UNIVERSIDAD POLITÉCNICA DE MADRID

Escuela Técnica Superior de Ingenieros de Telecomunicación

Departamento de Ingeniería de Sistemas Telemáticos

**INTEGRATED MANAGEMENT OF INNOVATION IN
UNIVERSITY-DRIVEN OPEN ECOSYSTEMS. AN
EVOLUTIONARY APPROACH**

TESIS DOCTORAL

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Máster Universitario en Seguridad Informática,

Máster Universitario en Administración y Dirección de Empresas

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RESUMEN

Las universidades públicas en Europa enfrentan en la actualidad una serie de grandes retos que hacen peligrar su posición como proveedores estratégicos de conocimiento. Las nuevas tecnologías se constituyen como uno de estos grandes retos, ya que pueden verse sus efectos en otros sectores tradicionales como son el bancario o el de comercio minorista. Sin embargo, son también precisamente las nuevas tecnologías las que habilitan nuevas oportunidades para el cambio de las universidades, permitiéndoles evolucionar hacia nuevos modelos más adaptados a los nuevos tiempos, y donde la innovación se presenta no solo como herramienta para su supervivencia, sino como fuente de nuevas ventajas competitivas y nuevas oportunidades para la colaboración.

El presente estudio de investigación presenta un nuevo marco de acción para la evolución de las universidades, aprovechando cada uno de los grandes retos identificados como nuevas oportunidades de transformación hacia sistemas integrados de gestión de la innovación, la investigación y la educación. Con este objetivo fundamental, son presentados dos enfoques, uno más incremental y otro más evolutivo, que facilitan el proceso de cambio de las universidades.

Las principales contribuciones del presente trabajo de investigación confirman la necesidad de un cambio del actual modelo utilizado por las universidades públicas, contribuyendo de forma muy positiva a la generación del debate necesario que debe tener lugar para su concienciación y paso a la acción. También se muestra la relación e importancia que tiene el conocimiento y su gestión tanto en la toma de las decisiones como en el proceso de innovación. Con este objetivo, se muestran distintas técnicas y herramientas, algunas generadas en el seno de este trabajo, que permiten un análisis cuantitativo de los ecosistemas de innovación de tipo universitario, con lo que es posible realizar no solo el seguimiento y análisis del ecosistema, con un incremento exponencial de información útil para la toma de decisiones, sino también conocer el comportamiento de sus distintos actores, mejorando la capacidad de actuación en beneficio de estos actores y del propio ecosistema. Finalmente, una de las principales contribuciones del presente trabajo son las nuevas líneas de investigación y trabajo que se abren, tanto desde el punto de vista de sistemas integrados de gestión de la innovación, hasta el esclarecimiento mismo del proceso de innovación.

Palabras clave: Ecosistema de Innovación, Gestión del Conocimiento, Gestión de la Innovación, Ecosistema de Innovación Impulsado por la Universidad, Técnicas de Gestión de la Innovación (IMT), Toma de Decisiones, Social Network Analysis (SNA), Sistema Integrado de Gestión de la Innovación, Ontología, Knowledge Graph, Biomimética.

ABSTRACT

Public universities in Europe currently face a series of major challenges that jeopardize their position as strategic knowledge providers. New technologies are one of these great challenges, since their effects can be seen in other traditional sectors such as banking or retail. However, it is also precisely the new technologies that enable new opportunities for the change of universities, allowing them to evolve towards new models more adapted to the new times, and where innovation is presented not only as a tool for their survival, but as a source of new competitive advantages and new opportunities for collaboration.

This research study presents a new framework of action for the evolution of universities, taking advantage of each of the major challenges identified as new opportunities for transformation towards integrated systems of innovation management, research and education. With this fundamental objective, two approaches are presented, one more incremental and the other more evolutionary, which facilitate the process of university change.

