A systematic review of capability and maturity innovation assessment models: Opportunities and challenges

M. Giménez-Medina [a,b,*], J.G. Enríquez [b], F.J. Domínguez-Mayo [b]

[a] *Emergya, Calle Luis de Morales, 32, 41018 Sevilla, Spain*

[b] *Computer Languages and Systems Department. University of Seville, Spain. Escuela Técnica Superior de Ingeniería Informática, Avenida Reina Mercedes, s/n., 41012, Seville, Spain*

Keywords:
Innovation assessment
Innovation management
Technological innovation
Capability maturity model
Innovation management systems
Systematic mapping study

A B S T R A C T

Public funding, being the primary source for innovation, imposes restrictions caused by a lack of trust between the roles of public funders and organisations in the innovation process. Capability and maturity innovation assessment models can improve the process by combining both roles to create an agile and trusting environment. This paper aims to provide a current description of the state-of-the-art on capability and maturity innovation assessment models in the context of Information and Communication Technologies. To this end, a Systematic Mapping Study was carried out considering high-quality published research from four relevant digital libraries since 2000. The 78 primary studies analysed show several gaps and challenges. In particular, a common ontology has not been achieved, and Innovation Management Systems are scarcely considered. Concepts such as open innovation have not been correctly applied to incorporate all Quadruple Helix stakeholders, especially the government and its role as a public funder. This implies that no studies explore a standard agile public–private maturity model based on capabilities since the public funders' restrictions have not been considered. Furthermore, although some concepts of innovation capabilities have evolved, none of the studies analysed offer a comprehensive coverage of capabilities. As potential future lines of research, this paper proposes 11 challenges based on the 5 shortcomings found in the literature.

1. Introduction

Innovation is a multidimensional, complex, unpredictable, and non-linear process (Rejeb & Younes, 2018) that has been studied from different perspectives, levels, and approaches for many years. Most studies have failed to capture the full complexity of all the innovation foundation processes they have tried to describe (Balmaseda et al., 2007).

Innovation is also a fuzzy concept, often lumped together with R&D in the literature, where it may appear as (1) a process encompassing R&D, (2) an outcome of R&D, or (3) a later phase of R&D. In Spanish-speaking countries, R&D is translated as I+D+i (R+D+i), including innovation after research and development. Innovation is a scientific cross-cutting topic, so it is difficult to compare how it is approached in different fields. It is also a dual process (Cropley et al., 2011) that requires systematisation and creativity. Systematisation is achieved mainly through Innovation Management Systems (IMS). It may, however, disrupt the freedom that is necessary for creativity (Jayawarna & Holt, 2009; Kondo, 1996). Ultimately, innovation needs to be open (Chesbrough et al., 2006), with the participation of different stakeholders as defined in the concept of the quadruple helix, i.e., government, industry, academia, and citizens (Carayannis & Campbell, 2009). This paper discusses the importance of one of those actors (i.e., the government) as a public funder in the innovation process.

Public funding is the driving force for European innovation, as private investment in this area is not as developed as it is in others. While Europe has the highest public expenditure in R&D, overall private investment is only 19%, behind China (i.e., 24%) and the United States (i.e., 28%) (Bughin et al., 2019). Public R&D expenditure in the EU in 2019 was 2.19% of Gross Domestic Expenditures[1] and successful R&D activity relies much on administration efficiency to distribute this funding. In Spain, for example, around one out of every two euros of the R&D budget – that is to say, 47,9% –, is not being spent[2]). According to the OECD, policy needs to be able to guide innovation efforts to where they are most needed. This has implications for how governments support research and innovation in companies (OECD,

* Corresponding author.
E-mail addresses: mgimenez@emergya.com (M. Giménez-Medina), jgenriquez@us.es (J.G. Enríquez), jdominguez@us.es (F.J. Domínguez-Mayo).

[1] https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20201127-1.

[2] https://cotec.es/observacion/ejecucion-presupuestaria-de-la-i-d-del-sector/bbc598f2-edc4-a458-5c25-4dc1475c8545.

2021). As mentioned above, the concepts of R&D and innovation are mixed and often interchanged in academic studies.

The effectiveness of government support for R&D has a positive but modest impact on innovation at the company level (Petrin, 2018). At the same time, however, the ineffectiveness of public funding is a problem for innovation, especially in Europe, where private investment is less developed. This paper attempts to study the problem with the help of currently proposed innovation models. Given that innovation is achieved through projects undertaken by innovative organisations (called executors in this paper), it is subject to the triple constraint, or project management triangle (Atkinson, 1999): *scope-time-cost*. Organisations need capabilities and resources to develop innovation projects. Funding – the main obstacle to innovation, according to the EU Green Paper on Innovation (Commission, 1995) – is the primary resource. Funding stresses time and scope, causing projects to lose their innovative character. So despite being necessary, it can also hinder innovation. This is known as the implementation paradox (Giménez Medina, 2020). From ideation to execution, innovation needs speed to take advantage of its "momentum" — the time during which an innovation-opportunity window is open. In contrast, public funding is a slow, restricted, and bureaucratic process that restricts projects in terms of scope and time. The implementation paradox assumes that the restrictions are caused by public funders' lack of trust and understanding of the innovation process. Increasing the knowledge and empathy of public funders through the executor maturity would increase their trust and limit their restrictions. Building a model that assesses capability and maturity and compares good practices between executors should therefore be researched as a potential solution.

In this study, a systematic mapping study (SMS) (Petersen et al., 2008) was carried out to provide an overview of the problem. The SMS is a type of literature review, similar to systematic literature reviews (SLRs) (Kitchenham et al., 2009), but different in terms of its goals, breadth, validity issues, and implications.

The Main Research Question (MRQ) was: What is the state-of-the-art in assessing innovation in ICT[3] organisations in both academic and industrial fields? We were therefore looking for models that involve public funders and executors in the innovation process by assessing capability and maturity. The research aim was to investigate whether a common model that establishes trusting relationships between public funders and executors through capability-based maturity could improve the effectiveness of public financing by reducing its restrictions.

The rest of the paper is structured as follows. Section 2 presents the planning. Section 3 details the execution of the different phases of the SMS. Section 4 describes the classification scheme. Section 5 reports the results based on the classification scheme. Section 6 discusses the results and identifies a set of challenges and future lines of work. Section 7 reviews related works comparing their findings with ours. Section 8 describes threats to the paper's validity, and Section 9 summarises the conclusions drawn from the study.

2. SMS planning

This section presents all the tasks performed in the planning phase, as defined in the SMS method proposed by Kitchenham et al. (2009) and Petersen et al. (2008).

2.1. Research questions

Since the MRQ (cf. Section 1) was too general, some Research Questions (RQs) were formulated to provide a more schematic response. RQs structure the MRQ as follows:

- RQ1. What methods, techniques or tools have been researched for assessing innovation in ICT organisations?
- RQ2. Which one/s has/have been used for assessing innovation in ICT organisations?
- RQ3. What is the nature of the proposals found for helping ICT organisations assess innovation?
- RQ4. What are the objectives pursued in research to enable innovation in ICT organisations?

[3] Information and Communication Technology.

The RQs were designed to learn more about the state-of-the-art research in the field of innovation application. The aim was to understand how academia studies innovation. It was essential to know what types of methods have been proposed (RQ1) and whether they have been validated in an industrial or a theoretical context, i.e., through experimentation based on a real-world industry case study or through academic experimentation using synthetic data (RQ2). It was also crucial to know the different research methods involved, so RQ3 analysed the critical elements of innovation (i.e., innovation capabilities, types of innovation, stakeholders and stages within the process). Finally, RQ4 analysed the studies' objectives to determine whether all relevant aspects of innovation had been considered (e.g., capability and/or maturity measurement, trust-building, innovation standards, and/or the decisive role of public funders).

2.2. Digital libraries and keywords

Four digital libraries (i.e., Scopus, IEEE Explore, ACM Digital Library, and ScienceDirect) were selected for this SMS. These databases are commonly used in the field of ICT. ACM Digital Library, IEEE Xplore, and ScienceDirect were included because these databases predominantly index publications in computer science, information management, and information technology. The large heterogeneous database Scopus was searched because it indexes publications in several potentially related disciplines such as innovation, finance, strategic management, business, and economics. The authors also agreed to include it because it is one of the most extensive academic databases.

Two general categories, "Innovation" and "Maturity/Capability Assessment", were defined to conduct the searches. For each category, different keywords were tested to confirm that relevant studies related to this research topic would be included in the search results. Two more relevant concepts, "Framework/Model/Standard" and "Investment", were also considered. However, the results obtained when the first of these was added produced noisy data due to its generic use, while the second produced only limited results. It was therefore decided to keep the first two categories (i.e., "Innovation" and "Maturity and/or Capability Assessment") in the searches and to study the others (i.e., "Framework/Model/Standard" and "Investment") in the execution phase.

Table 1 shows the keywords used to construct the queries to be executed in the digital libraries. Using the concept of "innovation" in digital libraries is very complex due to several factors. On the one hand, "innovation" does not have a generally accepted definition; it has multiple synonyms and is used in several scientific fields. On the other hand, the word "innovation" defines not only a concept but also a process that differs according to its field of application. Research and development (R&D), for instance, is different from "innovation" but is often used similarly. In some cases, "innovation" encompasses the whole process; other times, it refers only to the final part of the innovation process closest to the market. One clear example is the Spanish concept of I+D+i, referring to research, development and innovation. Here, the "i" refers to "innovation". Our search, therefore, considered the concepts of "Innovation" and R&D", "Innovation Management", and "Innovation Management Systems". The concept of maturity/capability assessment was straightforward: it was simply a question of adding the synonym "capability". In this category, one essential keyword was CMMI (Capability Maturity Model Integration), as a reference model for areas other than innovation.

Table 1
First set of keywords, giving the main terms.

Concept	Keywords
Innovation	Innovation, Innovation Management, IMS and R&D.
Maturity/Capability assessment	Maturity, Capability, Capacity and CMMI.

Table 2
Queries executed in each digital library.

