not the ones with most positive cultural acceptance in a country.

Communication: Skills Match: cómo los datos abiertos permiten analizar la demanda de las habilidades no cognitivas en el mercado laboral

TITLE IN ENGLISH: Skills Match: how the open data allows to analyse the demand of non-cognitive competences in the labour market.
AUTHORS: V. Pospelova, L. Fernández Sanz, M. de Buenaga, I. López Baldominos
REFERENCE: ISSN: 2531-0607. XXVI Jornadas sobre Enseñanza Universitaria de la Informática (JENUI2020)

VOLUME: 5
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ABSTRACT: Non cognitive skills (NCS) are considered a specific subset of the so-called soft skills focused on behaviours and attitudes. Employers and human resources experts agree on their importance for employability, prioritizing this type of skills versus specific knowledge or skills for an occupation. Albeit its importance, the present scenario is hindered by the lack of homogeneity in terminology and concepts as well as the absence of widely used standards. The Skills Match project has contributed to solve this situation, firstly creating a solid NCS framework which, in the end, enables a new approach to analyse the demand of skills in specific occupations with open data from big EU initiatives like ESCO or OVATE. This new approach and the results of data analysis allows us to explain the most demanded and recommended NCS for ICT job positions, which will allow teachers to adapt the students' training.

Communication: Análisis de habilidades de los perfiles profesionales involucrados en los proyectos informáticos

TITLE IN ENGLISH: Analysis of the competences of the professional profiles related to IT project management.
AUTHORS: V. Pospelova, I. López Baldominos, L. Fernández Sanz
REFERENCE: ISBN: 978-84-18979-68-2. XII Congreso Internacional sobre Aplicación de Tecnologías de la Información y Comunicaciones Avanzadas (ATICA 2021)
PAGES: 260-267
DATE: 2021
EDITORIAL: Universidad de Alcalá

ABSTRACT: Human resources are one of the key elements for the success of an IT project. Their qualification and knowledge of hard and soft skills and an effective identification of these skills in the the demands of each role or position are essential for the success of each project. The efforts to determine the recommended soft skills for professional roles in the in the field of information technologies and information systems (IT/IS) have limited results due to the use of manual procedures, the lack of use of use of frameworks in the analysis and small sample sizes. This paper presents a new approach that exploits existing reference models such as ESCO, e-CF and NCSF (NCS Framework) as a basis for analysing large datasets connected to ESCO database which has thousands of relationships between occupations and soft skills and also connected to Ovate tool, which contains millions of online jobs advertisements data. The combination of labour market information with ESCO's expert opinion and the analysis of the main reference frameworks, has determined the recommended soft skills profiles for the most popular professional roles in IT. The method proposed in this work allows to analyse all IT/IS profiles, as well as to extend the study to technical competences.

7.3 Participation in European Projects linked to the results of doctoral work

During this thesis development, the candidate participated as assistant researcher in different European level projects.

Project: Skills Match

ROLE: Participant
REFERENCE: DG CONNECT LC-00822001 (OKT2017)
FINANCED BY: ECOKT (DG Connect)
DURATION: 01/06/2018 - 31/05/2020
BUDGET: 998.268€

DESCRIPTION: The aim of Skills Match project is to develop the assessment and learning technology in order to help users to adapt their skills to the demanded of the labour market. The solution proposed in this project will integrate and improve the development of Non-Cognitive Skills (NCS). During the project, the partners that participated in this project created an online platform for the assessment and the evaluation of these NCS. The platform also recommends training courses based on Open Education Resources (OER) and Massive Open Online Courses (MOOCs) according to the user gap and the desired occupation. Skills Match platform is capable to evaluate user NCS level showing strong and week points in relation to what is recommended for the desired occupation. A personalized training itinerary including a portfolio linked to open badges that will provide recognition of the new skills has been developed in this platform.
The partners' countries that participated in this project are Sweden, Spain, Ireland, and Italy.