The main contributions of this research work confirm the need for a change of the current model used by public universities, contributing in a very positive way to generating the necessary debate that must take place for their awareness and action. It also shows the relationship and importance of knowledge and its management both in the decision-making process and in the innovation process. With this objective, different techniques and tools are shown, some generated within this work, that allow a quantitative analysis of the innovation ecosystems of university type, with which it is possible to conduct not only the monitoring and analysis of the ecosystem, an exponential increase of useful information for decision making, but also to know the behavior of its different actors, improving the acting capacity for the benefit of these actors and the ecosystem itself. Finally, one of the main contributions of this work is the new lines of research and work that are opened, both from the point of view of integrated systems of innovation management, to the very clarification of the innovation process.

Keywords: Innovation Ecosystem, Knowledge Management, Innovation Management, University-driven Innovation Ecosystem, Innovation Management Techniques (IMT), Decision-making, Social Network Analysis (SNA), Integrated Innovation Management System, Ontology, Knowledge Graph, Biomimetic.

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1 INTRODUCTION

“War is ninety percent information.” —Napoleon Bonaparte.

However, *“What we know is a drop, what we don't know is an ocean.”* — Isaac Newton.

1.1 Importance and rationale of the topic

Innovation is presented as one of the most important tools for improving the competitiveness of organizations (Fransman, 2018; Farinha et al., 2016; Fagerberg et al., 2007; Iansiti and Levien, 2004; Tidd et al., 2001). For that reason, the management of innovation is particularly important, at a time when competitiveness crosses borders, due to key issues such as globalization and digitalization, which makes it necessary to continuously monitor all those factors that could affect their development and, ultimately, the sustainability and survival of organizations.

Innovation is a process composed of a set of technical, organizational, productive and commercial stages that lead to the successful launch in the market of new manufactured products or new services. It is therefore a complex and diversified activity, with many components in interaction that act as sources for new ideas. This complex structure makes very difficult to discover the consequences that a new event of these characteristics can cause in the innovation process itself (Jalonen and Lehtonen, 2011; Escorsa and Valls, 2003).

Indeed, there are many internal and external obstacles encountered by organizations when innovating or adopting an innovation such as the culture of organizations and their training, the regulation, the environment, etc. (Amara et al., 2016; Loewe and Dominiquini, 2006; Malerba, 2005). Despite the efforts made, most of the attempts to create new products and services still fail in a high percentage. In fact, around 60% of the development of new products or services are discarded, even before they reach the market. On the non-previously discarded ones, 40% do not get a sufficient commercial return, so they also fail. So, nearly 75% of the capital invested by organizations in the development of new products or services is not finally transformed into innovations (Christensen et al., 2016; Leonard, 1998). Therefore, innovation can fail in whatever point of the process and every bad decision, however small it may be, can lead us to a path with no way out. In this sense, well-informed decision-making, based on sufficient but also relevant information, with tools and analytical models that allows extracting maximum benefit from all that information, takes on a special role to avoid or at least mitigate, the most of the risks associated with the innovation process.

The digitization of information, advances in automation, unprecedented access to data and the democratization of knowledge are transforming all sectors of our economy: health, transport, energy, etc. According to data from the study conducted by McKinsey¹, a dozen technologies, including genomics, energy storage and automation, will drive an important economic and social transformation in the coming years. With a potential economic impact of between \$14 billion and \$33 billion per year in 2025, the value of these emerging technologies could constitute one third of the world's GDP².

Universities are not isolated entities immune to society changes. They also suffer the consequences of other deep changes in society and they will share with other institutions the fate of society evolution (Marshall, 2018; Etzkowitz et al., 2000). During this decade, the fast evolution towards the so-called “*digital economy*” and the exponential growth and availability of innovative solutions based on “*digital platforms*” embedded in the so-called “*collaborative economy*” (Kostakis and Bauwens, 2014) are affecting all public and private entities by disrupting the value-chains of all economic sectors. The higher education sector and universities in particular, are not immune to this challenge. Then, the key question at this stage is to assess at what extent universities will continue playing their main role in society as the main focus for generating and transmitting knowledge to future generations or it should be a responsibility increasingly shared with other actors, even when its core values were still preserved (León et al., 2019). Here is where innovation could play an important role for their competitiveness and subsistence, but also for their sustainability in time.