Digital Library	Query
SCOPUS	TITLE ((“Innovation” OR “Innovation Management” OR “IMS” OR “R&D”) AND (“Maturity” OR “capacity” OR “capability” OR “CMMI”))
IEEEX	(((((“Document Title”:Innovation) OR “Document Title”:“Innovation Management”) OR “Document Title”:IMS) OR “Document Title”:“R&D”) AND ((((“Document Title”:Maturity) OR “Document Title”:capacity) OR “Document Title”:capability) OR “Document Title”:CMMI))
ACM	Title:(Innovation OR “Innovation Management” OR “IMS” OR “R&D”) AND Title:(Maturity OR capacity OR capability OR CMMI)
ScienceDirect	(Innovation OR “Innovation Management” OR “IMS” OR “R&D”) AND (Maturity OR capacity OR capability OR CMMI)

2.3. Query building

Once the search terms were defined, the primary queries were built for different libraries (cf. Table 2). Limitations in some of the digital libraries required specific search string designs for each library. The searches were carried out on the titles of documents because, due to the multidisciplinary nature of innovation, all the keywords were very popular, and none were specific. Because of the wide variety of innovation terms, the introduction of abstracts and keywords produced an unmanageable amount of results (i.e., more than 50 K). These concepts were application fields or technologies, but in this study, we were looking for generic models for the innovation process as applied in any field or technology.

2.4. Inclusion and exclusion criteria

The inclusion (IC) and exclusion (EC) criteria for selecting the primary studies to be used in this research are listed in Table 3 together with an explanation of why they were chosen.

Four IC were defined based on year of publication (IC1), the field of study (IC2), document type (IC3), and language (IC4). The studies included, therefore, were those published during the last 20 years (IC1) in prestigious journals, conferences, or editorials (IC3), corresponding to the fields of Computer Science, Engineering, Business, Management, or Accounting (IC2), and written in English (IC4). Different fields of study (EC2) were considered due to the multidisciplinary nature of innovation. These fields were chosen because innovation is, by its nature, an area of management that must be business-oriented. Since innovation can be applied to all scientific fields, we focused on ICT, choosing Computer Science and Engineering as fields of application.

Three EC were considered: the duplication of studies (EC1); relevance, to ensure quality based on indexings (EC2); and scope of application (EC3), to ensure that the studies included dedicated frameworks or models in line with the criteria. In EC3, prescriptive studies that proposed solutions (i.e., constructs, models, methods, or instances) aimed at assessing/enabling innovation capability or maturity in ICT organisations were considered. These solutions had to analyse the entire innovation process that could be used to create a new relationship model with the public administration to increase trust and, thereby,

Table 3
Exclusion and Inclusion criteria.

Id	Criterion	Assessment
IC1	Publication year	Only studies from 2000 onwards were included, covering more than 20 years.
IC2	Field	Computer Science, Engineering or Business, Management and Accounting.
IC3	Document type	Articles, Conference Papers or Book Chapter.
IC4	Language	English.
EC1	Duplicated	Studies duplicated in different libraries were excluded.
EC2	Academic Relevance	To set up the quality assurance criteria that would corroborate the scientific rigour of the study, the following indexes were taken as references: Journal Citation Report (JCR), Scholarly Publisher Indicator (SPI) and GII-GRIN-SCIE (GGS) Conference Rating. Studies not appearing in these indexes were excluded.
EC3	Scope relevance	The relevance of the studies was evaluated by a peer-reading of the title and abstract.

boost the effectiveness of public funding — as stated in the MRQ presented in Section 1). The “framework” concept we were looking for had to include a model but could also include methods and/or instantiations — software tools to support the model and/or methods. Innovation is a vast concept, so proposals that applied innovation in specific fields as a means of improving specific tasks, modules, or processes (e.g., e-commerce, communication, medical, human resources, or IT innovation fields such as IoT, Big data, and artificial intelligence) were eliminated.

3. SMS execution

Once the planning was agreed upon, in April 2020, the queries were executed in the digital libraries, and the inclusion and exclusion criteria were applied. This section details the results obtained during this rigorous selection process (cf. Fig. 1).

Queries were adapted for each digital library. Search strings, metadata (including title, author, document type, publication year, and DOI), and abstracts of the studies found were stored, organised, and classified in an Excel spreadsheet. A total of 4615 studies were found in all the digital libraries. After applying the four IC, 1550 studies were removed, leaving 3065 studies.

An accumulative process was then followed to eliminate the duplicates (EC1). This was done by keeping Scopus as the main library and removing duplicate entries from the other libraries. In Scopus itself, 3 duplicated studies were removed. In IEEE, the elements duplicated in Scopus (72 studies) were eliminated. In ACM, 1 study was duplicated in this library, and 53 works duplicated in Scopus+IEEE were discarded. A total of 42 studies duplicated in ScienceDirect were deleted from Scopus+IEEE+ACM. In total, 172 studies were removed, leaving 2893 studies for later analysis.

The last step was to apply the remaining two exclusion criteria. After applying EC2 (academic relevance), 2289 studies were removed, leaving 604 studies. Finally, criterion EC3 (scope relevance) was applied by peer-reading, with two researchers evaluating the title and abstract of each study. After reaching a consensus on each of the works, 526 studies were removed. The SMS, therefore, produced 78 primary studies for analysis.

4. Classification scheme

This section provides an in-depth analysis of all features defined for the classification scheme.

RQ1 aimed to determine what methods had been researched for assessing innovation in ICT organisations. To answer this question,

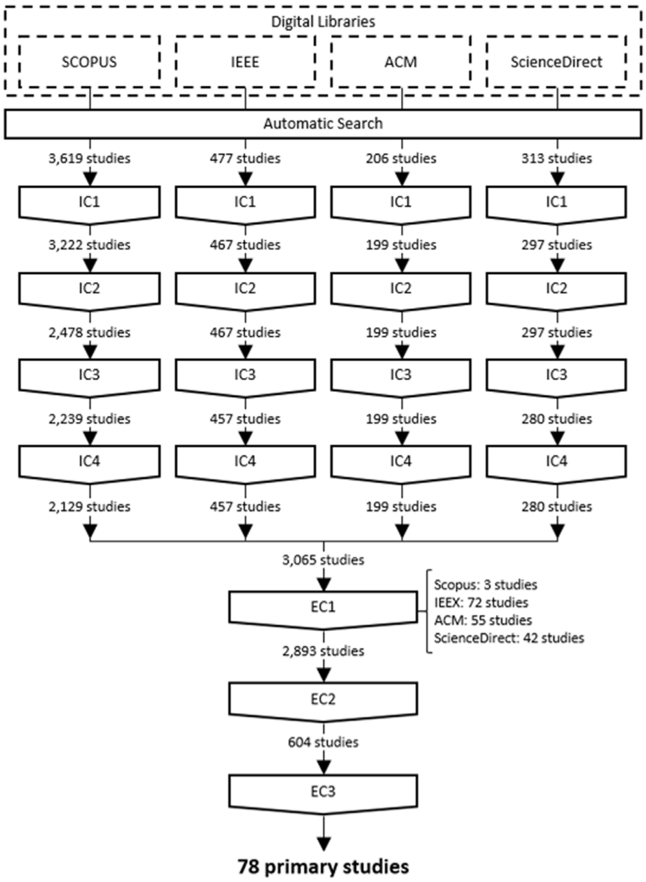

Fig. 1. Summary diagram of primary studies selection process.

four features, i.e., *Construct*, *Model*, *Method*, and *Instantiation*, were defined, taking Design Science's model (Wieringa, 2014) as a reference (cf. Section 2 of Supplemental Material for a complete description). Moreover, the aforementioned "Framework" concept includes not only a model but also methods and/or instantiations.

RQ2 aimed to determine whether the research works proposed in this field were practical or theoretical. The following features were defined to answer this question. We wanted to know if the studies had been validated or not. Validation would be ranked with *Validated* and *NotValidated* features. *Validated* features were divided into *IndustrialValidation* or *AcademicValidation*. If a study had any kind of validation, it would also be ranked with the *Survey*, *CaseStudy* or *Experiment* features (Wieringa, 2014).

RQ3 aimed to study the problem facing innovation assessment methods. The following features were defined to answer this question.

First, we wanted to know what *InnovationCapabilities* were considered in the studies. Analysis of the papers revealed many capabilities covering innovation, and so a set of capabilities was built up to bring them all together (cf. Table 4).

Secondly, it was important to identify the *InnovationType*. It can refer to the kind of innovation, the type of output, or the innovation result (Baregheh et al., 2009): no consensus exists in the literature in this regard. In this study, therefore, the *InnovationType* was created as the literature was reviewed, following recommendations from Oslo Manual (OECD & Eurostat, 2018), ISO 560000,[4] Baregheh et al. (2009), Keeley et al. (2013) and Schumpeter and Backhaus (2003). Six types of innovation were considered and chosen as features within our classification scheme *ProductInnovation*, *ServiceInnovation*, *ProcessesInnovation* (i.e., production or distribution), *TechnologyInnovation*, *MarketingInnovation*, and *OrganisationalInnovation* (i.e., Human Resources, Culture, Technology transference). A field was also included to classify generic innovation (i.e., *GenericInnovation*).

Thirdly, we wanted to understand how the *StakeholdersRole* was addressed in the studies. In the innovation process, the participation of stakeholders is crucial. Concepts like the *QuadrupleHelix* emphasise the need to consider not only the organisation itself but also the public administration, the academia, and society, fostering the co-evolution and cross-integration of different knowledge modes (Carayannis & Campbell, 2009). The Horizon Europe programme[5] reinforces this idea by adopting Mariana Mazzucato's concept of missions (Mazzucato, 2018) which aimed to combine the thrust of the four elements in the *QuadrupleHelix*. Without the thrust of all four helixes, innovation loses its strength. To include the role of public funders, the following features, i.e., *InnovationDepartment*, *Organisation*, *SomeStakeholders*, *QuadrupleHelix* and *QuadrupleHelix + PublicFunders* (cf. Section 3 of Supplemental Material for a complete description), were defined. The subsequent features include the previous ones' stakeholders.

Fourthly, we wanted to know where proposals were located within the *InnovationProcess* (e.g., closer to ideation or management). As already mentioned, innovation is a complex process involving very different phases. Its scope will vary depending on the phase or phases the *Model* focuses on. Here, four features were defined: *Ideation* (doing — generate ideas), *Execution* (doing — execute ideas), *Managing*, *Enabling* (support), *Improving* (assess). All of them were inspired by CMMI (cf. Section 4 of Supplemental Material for a complete description).

Fifthly, *OrganisationType* (i.e., *PublicAdministration* or *PrivateOrganisation*) were analysed to find out whether the model would be applicable to a specific *SectorType* (i.e., *Sectorial*) or could be implemented generically (i.e., *Multisectorial*).

Other relevant perspectives, such as the concepts of *OpenInnovation* (Chesbrough et al., 2006), *Agile* (Sutherland & Sutherland, 2014), *CBV* (i.e., Capability-Based View) (Hasan, 2014) and *RBV* (i.e., Resource-Based View) (Wernerfelt, 1984) theories would also be investigated.