Project: SMACITE

ROLE: Participant
REFERENCE: Lump-Sum - 101052513
CO-FINANCED BY: European Union - EACEA
DURATION: 01/06/2022 - 31/05/2025
BUDGET: 1.675.545€

DESCRIPTION: The project aims to address the skills gap of Smart Cities technicians and engineers, by designing and testing a vocational education and training program that is based on a novel and multi-disciplinary curriculum combining digital skills on Smart Cities enabling technologies, with soft, entrepreneurship and green skills. The main project beneficiaries are Smart Cities technician and engineers, from the public sector (i.e. municipalities) or enterprises providing Smart Cities solutions as well as HEI and VET students interested in Smart Cities. The curriculum will be tested through 4 national pilots in Greece, Bulgaria, Spain and Italy with at least 160 trainees. The certification of the skills and competences will follow a two-fold approach: a) using micro-credentials to recognize the knowledge and skills gained through the successful completion of each online training module at the MOOC and Virtual Worlds and b) designing the "Smart Cities Specialization Certification" that will be awarded to those passing online certifications exams with e-proctoring after the completion of the

training modules. The project will create an ecosystem for the co-design and co-development of an innovative curriculum and technology-enhanced learning tools for the upskilling/reskilling of Smart Cities technicians and engineers.

7.4 Participation in development of European standards on skills frameworks

During this doctoral period, the candidate participated as assistant researcher in contracts for the development of European standards on ICT professionalism and frameworks.

E-Competence Performance Indicators and Common Metrics

REFERENCE: 2019/00234/001 (SA 2018-14)
FINANCING ADMINISTRATION: UNINFO
DURATION: 22/09/2019 - today
BUDGET: 29.280€

ICT Professionalism and Digital competences

REFERENCE: 2019/00140/001 (SA 2018-13)
FINANCING ADMINISTRATION: UNINFO
DURATION: 14/06/2019 - 14/10/2021
BUDGET: 27.090€

E-Competence Framework

REFERENCE: 2018/00032/001 (SA 2017-03)
FINANCING ADMINISTRATION : UNINFO
DURATION: 22/01/2018 - 28/02/2020
BUDGET: 40.170€

7.5 International research stays

During the development of this thesis, the author made two research stays outside Spain a total duration of, at least, three months.

The first research staying took place in Østfold University College (Halden, Norway) from 15/08/2022 to 09/09/2022. During this stay, it was possible to work on some of the research questions raised because of the hypothesis of this work, especially on "*can the relationships between professional profiles and their competences, skills, knowledge, and attitudes be explored in real context scenarios to lead to more sophisticated results such as specialised competence frameworks?* (**RQ3**).

The second research staying took place in University of Alaska Anchorage (Anchorage, AK, United States of America) from 01/07/2023 to 23/09/2023. During this stay, it was possible to learn new

methods for big data analysis, results classification, and natural language processing. The work developed during this research staying is connected to the **OBJ 2** and the **OBJ 3** of this thesis.

Universidad de Alcalá supported both research stays through two grants for funding staff mobility. Local researchers in charge of guidance and supervision of the work of the author during both research stays issued the two corresponding reports validating the research work done.

8. CONCLUSIONS AND FUTURE WORK

The previous sections have presented the articles included in the compendium of publications that presents the results produced by the doctoral work. The three publications have been published in impact journals and conferences. They represent an additional external validation of the quality of the research work. Along the whole process of the doctoral work, we had emphasized the contribution of the usage of reference frameworks and large and varied datasets for the analysis of labour market and experts' recommendations to generate ICT professional profiles with description of recommended skills, knowledge and attitudes or soft skills. This section presents a summary of the main points concluded from the work in this thesis and suggests possible lines of future work exploiting the approach adopted in our research.

8.1 Conclusions

The first publication, "Big data and skills frameworks to determine recommended profiled of soft skills for IS development", has shown how it is possible to exploit the existing tools and sources with big datasets in combination with reference frameworks. This approach combining both sources (job market analysis and experts' opinion from reference databases), lead to stronger results and conclusions rather than the mere usage of one limited single survey. In this publication, it was applied to the analysis of soft skills recommended for some of the ICT occupations, those linked to information systems development. This publication clearly shows the limitations of the existing literature (e.g., surveys with small number of replies, small job ads dataset with manual compilation, limitation of dataset to one country, absence of reference frameworks or terminology, etc.). This conference communication offered a clear example of the application of an improved approach for ICT professional profiles based on variety of data sources for soft skills, using a framework previously matched to ESCO to get consistent results.

In the second publication, "User and Professional Aspects for Sustainable Computing Based on the Internet of Things in Europe", the main focus was the usage of different ICT frameworks to generate a solid survey design with a rigorous process for its validation by experts. This approach allows the easy expression of results for ICT profiles in a way universally understood directly thanks to the use of common terminology extracted from the frameworks and recognized throughout Europe. This publication explored human factors and stakeholders' opinion linked to real case scenario of Smart Cities projects, thanks to the participation in a multinational EU-funded project. The collected sample was then directly linked to the ESCO classification as well as to EN16234 framework.