With respect to the information, during the last twenty years all advanced countries have quickly moved from a complex information society driven by the “*accumulation of information*” captured from many sources to another one commonly known as *knowledge-based society*, where the emphasis is put on the way that knowledge is generated, processed, shared and used. Knowledge is much more than mere information. It adds value to the products or services of any organization, since it becomes a proactive element to address and solve complex problems in dynamic globalized contexts. At this stage, the information per se has no relevant value unless it is contextualized,

¹ Disruptive technologies: Advances that will transform life, business, and the global economy https://www.mckinsey.com/~media/McKinsey/Business%20Functions/McKinsey%20Digital/Our%20Insights/Disruptive%20technologies/MGI_Disruptive_technologies_Full_report_May2013.ashx

² 4 Ways universities are driving innovation <https://www.weforum.org/agenda/2018/01/4-ways-universities-are-driving-innovation/>

analyzed and used in benefit of citizens and institutions (OECD, 2015; Maassen and Stensaker, 2011; OECD, 1997).

Today, every public or private entity should manage its “*core knowledge*” (on technology, business processes, clients/providers, or human resources) in all relevant areas of its activity. “*Knowledge processing*” in this context means much more than the art of collecting information about something or even its organization in a structured way for further retrieval. It should provide the added value to products or services creation processes in any organization and became a key pro-active tool to address and solve complex problems in globalized and very dynamic contexts (Sjödén, 2018; Burgin and Mikkilineni, 2017).

The set of entities’ business processes to use or exploit knowledge (in the sense expressed above) for decision-making has been usually termed as “*business intelligence processes*”³. This concept does not only apply to get better support for the management of resources in private firms and public institutions but it also became a weapon to increase and sustain organizations’ competitiveness by allowing end-users to access and analyze quickly and straightforward the information required to make decisions at the operational, tactic and strategic levels. It is about supporting decision-making through the contextualized analysis of information (Chaudhuri et al, 2011). In short, it became a powerful tool for *smart decision-making*.

There are several tools to support decision-making. One of the best known is the so-called Balance Scorecard (BSC). It is a strategic management tool that enables the monitoring of business information based on a series of indicators generated from the internal information of the organization (external factors are not taken into account) to identify deviations and apply corrections in function of its strategy. In addition, this tool is able to anticipate possible unwanted futures, although the latter with much less security (Kaplan and Norton, 2007).

Today, even if large entities have sophisticated tools and methods well anchored in the institutional strategy, it is not common to find complex and sophisticated decision-making tools implemented and used by SMEs, but also neither by universities. Apart from the fact that universities understand competitiveness in a very different way, one of the main reasons come from the way that data is

³ In 1989, Howard Dresner (later on in Gartner Group) proposed the term “*business intelligence*” as an umbrella to describe “*concepts and methods to improving decision-making in the firm by using fact-based support systems*”. Not until the end of the 90’s its use was widely extended (http://en.wikipedia.org/wiki/Business_intelligence).

managed, which also hinders its analysis and subsequent performance. Many organizations are currently using data to make better decisions about their strategic and operational directions. However, and although data are also growing in universities, the most of them are still scattered across desktops, departments, they come in various formats and, therefore, making it difficult to retrieve or consolidate. The ability to analyze diverse information sets is needed, regardless of where they originate, and consolidating data stored in silos within institutions, managing and governing the data while securing sensitive information across databases, is a key requirement for implementation of Big Data⁴ in higher education (Daniel, 2015; Daniel and Buston, 2013). In other words, data warehousing can be an effective approach to unlock the value of Big Data in higher education.