RQ4 aimed to identify the objectives and focus of the studies. The following features were defined to answer this question. Firstly, *ProposalType* was analysed through four features: *NewProposal*, *ImprovementofExistingOne*, *ExistingProposal* and *ComparativeProposals*. Secondly, *CapabilityAssessment* and *MaturityAssessment* features were defined to determine whether Capability and Maturity had been assessed. Thirdly, the final objectives of proposals were analysed through two features: *TrustBuilding*, to determine whether the trust was considered in the models, and *FacilitateInvestment* to find out whether public funders played a role in the models. Finally, the *InnovationStandards* feature analysed whether the proposals considered innovation standards (e.g., ISO 56000) within their models.

5. SMS reporting

This section reports the data obtained once all the primary studies had been analysed using the classification scheme. As mentioned in Section 4, the classification scheme evolved iteratively as the primary studies were analysed, with new features being added and initially proposed features being removed or rearranged. The primary studies were thus classified through two complete iterations via peer-to-peer reading. Finally, in a third iteration, the results were agreed upon. The data obtained for each RQ are described below.

[4] https://www.iso.org/standard/69315.html.

[5] https://ec.europa.eu/info/horizon-europe_en.

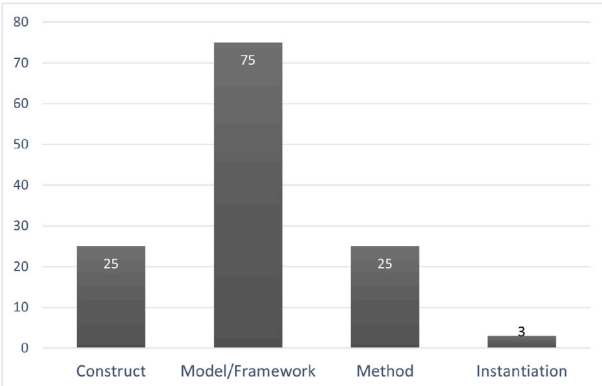

Fig. 2. Methods for assessing capabilities/maturity.

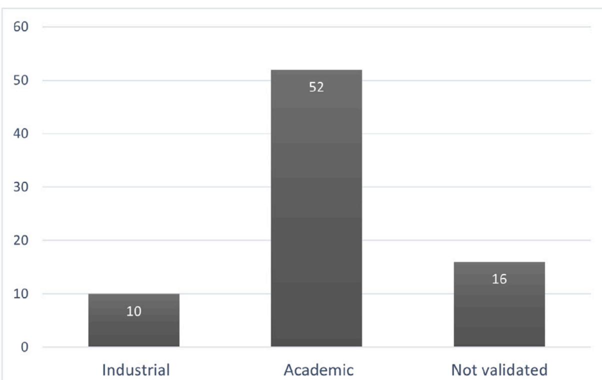

Fig. 3. Validation of the primary studies.

RQ1 asked: What methods, techniques, or tools have been researched for assessing innovation in ICT organisations? As observed in Fig. 2, only a few studies presented a tool (i.e., *Instantiation*) that supported their proposed *Model*. Moreover, only 20% of the studies proposed a *Method*. Most studies proposed *Model*, which is related to the defined SMS keywords. Only a few studies (i.e., less than 20%) proposed *Construct*. Of these, all except one also proposed a *Model*.

RQ2 asked: Which one/s has/have been used for assessing innovation in ICT organisations? Studies with *IndustrialValidation* were scarce (i.e., less than 13%) as can be seen in Fig. 3. Most of them (i.e., 68%) proposed *AcademicValidation*. As reflected in Fig. 4, the predominant validation type was the *CaseStudy* (i.e., 49%), followed by *Survey* (i.e., 31%). Most of the proposals that presented the latter type of validation were related to *AcademicValidation*. It should also be mentioned that none of the validated studies presented *Experiment*, while 20% of them were *NotValidated*. The *IndustrialValidation* variable was mainly associated with the *CaseStudy*. Only 2% of the studies that provide a *Method* or *Instantiation* (i.e., 22%) propose *IndustrialValidation* by *Case Study*. This implies that few academic papers include validation in a real business environment in their scope.

RQ3 asked: What is the nature of the proposals found for helping ICT organisations assess innovation? As the studies were analysed, the importance of *InnovationCapabilities* became more relevant. Most studies (i.e., 97%) were based on the discovery, use and development of one or more capabilities. It was, therefore, necessary to compile the different capabilities. In Table 4, the capabilities have been grouped into categories and subcategories. Whenever there was no subcategory, the superior category was maintained. Each capability was defined in the innovation context, together with the number and the percentage of its appearances in the literature. Capabilities were sorted in descending order by category. As reflected in Table 4, 23 different innovation

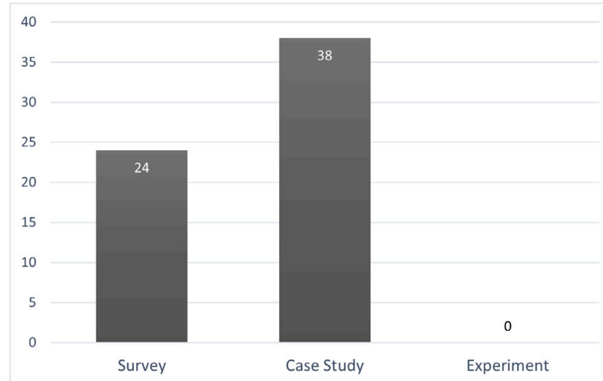

Fig. 4. Types of validation of primary studies.

Fig. 5. Stakeholders levels of context.

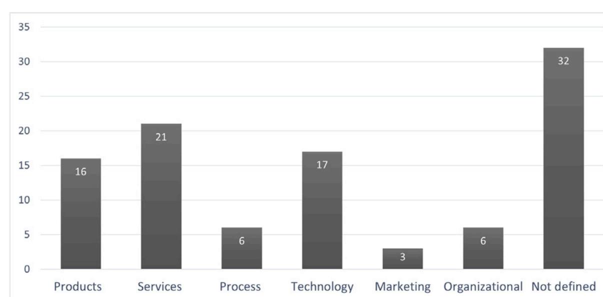

Fig. 6. Innovation Type.

capabilities appear in the literature, many of them very similar. This gap will be discussed in Section 6. Three categories can be intuitively arisen: capabilities related to boosting innovation (i.e., 52%), capabilities aimed at improving management (i.e., 31%), and, as general enablers, emerging ICT capabilities (i.e., 17%). Capabilities related to boosting innovation are those that have a direct impact on the innovation process itself (e.g., ideation, knowledge management and other business skills). Management capabilities focus on improving operational aspects, with transaction capability being the most relevant (i.e., 11%). IT capabilities are related to technologies that enable the two previously mentioned capability types.

It was essential to know what *InnovationType* the proposed models focused on and whether their models were generic. As shown in Fig. 6, most of the proposed models (i.e., 69%) were aligned with a specific type of innovation, with *GenericInnovation* – or undefined models – appearing in less than a third of the studies (i.e., 32%). It should be noted that *ServiceInnovation* (i.e., 21%) was the subject

Table 4
Set of capabilities found in the studies.

Category	Subcategory	Capability	Definition	Total	%
Boost Innovation	Ideation	Creativity	The degree to which an organisation is able to generate new and constructive ideas (or products) in the complex organisational setting (Woodman et al., 1993)	3	1, 3%
		Inventive	The company's capability to internally explore or generate new knowledge (Tran et al., 2020)	2	0, 9%
	Knowledge	Knowledge management	An organisational mechanism to continually and intentionally create knowledge in organisations (Von Krogh et al., 2001)	38	16, 5%
		Sensing	Company's ability to identify innovations trends and their linkages to its business model and the customer value propositions (Inigo et al., 2017)	4	1, 7%
		Reconfiguring	The ability of an organisation to rebuild assets and also gain knowledge for creativity that will enable it to utilise opportunities and survive threats (Wogwu & Hamilton, 2018)	3	1, 3%
		Seizing	A company's ability to take advantage of the internal and external opportunities detected by reconfiguring the business model (Inigo et al., 2017)	3	1, 3%
		Transformative	Company enduring ability to transform available general knowledge and competence into specific knowledge and competence (Tran et al., 2020)	3	1, 3%
	Skills	Dynamic	Subset of the competences/capabilities which allow the company to create new products and processes and respond to changing market circumstances (Teece & Pisano, 2003)	19	8, 2%
		Absorptive	The capability to explore and utilise external knowledge (Tran et al., 2020)	12	5, 2%
		Collaborative	A company's ability to manage any inter-company cooperation by identifying, building and adapting its partnerships (Zhang & Zhu, 2020)	10	4, 3%
		Explorative	The company's capability to search, variation, risk-taking, experimentation, play, flexibility, discovery, and innovation (March, 1991)	6	2, 6%
		Acquisition	A company's ability to acquire external knowledge, as a moderator of the leadership-innovation link (Crossan & Apaydin, 2010)	4	1, 7%
		Desorptive	A company's ability regarding the internal execution of external acquirements within the boundaries of the organisation (Lichtenthaler, 2007)	3	1, 3%
		Combinative	A managerial capability that permits the integration and recombination of knowledge (Phene & Almeida, 2008)	2	0, 9%
		Connective	The company's ability to store knowledge in inter-organisational relationships (Tran et al., 2020)	2	0, 9%

(*continued on next page*)

of greatest interest, together with the service innovation capability mentioned previously. Other studies focused on *Technology Innovation* (i.e., 17%) and *Product Innovation* (i.e., 16%). *Organisational Innovation*, *Processes Innovation* and *Marketing Innovation* received the least attention (i.e., 6%, 6%, and 3%, respectively).

The *Stakeholders Role* was critical in the innovation models since its involvement is instrumental in the innovation process. This feature was studied by extending the *Quadruple Helix* to include public funders (cf. Fig. 5). Models were also differentiated in terms of whether they applied only to *Innovation Department* (i.e., 33%) or the whole *Organisation* (i.e., 34%). Significantly, the vast majority of studies (i.e., 92%) did not consider *Quadruple Helix* in their models, and less than 3% of them took public funders into account.

Innovation as a process (i.e., *Innovation Process*) can be broken down into several phases (Rothwell, 1994), and it was necessary to know which phase or phases the models supported. As detailed in Fig. 7, most studies (i.e., 59%) applied their models to the *Improving*

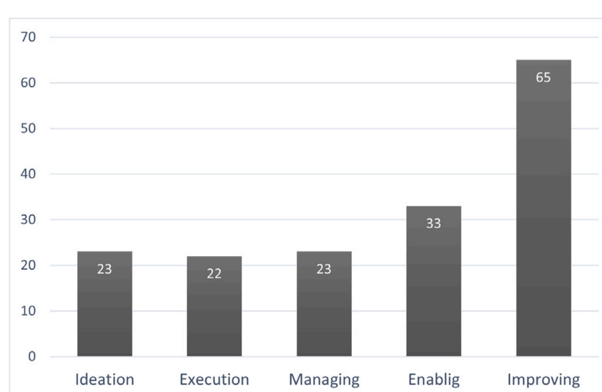

Fig. 7. Place in the innovation process.