In the last publication, "Mobile Application Development Skills Set Aligned with the E-Cf Framework and Industry Needs", the level of complexity of the results increased after applying more sophisticated techniques of statistical analysis. Based on the data collection methods developed in the previous publications of this thesis, with surveys linked to reference frameworks like ESCO and EN16234, it was possible to collect relevant and statistically meaningful dataset to propose a new framework, in this case, focused on occupations and roles in the area of mobile application development. This was possible after applying more sophisticated data analysis, going further than mere descriptive analysis, using techniques like the Exploratory Factorial Analysis (EFA). The

definition of this new framework proves how the different sources can be combined to reach a solid result, especially if experts already validate the different sources.

The set of the three publications shows a logical path where the proposed new approach, that adopts more effective and efficient methods, leads to increasingly precise, representative, and sophisticated results, overcoming the limitations of the traditional approaches seen in previously existing literature. This represents the confirmation of the main hypothesis because "**It is possible to improve the accuracy and the representativeness of the analysis of professional profiles (and their competences, skills, knowledge items, and attitudes) recommended for a good performance in ICT roles and occupations by modernizing the data collection methods and analysis**".

8.2 Future work

The results and the lessons learned during the doctoral work has inspired a set of future research activity to follow the exploitation of the main approach developed in this thesis. The following ones are the suggestions for future work:

1. The Ovate tool developed by Cedefop (and still under further refinement) contains big amount of data related to job advertisements: last recent numbers in summer of 2023 reach more than 100 million of job ads. These results collected by this tool are totally mapped to the ESCO framework. However, this tool has some limitation; for example, data are linked to ESCO group of occupations, rather than to individual occupations. Although this problem solves the relevance of number of data records acquired for each group, it does not allow a deep analysis for a specific position. One of the research lines in this field could be the development of specific web scraping tool that gather information from job portal and linking them to the individual ESCO occupation in the ICT field.
2. Another research line similar to the previous one is the link between job ads and the e-CF framework. The job ads are not still very frequently referring to e-CF competences in the description of positions or in the list of required profile for candidates. As the e-CF competences are described at high level, one of the approaches could be the analysis of ads using natural language processing techniques to identify the presence of more relevant elements of e-CF competences like the activities of its dimensions 2 and 3 or the examples of skills and knowledge of dimension 4. Using this catalogue of relevant terms from e-CF that could be stored into a database, it could be further exploited for different types of analysis. This database data could be combined with web scraping techniques to analyse the job ads text thus allowing the determination of the competences most demanded by the employers for a specific position.
3. Deeper research can be also developed in soft skills. The Skills Match framework, already linked to ESCO, can be the start point for deeper and more detailed link of this framework (with 36 skills and 778 buzzwords associated to these skills) to ESCO, to identify all the soft skills existing in the whole catalogue of almost 14.000 competences in the classification. Again, the use of natural language processing techniques could enable a semiautomatic process monitored and then validated by human experts.
4. Exploiting the expertise developed during this doctoral work, it is possible to address the research with other frameworks such as DigComp, the EU framework of digital competence

for citizens, in version 2.2 [49] at the moment of writing this document. DigComp describes the digital competences for users with 5 areas of competence to classify 21 competences with 8 levels of proficiency. Version 2.2 includes 250 examples of skills, knowledge, and attitudes framed in real scenarios. Mapping existing certifications as, for example, ICDL, or MOOC courses, based in the similarity of their descriptions to the catalogue of digital skills in the DigComp framework would provide a useful guideline for the education the training and recognition of digital skills.

5. Similar research studies can be also conducted for other frameworks, outside the EU. In United States of America, O*NET is the reference framework, already linked to ESCO. Another framework, SFIA, is used as reference by other countries as for example New Zealand [50]. The comparative analysis, especially in the case of soft skills, between different global frameworks can answer questions related to the cultural influence across the world, similarly to the study conducted by Hofstede [51]. It is also possible to detect relevant local differences in other aspects of professional profiles.

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Programa de Doctorado en Ingeniería de la Información y del Conocimiento

Propuesta de aplicación de nuevos enfoques de análisis de competencias y perfiles profesionales digitales

Proposal for the application of new approaches to the analysis of digital competencies and professional profiles

Tesis Doctoral presentada por:

VERA POSPELOVA POSPELOVA

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