In addition, to complicate matters further, universities usually have not the internal means to exploit them or the economic resources to outsource these processes to external specialized entities. The consequence is the high level of inherent risk assumed by those organizations without the necessary capability or knowledge to make more reasoned decisions.

In any case, and despite its benefits, tools like BSC present an inherent problem in their conception: "*the degree of intelligence*" of them is small. In short, as the name suggests, they are fundamentally conceptual tools and methodological support, but whose underlying information base is conventional and the data exploitation surface too. Although from the methodological point of view they internally require systematic reasoning about risks and opportunities, establish indicators and adopt measures on time, their ability to anticipate strongly evolving contexts is still poor (Chaudhuri et al, 2011). Thus, another possible (complementary) approach is the use of *artificial intelligence* techniques. Since the eighties, many tools were created and refined to codify the "*decision rules*", which are intuitively used by humans to make decisions. Once explicitly codified they intend to substitute human experts by automated computer-based systems, termed as *expert systems*, by extracting complex inferences from simple rules (Ericsson et al., 2018).

In spite of the strong hopes associated to this approach years ago, no relevant improvements were got since the beginning of this century. In a few words, expert systems were incapable of learning and react in face of "non-structured information" and fuzzy rules as the human brain does.

⁴ Big Data describes data that is fundamentally too big and moves too fast, thus exceeding the processing capacity of conventional database systems (Manyika et al, 2011).

Unfortunately, this is the usual context found in organizations and the source of complexities in decision-making processes. However, recently, a new set of decision-making support tools appeared from the “*cognitive computing*” field (Tejero and León, 2017). In short, cognitive computing refers to the development of computing systems modelled from the reasoning approach of human brain. After two decades of academic work, the first bunch of commercial systems has entered into the market.

Nowadays, due digitalization, some of the technological domains of interest to an organization are general (they are the so-called “*enabling technologies*”, as is the case of information and communication technologies, whose penetration in all organizations constitutes a fundamental basis of their competitiveness), while other technologies are specific to the products and services of the organization in question. For this reason, one of the areas of greatest interest to most organizations is the decision-making regarding the evaluation, acquisition and use of technology and the consequent analysis of its short, medium and long-term consequences in organizations (what is usually called “*technology intelligence*”). The analysis of technology consequences in the short, medium or long term constitutes a key element to ensure future competitiveness. This decision-making on technology in innovation ecosystems of university type is twice as important, due the knowledge generated and transmitted is technology: from its conception in the research dimension, until its launch to the market, as products and services.

From an operational point of view, the decisions on the selection, acquisition and absorption of a given technology imply to access a number of multidimensional information on the pre-selected technology obtained from multiple sources. Then, organizations should be able to analyze their relevance by filtering out non-useful information, and finally, to elaborate specific technology intelligence reports and recommendations for feeding-up decision making in the top management layers of the organization and, if adequate, to launch a technology-change process.

Within large private or governmental organizations, this process is addressed by a specific unit composed by highly qualified personnel, by using sophisticated tools and procedures to access to technology information and meta-information (contextual constraints) in order to provide the requested data and to feed up its smart interpretation in close interaction with the global technology strategy. Even when it is not totally clear what kind of information to search for, the analysis of scenarios and road mapping processes carried out by that unit constitutes valuable approaches. If a unit of this type is not available, it will be necessary to resort to the outsourcing of

the technological intelligence function as part of a periodic or sporadic consulting process with external entities, or to limit itself to the use of general purpose reports whose adaptation to the concrete needs of a certain entity is not desirable.

The diffusion of technologies in a certain market and the incorporation of new technologies in a specific organization have been widely analyzed (Rogers, 2010). It is noteworthy to note that for a given organization whose competitiveness depends on the ability to incorporate technologies into its products and services, doing so at times when it can have a competitive advantage is essential. From an operational point of view, the decision on the incorporation, or not, of a certain technology into an organization implies accessing and processing, from a multidimensional approach, all types of information relevant to it, obtained from various sources, analyzing its content, determine its relevance filtering that considered useful, and prepare reports and recommendations that feed the decision-making in the organization. Figure 1 shows an example of this type of decisions about technology, based on the process of technology intelligence: from the detection of a need for information about a technology or specific technological area, to obtaining the necessary knowledge to make decisions, once shared that knowledge with the different stakeholders.