Table 4 (*continued*).

Category	Subcategory	Capability	Definition	Total	%
Innovation management	Innovation management	Transaction	A set of skills, knowledge and routines that the company develops in order to transact in the market (buy and sell) at the lowest possible cost (Tello-Gamarra & Zawislak, 2013)	25	10, 8%
		Operational	A company's learning skills and ability to enhance the most efficient use of technological resources and assets such as new and improved production technologies, managerial and organisational structures for innovation and new or improved innovation processes (Zhang et al., 2013)	23	10, 0%
		Management	In innovation context, the company capability to resolve administrative issues related to the funding process	18	7, 8%
		Development	A company's technological ability to constantly develop new marketable product (Moorman & Slotegraaf, 1999)	9	3, 9%
		Diffusion	A company's ability to disseminate the results of its innovation process to all stakeholders of the Quadruple Helix	2	0, 9%
		Application	The company's ability to translate the final or partial outcomes of the innovation process to real internal or external challenges	1	0, 4%
		Delivery	A company's ability to provide innovation process outcomes internally and externally in a timely manner	1	0, 4%
ICT	ICT capability	ICT capability	The ability of companies to make effective use of technical knowledge in order to improve production processes and develop new products and services	38	16, 5%

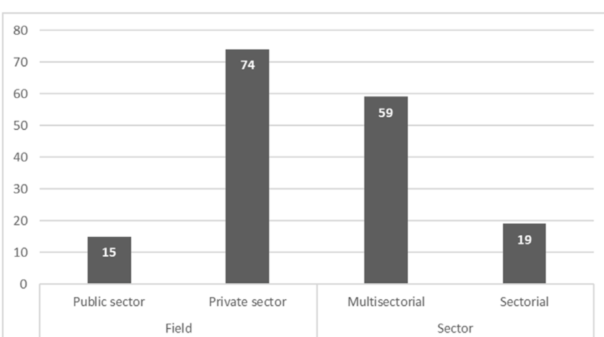

Fig. 8. Organisation type.

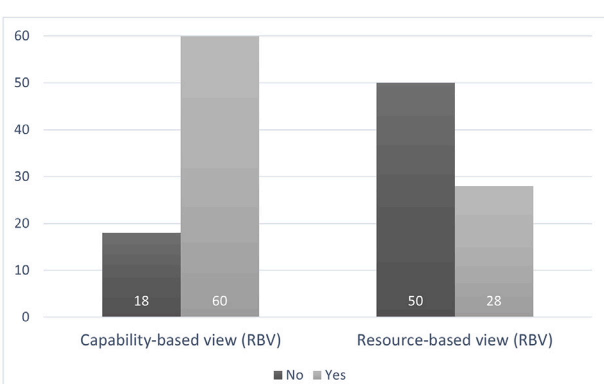

Fig. 9. CBV and RBV theories in primary studies.

(i.e., 39%) and *Enabling* (i.e., 20%) phases. Since the models were designed to improve innovation, this was expected, with the *Ideation* (i.e., 14%) and *Execution* (i.e., 13%) phases being pushed into the background.

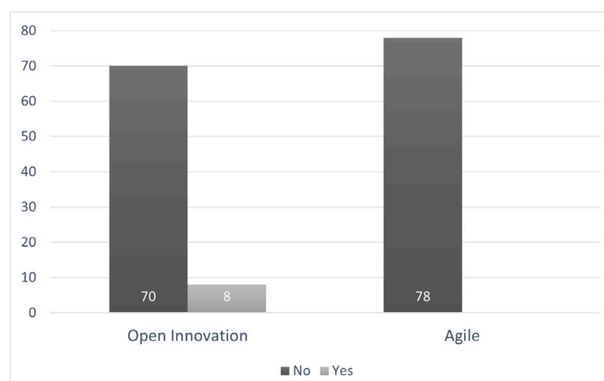

Fig. 10. Open Innovation and Agile concepts in primary studies.

Regarding the *OrganisationType*, the primary studies analysed focused mainly on *PrivateOrganisations*, i.e., 83%, and the models were mainly *Multisectorial*, i.e., 76% (cf. Fig. 8).

Two theories that appeared recurrently in the literature during the SMS were subsequently included in the study. These were *CBV* (i.e., Capability-Based View) and *RBV* (i.e., Resource-Based View), featuring in 77% and 36% of the primary studies found, respectively (cf. Fig. 9). It was also found that such relevant concepts as *OpenInnovation* and *Agile* did not appear. It is interesting to observe that no model for assessing innovation adopted the *Agile* principles,[6] and very few assimilate *OpenInnovation* (cf. Fig. 10).

[6] The agile principles, i.e, transparency, inspection and adaption, are inspired by the Scrum framework, available at: https://scrumguides.org/docs/scrumguide/v2020/2020-Scrum-Guide-US.pdf.

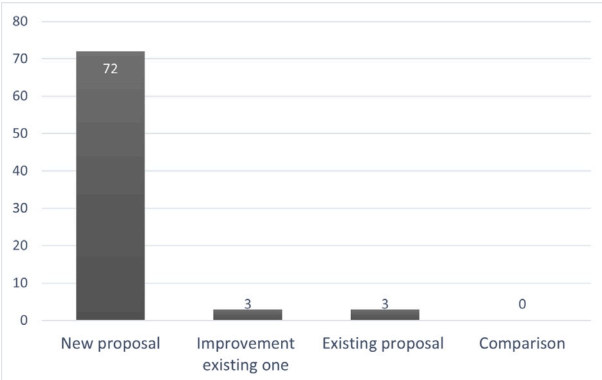

Fig. 11. Type of studies.

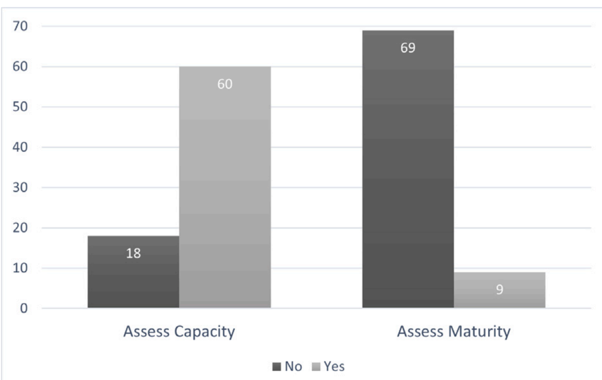

Fig. 12. Assess Capability.

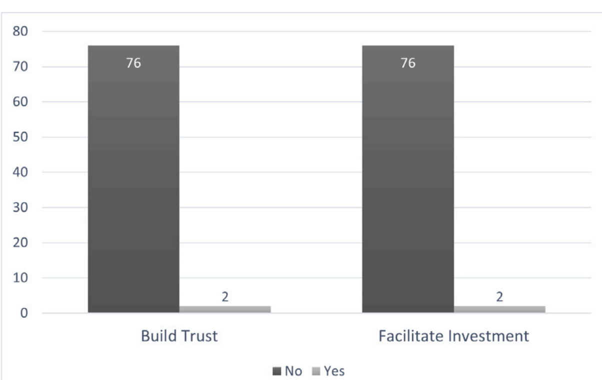

Fig. 13. Build Trust.

RQ4 asked: What are the objectives pursued in research to enable innovation in ICT organisations? The first thing analysed in this RQ was $ProposalType$, where it was found that no $Comparative\ Proposals$ had been presented. Most of the proposals (i.e., 92%) were $NewProposal$, as shown in Fig. 11.

Fig. 12 shows that most of the primary studies analysed (i.e., 77%) considered $CapabilityAssessment$, but very few (i.e., 12%) looked at $MaturityAssessment$. All those that did propose $MaturityAssessment$ also assess $Capability$ except for one (i.e., Berg et al. (2002)). Capability can be assessed using non-mathematical methods (e.g., surveys or hierarchical capability models) and mathematical methods (e.g., fuzzy techniques, the analytic hierarchy process, Bayesian networks or quadratic models). Only one study included $FacilitateInvestment$ in its scope, and only two considered $TrustBuilding$, as can be observed in Fig. 13. Remarkably, none of the studies considered IMSs together with $InnovationStandards$ as an inspiration for their models. The same conclusion was reached in Section 7. Both academia and industry are involved in creating standards, but academia does not consider those standards when analysing innovation. This gap should be analysed in future work.

In summary, regarding the above results, a general overview of the primary studies analysed produced the following profile: a $Model$, in which $Capability$ – not $Maturity$ – was measured, with $AcademicValidation$ through $Case\ Study$. The model focused on $Multisectorial$ and $Private$ organisations, fundamentally in $Product$, $Service$ and $Technology\ InnovationType$, with special attention to the $Improving$ phase within the $InnovationProcess$. Knowledge management, IT, Transaction and Dynamic were the main $InnovationCapabilities$ considered. The concepts of $Openinnovation$ and $Agile$ were rarely applied, and the CBV theory was relevant, while the RBV theory was not. $QuadrupleHelix$ and the decisive $FacilitateInvestment$ component were rarely studied as part of the innovation process.

In addition to the results obtained after matching the primary studies in the classification scheme, the most outstanding bibliometric details are described below. As can be seen in Fig. 14, there is growing interest in research into this topic, although a peak was detected in the years 2010 and 2011.

Fig. 15 shows the balance between conferences and journals, being the number of book chapters very low (i.e., 5%). The main libraries were Scopus, i.e., 50% and IEEE Xplore, i.e., 37% (cf. Fig. 16).

The vast majority of journals are very relevant (cf. Fig. 17), with a predominance of Q1s in the JCR ranking. Conversely, most of the conferences are still in a work-in-progress (i.e., WIP) situation within the SCIE ranking.

It should be noted that, as the studies were analysed, it was realised that they could be classified according to a series of parameters, based on two perspectives, i.e., type of model and scope of application. From the type of model perspective, they could be classified as:

- Static: Innovation is a generic concept. A single innovation model can be instantiated in any context and does not change concerning its characteristics. In some cases, the characteristics are ordered and organised in levels. They may also include techniques and tools to determine the relevance of the characteristics of the model.
- Dynamic: Innovation is a context-specific concept. Each context needs its own innovation model. When it is instantiated in an organisation, the characteristics that define innovation for that context must be discovered. They usually include techniques and tools to analyse and discover those characteristics of that set most appropriate for the specific context. In some cases, as in the static model, techniques and tools could be included to determine the relevance of the identified characteristics.

From the application perspective, studies could be classified as:

- Specific: Models created to study a field. The aim is the concrete results arising from the application of the model. They can be divided into: analytical-descriptive regional studies (i.e., they propose a model to describe a specific geographical area), or analytical-descriptive sectors studies (i.e., propose a model to describe a specific sector).
- Generic: General models for innovation assess within an organisation, without an application in a particular region or sector. The aim is the model itself.

Both model and application perspectives can be cross-referenced (cf. Section 5 of Supplemental Material for the complete classification of the 78 primary studies).

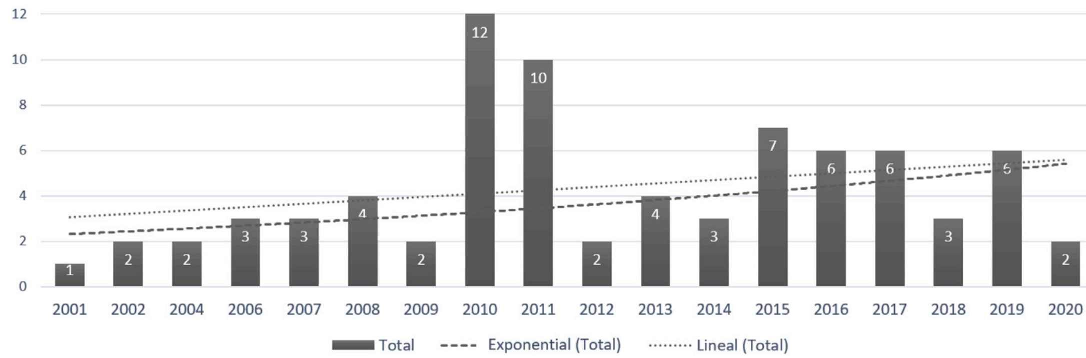

Fig. 14. Keyword bibliometric trend since 2000.

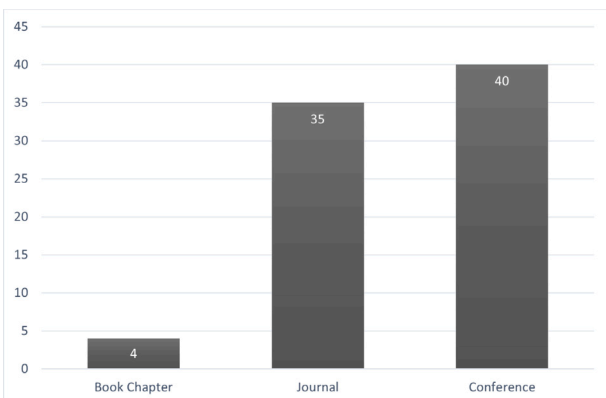

Fig. 15. Bibliometric document Type.

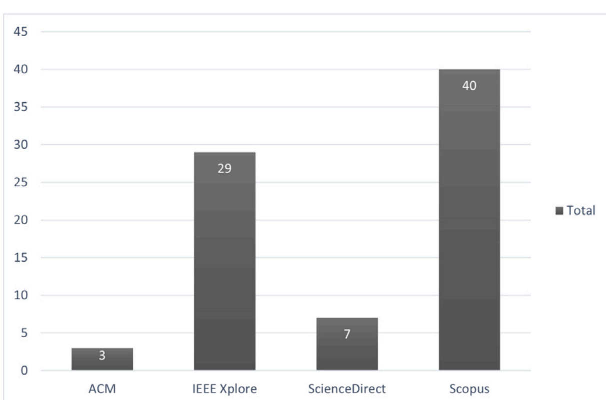

Fig. 16. Bibliometric libraries.

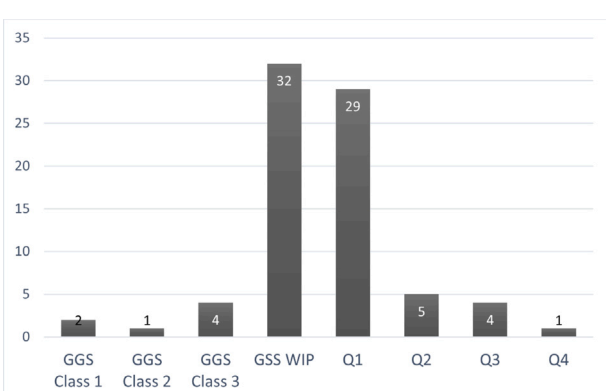

Fig. 17. Bibliometric relevance.

Table 5
Gaps found in the literature review.

Gap	RQs	CH
G1. Limited applicability of innovation models	RQ1, RQ2	CH1
G2. Lack of a common ontology	RQ1, RQ3, RQ4	CH2, CH3, CH4, CH5
G3. Lack of consensus on the innovation process	RQ3, RQ4	CH6, CH7
G4. Lack of application of agility concept	RQ3	CH8, CH9
G5. Lack of stakeholder engagement	RQ3, RQ4	CH10, CH11

6. Discussion and challenges

This SMS identified 78 primary studies classified in peer-reviewed journals, conferences, and book chapters. The studies were organised into 4 groups corresponding to the 4 RQs proposed in Section 2.1. This section is divided into different subsections dealing with the gaps found in the literature. Each gap is related to one or more of the proposed RQs. One or more challenges are suggested for each gap. Table 5 represents the relationship and traceability between RQs, gaps (G) and challenges (CH).

6.1. G1 - Limited applicability of innovation models

Regarding RQ1, the applicability of the results can be said to be limited (cf. Fig. 2). This affirmation is reinforced by RQ2, which found that the studies remained at an academic level and did not extend to organisations (cf. Figs. 3 and 4).

Challenge 1. Industry application of innovation models. Future works should research $Model$, $Method$ and $Instantiation$ applicability in operational environments with $Experiment$ in $IndustrialValidation$ bringing industrial feedback into the model. Industrial feedback can be added by means of an IMS, based, for instance, on ISO 56000 or CEN/TS 16555, which are rarely used.

6.2. G2 - Lack of a common ontology

RQ1 highlighted the low percentage of primary studies (i.e., 20%) that proposed $Construct$ (cf. Fig. 2). This illustrates the difficulty in standardising the basic concepts of innovation, emphasising that IMSs are not being applied — addressed in RQ4.

RQ3 provides a broader understanding of $InnovationCapabilities$. The great variety of these capabilities (some, like Absorbity and Acquisition, are very similar) seems to indicate a general lack of consensus, so semantic standardisation is required (cf. Table 4). The great diversity of $InnovationType$ (cf. Fig. 6) and the complex $InnovationProcess$ (cf. Fig. 7), illustrate the extraordinary complexity of innovation analysis, which is exacerbated by the fact that innovation can be analysed from a specific or $GenericInnovation$ perspective, focusing on the whole or different parts of the $InnovationProcess$. No correlation was found between the $InnovationType$ studied in the $Model$ or $Method$ and the phase in the $InnovationProcess$. It should be noted, however, that a high percentage of primary studies on $GenericInnovation$ (i.e., 39%) mainly addressed the $Improving$ phase.

Analysing the results obtained from RQ4, it can also be said that there are few $ComparativeProposals$. This is mainly due to the lack of semantic consensus, which makes it impossible to compare models (cf. Fig. 11).

Challenge 2. Creation of a common ontology. Innovation and R&D are two terms that are sometimes interchangeably used, generating significant confusion in the literature. The term "innovation" is complex, and it can involve activities, outcomes, and resources (OECD & Eurostat, 2018). It may refer to (1) a process that includes R&D, (2) an outcome, or (3) the next step after R&D. This has created an ontological loop where innovation is applied to the entire process and also forms part of it. An ontological standardisation of the main concepts and definitions is necessary to create a common language. Future works must deal with the complexity of innovation since it constitutes not only a field of study but also a process that can be applied transversely in all scientific and technical fields.

Challenge 3. Research for refactoring innovation capabilities. Future works should investigate the link between $InnovationCapabilities$ and the whole $InnovationProcess$, determining which $InnovationCapabilities$ and sets of good practices influence different $InnovationsTypes$ and each phase of the $InnovationProcess$. A solid starting point would be the work illustrated in Table 4, with its preliminary clustering of capabilities. Moreover, there is currently no consensus on $InnovationCapabilities$ ontology. Future works should therefore seek clusters of $InnovationCapabilities$ and orient them towards the $Agile$ concept.

Challenge 4. Linking capabilities to public funding. It would also be an exciting line of research to analyse mechanisms for evaluating $InnovationCapabilities$ within a maturity model to build trust in $PublicFunders$.

Challenge 5. Research into consensus on innovation types. A common ontology and structure that unifies the different types of innovation need to be researched. It should be analysed whether these types of innovation can have a common $InnovationProcess$.

6.3. G3 - Lack of consensus on the innovation process

Standardisation of the $InnovationProcess$ is inexistent. RQ3 showed that Knowledge Management, Dynamic and Absorptive capabilities are the most relevant $InnovationCapabilities$ (cf. Table 4). Our findings demonstrate the growing interest in: (1) knowledge management skills, (2) how knowledge is absorbed and managed, and (3) how companies can adapt to obtain maximum value dynamically.

The most researched $InnovationCapabilities$, therefore, correspond to the earlier stage of the $InnovationProcess$ (i.e., $Ideation$), where knowledge is collected and transformed into an organisation's asset. However, this is inconsistent with the fact that most studies into the $InnovationProcess$ focus on the final phase (i.e., $Improving$, cf. Fig. 8), within a specific $InnovationType$. Indeed, the most studied type of innovation is $ServiceInnovation$. Not focusing on the early phases of the $InnovationProcess$ means that the problems deriving from $Execution$ have not been studied in depth. Moreover, $Ideation$, as a driving force behind innovation, must play a more significant role. Only 10 out of 78 primary studies simultaneously analysed the $Execution$ and $Improving$ phases, and only one of them (i.e., Zambrano and Velásquez (2011)) did so generically, without focusing on any specific $InnovationType$. Surprisingly, none of the analysed studies used existing IMSs to conceptualise their innovation models. This may be because until 2020, there was no international standard (i.e., ISO 56000), and each country had its own innovation standard. The following dataset[7] details the huge variety of existing standards.

Challenge 6. Standardisation of the innovation process. A lack of consensus on the $InnovationProcess$ structure is evident. There are many different approaches to describing the $InnovationProcess$, all based on different theories proposing different structures. It is important to create a standard nomenclature for the main phases of the $InnovationProcess$. For this to happen, models would necessarily have to use existing IMSs, as mentioned above. Future works should also analyse whether different innovation types should have differentiated innovation process structures and whether a common structure can be created.