Figure 1. Technology intelligence process (source: Tejero and León, 2017)

Given this scenario, the emergence of new technologies and cognitive intelligence systems allows for innovative approaches that offer an effective improvement based on the implementation of disruptive services of technological intelligence based on cognitive intelligence adapted to the needs

of concrete decision-making. These cognitive services promise to combine a reduced cost of access and processing of externally available technological information with the ability of interactive tuning to specific needs through natural language question and answer systems (Hurwitz et al., 2015).

However, such as was mentioned above, to get the most out of the information available in universities for decision-making, a change is required. It is necessary, therefore, to propose new ways of managing information that allows us to use these new computing tools to extract the maximum benefits. In this sense, starting with the conceptualization of innovation ecosystems in the form of new information structures prepared for better management and use of information seems to be the most reasonable step, something that is possible today thanks to the use some new methods, tools and techniques, such as ontologies.

In fact, an ontology is a model of reality of the world and the concepts in the ontology must reflect this reality (Noy, 2001). According to Natasha Noy (2001), an ontology defines a common vocabulary for researchers who need to share information in a domain. It includes machine-interpretable definitions of basic concepts in the domain and relations among them. Sharing common understanding of the structure of information among people or software agents is one of the more common goals in developing ontologies. In reality, there is a fine line where the ontology ends, and the knowledge base begins. On the other hand, if we need to build a large ontology, we can integrate several existing ontologies describing portions of the large domain.

Therefore, taking into account the approach of this research, the definition of the ontology of an innovation ecosystem can be described, something that can help us not only to improve decision-making, but also for a better understanding, thanks to the new possibilities and details (e.g. through the generation of knowledge graphs), of how innovation happens.

2 METHODOLOGY

Research can be defined as a set of processes, systematic and empirical, that are applied to the study of a specific phenomenon (Kumar, 2019; Taylor et al., 2015; Fernández Collado et al., 2006). All research work is based on a methodology that acts as a guide to the research process. Therefore, the research methodology establishes a systematic process and methods that are applied to increase knowledge about a specific problem. In this way, the investigation methodology establishes the procedure that the research will follow to discover the problem, define the objectives and identify and understand their internal and external connections, to generalize and deepen the

knowledge acquired, reaching to demonstrate them with the greatest possible rigor, through checks carried out through examples and experiments, its application and usefulness.

The phases involved in the development of the present research have been based on a first conceptualization, from which a theoretical framework, mostly based on a systematic and deep review of literature, has been constructed to allow the identification of the problem and the statement of the objectives to offer solutions and new knowledge for the field. The proposed solutions are configured in an action framework, where different techniques and tools are shown that make it possible to solve the identified problem. For these purposes, several case studies are shown, with both qualitative and quantitative measurements and data, which show the usefulness and possibilities of application, allowing to finally establish a series of conclusions and future works of continuity for this research work.