Challenge 7. Research the development of models closer to the early stages of the innovation process. A lack of focus on the early stages of the $InnovationProcess$ is noticeable. An approach closer to the $Ideation$ and $Execution$ phases is necessary for future studies. These initial phases depend on external factors, which need to be incorporated into the models.

6.4. G4 - Lack of application of agility concept

Two theories detected in RQ3 and relevant to the $InnovationProcess$ (i.e., CBV and RBV) have to date been applied in a non-homogeneous manner, and less than 12% of the primary studies analysed applied them together (cf. Fig. 9). The studies found also lacked the $Agile$ approaches (cf. Fig. 10) that are necessary for the correct and successful $Execution$ of projects.

Challenge 8. Combined agile application of CBV and RBV theories. Future research must consider these theories in its $Model$ or $Method$. As mentioned above, $InnovationCapabilities$ are the muscle that moves the innovation levers within organisations and are also resource-dependent. Interdependence clearly exists between an organisation's capability set, its resources, the $InnovationType$ and the $InnovationProcess$ stage. Therefore, an Agile recasting of CBV and RBV theories within a common innovation model is necessary.

Challenge 9. Develop and validate the concept of Agile innovation management. Public funder $TrustBuilding$ could be achieved by including $Agile$ principles (i.e., inspection, transparency, and adaptation) in the $InnovationProcess$. This would help to plan, control and adapt its scope, timeframe and cost (i.e., funding) to the requirements of public funders' audits. Short, frequent iterative and incremental cycles of the $InnovationProcess$ might improve public funders' trust through transparency and inspection. Future research should analyse whether it is feasible to apply agility within the $InnovationProcess$ to reduce current public funders' restrictions.

6.5. G5 - Lack of stakeholder engagement

Regarding $StakeholdersRole$ in RQ3, less than 10% of the primary studies envisioned the $QuadrupleHelix$, with only 3% of them considering the $PublicFunders$ within their models (cf. Fig. 5). None of these studies had $IndustrialValidation$. Neither much attention is paid to $PublicAdministration$, despite its being one of the key $QuadrupleHelix$ components and, often, the primary funding investor. Finally, it should be noted that not enough importance was attached to the concept of $OpenInnovation$. Even when this was considered, it was not correctly applied in the models since not all stakeholders were taken into account.

Challenge 10. Rethinking stakeholders' role. Regarding RQ4, it was found that not enough attention had been paid to such a relevant factor as funding, or its effects on innovation development, since $QuadrupleHelix$ and $PublicFunders$ had not been considered as a

[7] https://doi.org/10.5281/zenodo.6998331.

means of improving $TrustBuilding$ (cf. Fig. 12). The government's role as a funder, and its restrictions, should also be considered.

As explained in Giménez Medina (2020), there is an implementation paradox in the $InnovationProcess$: public funding is needed, but processes are slow, restricted, and bureaucratic. The $InnovationProcess$ needs to be executed as soon as possible to take advantage of its "momentum". Delays often interrupt or distort the innovative process, leaving discovery results unexecuted or outside their "time to market".

Finally, $InnovationStandards$ (i.e., IMSs) were not considered in any of the studies analysed. This is surprising because standards are an unbeatable source of information for innovation management. Since innovation is limited because of the restrictions, public funding imposes on projects in terms of scope and time. Therefore, future works should investigate integrating $PublicFunders$ as an essential element within the $InnovationProcess$. To achieve this goal, significant changes must be made in the public administration, its capabilities and innovation policies. Special attention should be paid to the role of $PublicFunders$ within the $QuadrupleHelix$, and further research should be carried out into the effects of their funding and restrictions.

Challenge 11. Researching the impact of public funding on innovation capability and maturity models. The concept of an organisation's innovation maturity model necessarily involves a set of levels (e.g., Initial, Managed, Defined, Quantitatively Managed and Optimising, inspired by CMMI maturity levels) that describe the state of an organisation's resilience in carrying out innovation processes in times of pressure and adversity. An organisation that is mature in terms of innovation processes is more stable and generates more trust, and so there is a significant need to apply a Maturity Model within the $InnovationProcess$ and to involve $PublicFunders$ and other $Stakeholders$ in the early phases of $Ideation$ and $Execution$. Future works should research a $Model$ that $FacilitatePublic\ Funding$ by reducing risk and increasing $TrustBuilding$ based on $MaturityAssessment$, CVB and RBV. Such a $Model$ should be used as a methodological scale of public funders' trust to make the funding process more agile. Creating a common ontology that combines capabilities within a conceptual innovation $Model$ is necessary. This would make it possible to compare different organisations to ensure public funders' trust. Future research must also be closer to the industrial world and be experimentally validated using $Agile$ methods.

7. Related work

This section analyses both academic and industrial contexts. Starting with the academic context, it describes studies that have performed literature reviews on innovation capability and maturity models. Some of these studies appeared in the results of the Execution phase of the SMS described in this paper (cf. Section 7.1). It then focuses on the industrial context, describing existing IMSs (cf. Section 7.2). Finally, the related work described and the gaps and challenges detected and discussed in Section 6 are compared in detail (cf. Section 7.3).

7.1. Literary reviews on innovation capability and maturity models

Some proposals in the literature present a generalist view of innovation. In other words, although they focus on one or another capability or theory, they still take a holistic approach to the whole process, looking at their universal applicability to innovation types. In contrast, a proposal focusing on one innovation type or phase is considered a specific innovation. Haldma et al. (2012) and Shang et al. (2010) present a generalist non-structured review of innovation focused on innovation capability and performance assessment and dynamic innovation, respectively. Haldma et al. (2012) concludes that current literature does not provide comprehensive frameworks for assessing innovation capability and its effects. Shang et al. (2010), focus on the inputs and outputs of the innovation process, proposing a dynamic innovation model for demonstrating the cyclical relationship between different capabilities for continuous innovation. Carroll and Helfert (2015) also present a systematic review focusing on the knowledge taxonomy concerning innovation capability. The authors observe that the extant literature still lacks clarity and standardisation regarding the elements of innovation capability.

The vast majority of works present their results from a non-generalist perspective, i.e., they review specific innovation domains. For instance, concepts such as open innovation (Chesbrough et al., 2006), disruptive innovation (Christensen et al., 2013), innovation capabilities (e.g., IT capability, dynamic or absorptive capability) or Capability Maturity Models (CMM) are studied non-holistically.

The proposals presented in Carroll and Helfert (2015) and Hosseini et al. (2017) are focused on open innovation. Hosseini et al. (2017) conclude that the literature encompasses mature but isolated streams on open innovation capabilities, requiring an integrated capability framework. Assink (2006) and Berkowitz (2018) focus on disruptive and sustainable innovation, respectively. Only (Carroll & Helfert, 2015) review the applicability of CMM in an open innovation context.

Regarding types of innovation, the research community's interest in service innovation has increased. In Wang et al. (2016), an extensive literature review demonstrates that the existing service innovation frameworks lack a focus on business process improvement. Pöppelbuß et al. (2011) analyse service innovation and dynamic capability, concluding that existing models include activities that can be mapped to sensing, seizing, and transformation capability areas. Reinhardt et al. (2018) centre their research on low-end innovation, suggesting that successful low-end innovation results from building and orchestrating a diverse set of practices and processes.

IT and dynamic capabilities are the types most reviewed by the research community. Datta (2011) highlights the link between IT capabilities and company innovation. Shang et al. (2010) study dynamic capabilities, while (Frishammar et al., 2012) focus on process innovation capability in a review spanning several literature streams, i.e., technology and innovation management, operations management, organisational behaviour and general management.

Other papers focus their reviews on regional systems (Rejeb & Younes, 2018), on meta-organising companies (Berkowitz, 2018), or on National Innovation Systems as intermediaries levels in the building of institutional capabilities for innovation (Watkins et al., 2015). Reviews are also conducted from the perspective of company types. Igartua et al. (2018) carried out a literature review on maturity models in small and medium-sized enterprises (SMEs). El Hanchi and Kerzazi (2020) focus on startups and concludes by demonstrating the enormous variability and complexity of the innovation concept. Vadastreanu et al. (2015) argue that a consistent body of theory remains elusive despite extensive literature.

7.2. Innovation management systems

IMSs are new players that have emerged in recent years and must be considered. They comprise management standards, norms or guidelines – similar to Quality Management Systems, i.e., ISO 9000 family[8] – but designed to manage innovation, [instead of quality,] in a systematised, standardised manner (Mir-Mauri & Casadesus-Fa, 2011). However, none of the works mentioned above includes IMSs within their scope.

Many standards exist at a national level. This does not make much sense since innovation is a cooperative activity and cannot be seen in isolation. The pioneering standards are the Spanish standard UNE 166002:2006 and its English counterpart BS 7000-1:2008. All other currently defined standards are based on these two.

ISO/TC 279 Innovation Management was established in 2013 to develop an international innovation standard that went beyond the

[8] https://www.iso.org/iso-9001-quality-management.html.

Table 6
Comparison of previous state-of-the-art works.

Reference	Updated	No. Papers Reviewed	Systematic review	Generalist	Frameworks	Capability Models Review	Maturity Models	ISO standards
Wang et al. (2016)	2014	No data	No	No	No	Yes	No	No
Carroll and Helfert (2015)	2014	No data	Yes	No	No	Yes	Yes	No
Raghuvanshi et al. (2019)	2014	43	Yes	Yes	Yes	No	No	No
Hosseini et al. (2017)	2016	127	Yes	No	Yes	Yes	No	No
Datta (2011)	2001	49	Yes	No	No	Yes	No	No
Haldma et al. (2012)	2011	No data	No	Yes	Yes	Yes	No	No
Pöppelbuß et al. (2011)	2011	No data	No	No	Yes	Yes	No	No
Shang et al. (2010)	2010	No data	No	Yes	Yes	Yes	No	No
Reinhardt et al. (2018)	2018	99	Yes	No	Yes	Yes	No	No
Berkowitz (2018)	2017	No data	Yes	No	Yes	Yes	No	No
Igartua et al. (2018)	2017	No data	No	No	Yes	No	Yes	No
Rejeb and Younes (2018)	2018	No data	No	No	Yes	Yes	No	No
Assink (2006)	2006	No data	No	No	No	No	No	No
Watkins et al. (2015)	2015	No data	No	No	No	No	No	No
Vadastreanu et al. (2015)	2015	No data	No	Yes	Yes	Yes	No	No
Frishammar et al. (2012)	2012	47	Yes	Yes	Yes	Yes	No	No
El Hanchi and Kerzazi (2020)	2020	125	No	No	Yes	Yes	No	No
Our proposal	2022	78	Yes	Yes	Yes	Yes	Yes	Yes

national sphere. It currently has 48 participating and 20 observer members. In 2019 and 2020, TC 279 started publishing the ISO 56000 series, covering the standardisation of terminology tools and methods and interactions between relevant parties to facilitate innovation.

All these standards refer to IMSs. Some of them even focus on innovation assessment, which make them particularly relevant to this research (e.g., ISO/TR 56004:2019, CEN/TS 16555-7:2016 EX, CWA 15899:2008, CWA 14924-4:2004, and PAS 1073: 2008). These standards are considered in the present study. We developed a dataset[9] listing the most important international and national standards as supplemental material.

Finally, it is important to stress that there is no consensus in the literature on whether standards either restrict or foster innovation (e.g., Blind (2016), DIN (2000) and Foray (1998)) or instead simultaneously restrict and facilitate innovation (e.g., Allen (2001)). The use of standards in models is also scarce, perhaps because the international standard appeared very recently (i.e., 2019).

7.3. Comparison between related work, gaps, and challenges

Proposals presented in Section 7.1 are compared in Table 6. There are some critical differences between them paper: (1) only a few works present a systematic review of a generalist nature, and they do not, however, review capability and maturity; (2) only one proposal reviews capability and maturity, but it is not generalist as it focuses on open innovation and service capabilities; (3) some proposals are generalist, but none review maturity models, and the latest one dates back five years; (4) most of the works review specific frameworks on which to base further work, but only one of them focuses on maturity; (5) the average update grade of studied papers is 2013, with only three papers dating back less than three years; and (6) none of the studies consider innovation standards.

The related literature covers numerous aspects of innovation, focusing on capability domains in innovation types or sectorial fields of application. However, neither domain provides a comprehensive generalist approach that considers the whole innovation process, including stakeholders and public funders. None of the studies focuses on funding. The three papers found closest to the present study are Frishammar et al. (2012), Haldma et al. (2012) and Shang et al. (2010), which take a generalist approach to innovation, reviewing frameworks and capability models. However, they do not study maturity models, and only one (i.e., Frishammar et al. (2012)) uses a systematic method reviewing 47 papers. These studies date back more than five years. Those that do propose maturity models (Carroll & Helfert, 2015; Igartua et al., 2018) are not generalist.

Regarding the number of studies reviewed, two proposals, El Hanchi and Kerzazi (2020) and Hosseini et al. (2017), review a significant number. However, neither of them reviews maturity models from a generalist perspective, which is the primary goal of this paper. The number of primary studies analysed in the present study (i.e., 79) is almost average (i.e., 81.6). It is also important to highlight the fact that most of the studies do not provide specific numbers because the methods they followed were not systematic (e.g., SLR or SMS).

This study contributes to the innovation field that can guide researchers and practitioners – mainly innovation managers and business managers – in creating and improving innovation development focused on investor's trust to ease the restrictions imposed by the financing. It should be noted that neither of the previous studies addresses the challenges (cf. Section 6) considered in this work. None explicitly mentions the need for industrial validation (CH1) of the proposed models. The ontological loop (CH2) is not addressed from the perspective of innovation as a process. Each study provides its own vision of capabilities, but they are not compiled from a critical point of view (CH3) or analysed from the investor's point of view (CH4). The variability of types of innovation is not tackled (CH5), and there is no reference to the minimal use of innovation standards in the literature (CH7). The models are not analysed from the agile perspective to improve the relationship with public funders (CH9) and do not focus on the early stages of the process (CH7), considering the CBV and RBV theories (CH8).

8. Threats to validity

This section examines, following the recommendations presented in Zhou et al. (2016), the threats to the validity that may compromise its results of this research. The main threats, grouped by the SMS execution phase, are described below, together with the mitigating actions taken.

8.1. Planning phase threats

The first threat to be considered is the formulation of inappropriate RQs. To mitigate this, preliminary research was carried out, consulting reference publications in R&D and innovation (e.g., Frascati Manual (OECD, 2015), Oslo Manual (OECD & Eurostat, 2018), EU Green Paper on Innovation (Commission, 1995), UNE R&D Standards such as ISO

[9] https://doi.org/10.5281/zenodo.6998331.

56000,[10] UNE 166000[11] and CWA 15899[12]) and reference maturity assessment publications (e.g., CMMI 2.0[13] and EFQM[14]). The first author of this paper also has more than ten years of experience working in ICT in the innovation field. Thanks to his expertise, an initial point of reference was established. Incorrect or incomplete search keywords in automatic searches were also considered a threat. The search string in the search process may have included inappropriate keywords related to the research topic. To alleviate this threat, several searches were carried out in the four digital libraries with different search strings and keywords. Terms were also added to the search string, and searches were performed in additional libraries. After several iterative searches and having analysed the number and titles of the results, a consensus was reached on the search string and the final keywords.

Others significant risks and bias detected during the evaluation of the primary studies were:

- The lack of standard languages and terminologies. It was noticed that there was no consensus on the concepts. Future works should address this issue by including a thesaurus or glossaries of innovation.
- Due to the scientific nature of the SMS, only scientific publications are considered in this paper. Therefore, grey literature is not covered. To mitigate this, IMSs (i.e., standards that have emerged from the business community) have been analysed (cf. Section 7.2).
- The role of the different stakeholders in the Quadruple Helix model is not always considered, especially the role of public institutions as funders. This causes an important bias that should be studied in future works.

8.2. Execution phase threats

Due to the universality of the concept of innovation, a large number of primary studies were identified. To choose the most relevant studies, appropriate inclusion and exclusion criteria were selected based on the first author's ten years of experience in innovation. A rigorous search strategy was defined, and a multi-step selection process was applied. Queries were also adapted to each of the digital libraries.

Regarding EC3, it is noteworthy that the reviewers had subjective conjectures, and this may have led to data inaccuracy and the incorrect classification of studies. This bias was mitigated by developing detailed guidelines in the review protocol before starting the review. During the paper screening phase, reasons for the inclusion/exclusion decision were also documented.

Finally, in the data extraction process, the reviewers could not understand the definition of the data extraction item and its relationship with the RQs, resulting in the incorrect classification of publications. This bias was mitigated by establishing a protocol for the study during the planning phase and having two researchers for reviewing each study. If no agreement was reached between them, a third researcher took the final decision.

8.3. Reporting phase threats

Although the authors of this paper have extensive experience in the sector, an expert assessment may have been lacking in the reporting section. To avoid this threat, conclusions and results were evaluated by an expert – an ICT company innovation manager with more than 15 years of experience in the sector – to understand and interpret their true meaning and significance.

9. Conclusions and future work

This paper is the result of a need to investigate the problems facing innovative organisations —executors benefiting public funding— and the government —as the main financier— in applying innovation from the new perspective of the Implementation Paradox defined by Giménez Medina (2020). According to this hypothesis, the $InnovationProcess$ is limited due to restrictions imposed by $publicfunders$. The $InnovationProcess$ needs funding but also needs freedom, and these two needs are currently far from being aligned. To solve the problem, the following assumption is made: $publicfunders$ will reduce their restrictions if their trust in executors is increased. An increase in trust can be achieved by applying agile models that assess the maturity of the executors' business $InnovationProcess$. These models can reduce the number of $publicfunders$' restrictions in higher maturity organisations, overcoming many innovation challenges. For this purpose, it is necessary to reconsider the public administration role, its capabilities and innovation policies and establish a new relationship model with the executors based on maturity.

In this paper, the state-of-the-art in models for assessing innovation maturity was analysed through an SMS in which 78 primary studies were selected after executing a rigorous systematic method.

The analysis of the results shows that the applicability of capability and maturity models is limited in the industry. There is a lack of consensus about the whole field of innovation, and syntactic and semantic standardisation is therefore necessary. One reason for this may be the fact that IMSs have scarcely been used to date. More attention should be given to IMSs in future works investigating innovation models.

The large number of capabilities found and the difficulty of horizontally applying innovation to all scientific fields at different stages of its process demonstrate this. A common ontology for innovation capabilities, innovation types and phases of the innovation process is needed. It would also be interesting to establish a research line to investigate how public funders can understand and compare organisations' innovation capabilities.

The lack of consensus also applies to the structure of the $InnovationProcess$, where the main stakeholders are not properly integrated. In the studies analysed, $QuadrupleHelix$ stakeholders, $OpenInnovation$ and the $Agile$ concept were not considered in the $InnovationProcess$. Neither did the studies take into account such a decisive factor as $publicfunders$ and the restrictions they impose on $Execution$. In fact, the $Execution$ phase – where successful innovation is most visible – received the least attention.

Maturity was rarely considered, while this concept is widely applied in other areas such as CMMI. Its application in innovation needs to be studied with an ontological standardisation that will make it possible to compare organisations and extract their best practices.

Future works need to study the maturity models application in the industry more closely. It is also necessary to explore the early phases ($Ideation$ and $Execution$) of the $InnovationProcess$ considering the $QuadrupleHelix + PublicFunders$. $Publicfunders$ are the cause of a set of limitations and restrictions that are not generally considered, especially in $Execution$. This could be mitigated by working on $TrustBuilding$, creating a maturity model capable of comparing best practices and building a trusting relationship between $publicfunders$ and funded organisations, i.e., executors.

CRediT authorship contribution statement

M. Giménez-Medina: Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing. **J.G. Enríquez:** Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing, Supervision. **F.J. Domínguez-Mayo:** Conceptualization, Methodology, Investigation, Writing – review & editing, Supervision.

[10] https://www.iso.org/standard/69315.html.
[11] https://www.une.org/encuentra-tu-norma/busca-tu-norma/norma?c=N0036141.
[12] https://tienda.aenor.com/norma-cen-cwa-15899-2008-32182.
[13] https://https://cmmiinstitute.com/.
[14] https://www.efqm.org/.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgements

This publication is part of the project PID2019-105455GB-C31, funded by MCIN/ AEI/10.13039/501100011033/ and by the ''European Union''.

References

Allen, D. (2001). Standardization and innovation in information technology. In *2001 2nd IEEE conference* (pp. 149–153).

Assink, M. (2006). Inhibitors of disruptive innovation capability: a conceptual model. *European Journal of Innovation Management*.

Atkinson, R. (1999). Project management: cost, time and quality, two best guesses and a phenomenon, its time to accept other success criteria. *International Journal of Project Management*, *17*(6), 337–342.

Balmaseda, E. M. V., Elguezabal, I. Z., & Clemente, G. I. (2007). Evolución de los modelos sobre el proceso de innovación: desde el modelo lineal hasta los sistemas de innovación. In *Decisiones basadas en el conocimiento y en el papel social de la empresa: XX congreso AEDEM* (p. 28).