- Chapter 1. INTRODUCTION

- Introduction to the thesis. Presentation of the importance and rationale of the topic, but also the scope and structure.
- Chapter 2. METHODOLOGY
 - Definition of the research framework applied. It is defined the procedure to conduct the research and its scope.
- Chapter 3. THEORY BACKGROUND
 - Review of the literature and the definition of the base of concepts that will configure the theoretical frameworks that ground the research work. In this chapter is presented “**WHY** is needed a change?”
- Chapter 4. PROBLEM OR OPPORTUNITY
 - Identification of the current challenges and selection of the main challenge to be addressed in this research. This chapter is dedicated to show what is happening: “**WHERE** is the problem or opportunity?”
- Chapter 5. OBJECTIVES
 - Definition of what can be done to face the challenges of the identified problem or opportunity. In this chapter is described the objectives: “**WHAT** can we do to solve the problem?”
- Chapter 6. ACTION FRAMEWORK
 - Definition of the set of actions, following different approaches (implying different techniques and tools) that allow to face the identified challenges according to the defined objectives. The actions will follow methodology (presented in this chapter) that includes the technological contributions and real word scenarios for their contextualization. In this chapter is shown a framework of approaches, tools and techniques to solve the identified problem: “**HOW** we can do it possible?”
- Chapter 7. CONCLUSIONS AND FUTURE WORK
 - In this chapter is summary a set of conclusions and future lines of work: summary of conclusions and lessons learned, contributions, inputs for discussion, limitations of the work and pointing to the different lines of work that are opened with this research work.

2.2 Scope and approach of the research

The presented research work is mostly focused on the context of the current state of universities. Furthermore, the proposed solutions will explore different approaches to address the challenges defined in the objectives chapter. Firstly, approaches that develop the current trends on innovation management in university ecosystems will be explored. In addition, other approaches, more oriented to the current trends in computer science will be also included.

In order to demonstrate the validity, usefulness and benefits of the action framework, the ideal option would happen because a university decided to implement one of the two approaches included in the framework of action. This fact, without a doubt, would help to demonstrate with real data its possible application and use by other universities. However, this option is unfeasible for several reasons. On the one hand, the aforementioned university would have to accept that it has problems, its interest in improving and undertake the change at the institutional level, as well as having the necessary resources to implement this important change. On the other hand, the implementation of a change of this depth in an organization of the type of a university, an entity "in production", would involve a time that would escape the usually intended for the development of a thesis. Therefore, this option, although interesting, does not seem realistic.

Discarding the "ideal option", an option that could a priori be valid would be for a university to decide to share its data so that, in the context of this research, a complete simulation of the application of the proposed framework of actions could be carried out. This option, which can undoubtedly be interesting and could be viable, could not really be carried out due to one of the great challenges that are shown below in Chapter 4, related to the usual lack of information available by universities (moreover, in digital format); even having part of the information required for the implementation of the framework, the non-accessibility of this from the outside, as it was often considered as internal and confidential use (the information necessary for the implementation of the framework is usually strategic in nature for universities), would be a clear obstacle to their sharing, due to their sensitive nature, for use in a doctoral thesis.

Therefore, the approach finally used for this research focuses on demonstrating the capacity and viability of the different tools and approaches shown in the framework of action, as well as its usefulness and benefits, through the use of specific and limited application case studies. The set of application cases will offer the reader the option of observing the applicability of these tools and approaches in the context of the universities; specifically, they will be tested in the case of the Universidad Politécnica de Madrid, thanks to the access that both the doctoral student and the

thesis directors have to certain information of this university. In this sense, the focus will be on demonstrating those aspects and most relevant tools, such as the application of taxonomies for the generation of the graph of an innovation ecosystem of university type, enabling the application of mature and well-known techniques such as Social Network Analysis (SNA), or within the most disruptive approach show the use of ontologies and knowledge graphs, for the creation of services of high strategic interest such as technology intelligence.

In this way, according to the idiosyncrasy of each university, the results shown will make it possible to understand if it is possible to undertake, partially or completely, all or only some of the steps of the proposed action approaches.

3 THEORY BACKGROUND

"There is a book always open to all eyes: Nature" — Jean-Jacques Rousseau

The main topic of this research is related with innovation management in universities-driven ecosystems through current technologies to improve the decision-making process. This chapter explore the main concepts, trends and limits through and exhaustive literature revision. The theoretical background obtained will be used as the foundations for the next developments in the research work.

3.1 Conceptual schema of the chapter

Figure 3 shows the conceptual schema of the chapter. The chapter is divided in four main blocks: 1) innovation ecosystems, from the perspective of natural ecosystems, from which so much can be learned, will be addressed, and with a focus on the role of universities, as strategic providers of knowledge of this type of ecosystem; 2) knowledge management, demonstrating its importance both for decision-making and for its connection with innovation, within the different types of existing knowledge; 3) innovation management, necessary to maximize the performance of the innovation model used, now open innovation type, and where innovation management techniques (IMT) play a fundamental role; and 4) network analysis, which allows both the measurement and extraction of new and varied knowledge of incalculable value for decision making in ecosystems based on the exchange of knowledge.

Figure 3. Conceptual schema of the Theory Background Chapter (source: own elaboration)

Blue color is used to show the main topics of the chapter. The main concepts of the topics are shown in **black color**. Finally, **orange color** is used to show the key concepts of the main concepts.

3.2 Ecological and innovation ecosystems

According to Oxford dictionaries⁵, “*ecosystem*” can be defined as follows:

- (Ecology) “*A biological community of interacting organisms and their physical environment*”.
- (in general use) “*A complex network or interconnected system*”.

The term ecosystem was proposed by the British botanist Arthur Tansley in 1935, to define the basic functional unit in ecology, which encompasses the biotic⁶ communities and the abiotic⁷ environment of a specific region, where each of them influences the properties of the other. In the last decade, the literature related to innovation reflects a significant growth of interest in the term

⁵ Ecosystem definition <https://en.oxforddictionaries.com/definition/ecosystem>

⁶ Biotics describe living or once living components of a community. For example organisms, such as animals and plants.

⁷ In the field of biology and ecology, the abiotic term designates what is not biotic, that is, it is not part of or not a product of living beings, as inert factors: climatic, geological or geographical, present in the environment and affecting ecosystems.

ecosystem of innovation, as a conceptual mechanism for improving the weakness of structural innovation (Tsujiimoto et al., 2018; Gretschnann, 2014; Howells and Elder, 2011; Adner and Kapoor, 2010). Innovation ecosystems are dynamic systems made up by actors and connected by knowledge flows based on the relationships of these actors (Tejero and León, 2016). Below, its evolution from the national innovation systems to the concept of innovation ecosystem used today is presented.

The knowledge that we currently have about innovation ecosystems is still very far from the vast knowledge that we have about ecological ecosystems, much more studied. That is why the following section summarizes some of the most relevant aspects of ecological ecosystems, which will serve as a source of inspiration for the development of new theories and approaches applicable to innovation ecosystems.

3.2.1 Ecological ecosystems as a source of inspiration

According to the RAE⁸, ecosystem is defined, at a biological level, as "*the community of living beings whose vital processes are related to each other and are developed according to the physical factors of the same environment*". In ecology, the components that are distinguished in an ecosystem are the biocenosis and the biotope (Sukachev, 1958; Tansley, 1935). The biotope and the biocenosis are strongly related, due to the processes of adaptation of living organisms to the environment and the influence of living beings on the biotope. The biotope has characteristics that condition living organisms that can develop, elements such as relief, climate, soil, water, temperature and luminosity. The set of individuals of the same species is called "population". Thus, the biocenosis is the set of several populations of organisms that live in a specific place, a place that is commonly attributed the name of "habitat".

Biodiversity, or biological diversity, is the variety of life on Earth, which includes all organisms, species and populations, the genetic variation between them, and their complex sets of communities and ecosystems (Bisby et al., 1995; Heywood et al., 1995; Wilson, 1988). It is a consequence of the evolution of living beings to adapt to the different conditions of the biotope. Biodiversity is important to maintain the equilibrium and stability of the ecosystem, but it is also the source of new resources (food, materials, medicines, ...). In addition, it is the basis for resistance to environmental pressure phenomena (water, light, etc.) in the biotope, due to the greater genomic adaptation capacity of the population's species.

⁸ Real Academia Española. <https://dle.rae.es> – In spanish

The function performed by an organism in the ecosystem is called an "ecological niche", that is, the "profession" that the organism performs in the ecosystem (Elton, 2001). Thus, the types of organisms in an ecosystem according to their function can be classified, broadly speaking, into producer organisms, consumer organisms and decomposing organisms.