Baregheh, A., Rowley, J., & Sambrook, S. (2009). Towards a multidisciplinary definition of innovation. *Management Decision*, [ISSN: 0025-1747] *47*(8), 1323–1339.

Berg, P., Leinonen, M., Leivo, V., & Pihlajamaa, J. (2002). Assessment of quality and maturity level of R&D. *International Journal of Production Economics*, *78*(1), 29–35.

Berkowitz, H. (2018). Meta-organizing firms' capabilities for sustainable innovation: A conceptual framework. *Journal of Cleaner Production*, *175*, 420–430.

Blind, K. (2016). The impact of standardisation and standards on innovation. In *Handbook of innovation policy impact* (pp. 423–449). Cheltenham, UK: Edward Elgar Publishing.

Bughin, J., Windhagen, E., Mischke, J., Sjatel, P., & Gürich, B. (2019). *Innovation in Europe: Changing the game to regain a competitive edge': Technical report discussion paper*.

Carayannis, E. G., & Campbell, D. F. (2009). 'Mode 3'and'quadruple helix': toward a 21st century fractal innovation ecosystem. *International Journal of Technology Management*, *46*(3–4), 201–234.

Carroll, N., & Helfert, M. (2015). Service capabilities within open innovation. *Journal of Enterprise Information Management*, *28*(2), 275–303.

Chesbrough, H., Vanhaverbeke, W., & West, J. (2006). *Open innovation: researching a new paradigm*. Oxford University Press on Demand.

Christensen, C., Raynor, M. E., & McDonald, R. (2013). *Disruptive innovation*. Harvard Business Review.

Commission, E. (1995). *Green paper on innovation*. Office for Official Publications of the European Communities.

Cropley, D. H., Kaufman, J. C., & Cropley, A. J. (2011). Measuring creativity for innovation management. *Journal of Technology Management & Innovation*, *6*(3), 13–30.

Crossan, M. M., & Apaydin, M. (2010). A multi-dimensional framework of organizational innovation: A systematic review of the literature. *Journal of Management Studies*, *47*(6), 1154–1191.

Datta, A. (2011). Information technology capability, knowledge assets and firm innovation: A theoretical framework for conceptualizing the role of information technology in firm innovation. *International Journal of Strategic Information Technology and Applications (IJSITA)*, *2*(3), 9–26.

DIN (2000). German institute for standardization e. v., economic benefits of standardization: Summary of results. URL: http://www.iso.org/sites/materials/benefits-of-standards/benefits-detaild2d1.html?emid=12.

El Hanchi, S., & Kerzazi, L. (2020). Startup innovation capability from a dynamic capability-based view: A literature review and conceptual framework. *Journal of Small Business Strategy*, *30*(2), 72–92.

Foray, D. (1998). Standards and innovation in technological dynamics. *StandardView*, *6*(2), 81–84.

Frishammar, J., Kurkkio, M., Abrahamsson, L., & Lichtenthaler, U. (2012). Antecedents and consequences of firms' process innovation capability: a literature review and a conceptual framework. *IEEE Transactions on Engineering Management*, *59*(4), 519–529.

Giménez Medina, M. (2020). Towards an agile innovation capability maturity framework to enhance investments on ict organizations. In *CAiSE-DC 2020: 32nd international conference on advanced information systems engineering (2020)* (pp. 21–31). CEUR-WS.Org.

Haldma, T., Näsi, S., Grossi, G., Saunila, M., & Ukko, J. (2012). A conceptual framework for the measurement of innovation capability and its effects. *Baltic Journal of Management*, *7*(4), 355–375.

Hasan, H. (2014). *Being practical with theory: a window into business research*. Faculty of Business, University of Wollongong.

Hosseini, S., Kees, A., Manderscheid, J., Röglinger, M., & Rosemann, M. (2017). What does it take to implement open innovation? Towards an integrated capability framework. *Business Process Management Journal*, *23*(1), 87–107.

Igartua, J. I., Retegi, J., & Ganzarain, J. (2018). IM2, a maturity model for innovation in SMEs. *Dirección y Organización*, (64), 42–49.

Inigo, E. A., Albareda, L., & Ritala, P. (2017). Business model innovation for sustainability: Exploring evolutionary and radical approaches through dynamic capabilities. *Industry and Innovation*, *24*(5), 515–542.

Jayawarna, D., & Holt, R. (2009). Knowledge and quality management: An R&D perspective. *Technovation*, *29*(11), 775–785.

Keeley, L., Walters, H., Pikkel, R., & Quinn, B. (2013). *Ten types of innovation: the discipline of building breakthroughs*. John Wiley & Sons.

Kitchenham, B., Brereton, O. P., Budgen, D., Turner, M., Bailey, J., & Linkman, S. (2009). Systematic literature reviews in software engineering–a systematic literature review. *Information and Software Technology*, *51*(1), 7–15.

Kondo, Y. (1996). Are creative ability and work standardization in contradictory relationship? *Training for Quality*, 35–39.

Lichtenthaler, U. (2007). The drivers of technology licensing: An industry comparison. *California Management Review*, *49*(4), 67–89.

March, J. G. (1991). Exploration and exploitation in organizational learning. *Organization Science*, *2*(1), 71–87.

Mazzucato, M. (2018). Mission-oriented innovation policies: challenges and opportunities. *Industrial and Corporate Change*, *27*(5), 803–815.

Mir-Mauri, M., & Casadesus-Fa, M. (2011). Normas para la gestión de la innovación. Un análisis comparativo. *Dyna (Bilbao)*, *86*(1), 49–58.

Moorman, C., & Slotegraaf, R. J. (1999). The contingency value of complementary capabilities in product development. *Journal of Marketing Research*, *36*(2), 239–257.

OECD (2015). Frascati manual 2015. http://dx.doi.org/10.1787/9789264239012-en.

OECD (2021). Oecd science, technology and innovation outlook 2021. http://dx.doi.org/10.1787/75f79015-en.

OECD, & Eurostat (2018). Oslo manual 2018. http://dx.doi.org/10.1787/9789264304604-en.

Petersen, K., Feldt, R., Mujtaba, S., & Mattsson, M. (2008). Systematic mapping studies in software engineering. In *12th EASE* (pp. 1–10).

Petrin, T. (2018). *A literature review on the impact and effectiveness of government support for R&D and innovation*. ISIGrowth.

Phene, A., & Almeida, P. (2008). Innovation in multinational subsidiaries: The role of knowledge assimilation and subsidiary capabilities. *Journal of International Business Studies*, *39*(5), 901–919.

Pöppelbuß, J., Plattfaut, R., Ortbach, K., Malsbender, A., Voigt, M., Niehaves, B., & Becker, J. (2011). Service innovation capability: Proposing a new framework. In *2011 FedCSIS* (pp. 545–551). IEEE.

Raghuvanshi, J., Ghosh, P. K., & Agrawal, R. (2019). Taxonomy of innovation capability framework with future directions. *International Journal of Business Excellence*, *17*(3), 265–289.

Reinhardt, R., Gurtner, S., & Griffin, A. (2018). Towards an adaptive framework of low-end innovation capability–A systematic review and multiple case study analysis. *Long Range Planning*, *51*(5), 770–796.

Rejeb, H. B., & Younes, M. A. B. (2018). Proposition of a methodological framework for measuring innovation capacity of Tunisian companies. *International Journal of Technology, Policy and Management*, *18*(2), 89–124.

Rothwell, R. (1994). Towards the fifth-generation innovation process. *International Marketing Review*, *11*(1), 7–31.

Schumpeter, J., & Backhaus, U. (2003). The theory of economic development. In *Joseph Alois schumpeter* (pp. 61–116). Springer.

Shang, S. S., Wu, S.-H., & Yao, C.-Y. (2010). A dynamic innovation model for managing capabilities of continuous innovation. *International Journal of Technology Management*, *51*(2–4), 300–318.

Sutherland, J., & Sutherland, J. (2014). *Scrum: the art of doing twice the work in half the time*. Random House Business.

Teece, D., & Pisano, G. (2003). The dynamic capabilities of firms. In *Handbook on knowledge management* (pp. 195–213). Springer.

Tello-Gamarra, J., & Zawislak, P. A. (2013). Transactional capability: Innovation's missing link. *Journal of Economics Finance and Administrative Science*, *18*(34), 2–8.
Tran, H. T., Santarelli, E., & Wei, W. X. (2020). Open innovation knowledge management in transition to market economy: Integrating dynamic capability and institutional theory. *Economics of Innovation and New Technology*, 1–29.
Vadastreanu, A., Bot, A., Farcas, F., & Szabo, I. (2015). Innovation capability-the main factor for wealth creation. In *2015 ROLCG* (pp. 1–4). IEEE.
Von Krogh, G., Nonaka, I., & Aben, M. (2001). Making the most of your company's knowledge: a strategic framework. *Long Range Planning*, *34*(4), 421–439.
Wang, K., Widagdo, J., Lin, Y., Yang, H., & Hsiao, S. (2016). A service innovation framework for start-up firms by integrating service experience engineering approach and capability maturity model. *Service Business*, *10*(4), 867–916.
Watkins, A., Papaioannou, T., Mugwagwa, J., & Kale, D. (2015). National innovation systems and the intermediary role of industry associations in building institutional capacities for innovation in developing countries: A critical review of the literature. *Research Policy*, *44*(8), 1407–1418.
Wernerfelt, B. (1984). A resource-based view of the firm. *Strategic Management Journal*, *5*(2), 171–180.
Wieringa, R. J. (2014). *Design science methodology for information systems and software engineering*. Springer.
Wogwu, V. E., & Hamilton, D. I. (2018). Reconfiguration capability and competitive advantage: A study of port harcourt public health sector. *Management*, *8*(2), 47–53.
Woodman, R. W., Sawyer, J. E., & Griffin, R. W. (1993). Toward a theory of organizational creativity. *Academy of Management Review*, *18*(2), 293–321.
Zambrano, J. J. A., & Velásquez, J. R. (2011). Strategic innovation decisions and innovation capabilities: Decision and action models. In *2011 proceedings of PICMET'11: technology management in the energy smart world (PICMET)* (pp. 1–10). IEEE.
Zhang, J. A., Garrett-Jones, S., & Szeto, R. (2013). Innovation capability and market performance: the moderating effect of industry dynamism. *International Journal of Innovation Management*, *17*(02), Article 1350004.
Zhang, F., & Zhu, L. (2020). Firm collaborative capability and new product development performance: the mediating role of heterogeneous knowledge acquisition. *International Journal of Emerging Markets*.
Zhou, X., Jin, Y., Zhang, H., Li, S., & Huang, X. (2016). A map of threats to validity of systematic literature reviews in software engineering. In *2016 23rd APSEC* (pp. 153–160). IEEE.