"Producer organisms" are those that produce organic matter (mainly vegetables, but also bacteria or archaea). They capture atmospheric CO₂ to incorporate it into organic molecules with the use of solar energy. They are the origin of the food chains that occur in ecosystems, where the rest of organisms, in one way or another, depend on them to survive.

"Consumer organisms", in turn, can be divided into primary, secondary and tertiary. The primary ones, which correspond to the herbivorous animals, are those that obtain their food through the producers. Secondary consumers, or carnivores, that correspond to those animals that feed on herbivorous animals. Tertiary consumers, whose food is secondary consumers, that is, they feed on other carnivorous animals.

Finally, "decomposing organisms" are the organisms that act by decomposing dead organic remains. Mainly, it is bacteria and fungi. In this way, the products generated from the decomposition can be used again by producing organisms, thus closing the cycle of matter of the ecosystem.

3.2.1.1 Relations in an ecological ecosystem

In an ecological ecosystem a great variety of relationships between the species that form the biocenosis are carried out (Smith et al., 2006; Caughley and Sinclair, 1994). These relationships can be generally beneficial when they improve the survival of each species, or harmful if they increase their mortality. According to these relationships, the populations of an ecosystem can vary over time. Thus, two main types of relationships are distinguished: intraspecific and interspecific.

"Intraspecific relationships" are those established between individuals of the same species. They are beneficial if they favor their survival and harmful in many cases, although not in all, if they provoke competition between individuals. Intraspecific relationships distinguish relations of association and competition.

- "An association relationship "occurs when groups of individuals form to obtain certain benefits: Greater ease in hunting and obtaining food; Defense against predators of the species; Reproduction by proximity of the sexes in the group; Care and protection of the

young; Achievement of complex collective tasks through specialization of subgroups of individuals with simple tasks (insects).

- "A competitive relationship" occurs when two individuals compete with each other. They can compete for: the resources of the environment (area of the territory, food, light, nutrients, etc.); Reproduction (fighting for the opposite sex); Social dominance (an individual or group of individuals is imposed on others, for one of the reasons mentioned above).

On the other hand, "interspecific relationships" are those that are established between different species of an ecosystem. The most common interspecific relationships are (Caughley and Sinclair, 1994): competition, predation, parasitism, mutualism and commensalism.

- "Of competence", when they fight for a limited resource (food, territory, etc.).
- "Depredation", when an organism (predator) obtains a benefit from another species, which is harmed and usually kills (prey), or submits to a prolonged unwanted dependency relationship (slavery).
- "Parasitism", when an organism (parasite) lives at the expense of another (host), from which it obtains what is necessary to live and producing some kind of damage.
- "Mutualism", it is a relationship in which two species obtain a mutual benefit.
- "Commensalism", in which a species (commensal) obtains a benefit from another without the latter having any harm.

3.2.1.2 Levels, chains and trophic networks

The relationships in the biocenosis are formed by the different trophic or alimentary levels of the ecosystem, passing matter and energy from one organism to another. Here, it is possible to distinguish the concepts of trophic level, trophic chain and trophic network (Jorgensen and Fath, 2014; Alberts et al., 2012).

- "Trophic level". It groups all the species that have the same type of feeding and that, therefore, compete for the same resources. Higher levels have a diet based on lower-level species. The different levels are represented in the form of a trophic pyramid, with a progressive reduction of matter and energy (level 1 producers, level 2 primary consumers, level 3 secondary consumers and level 4 tertiary consumers). The pyramid can report the amount of organic matter or biomass of a trophic level, the number of individuals at a trophic level, and the energy that has a trophic level.

- "Food chain". It is a simple and linear sequence of organisms that feed on each other, and that belong to different trophic levels. An example of a chain could be formed by algae (producer), carp (primary consumer) and heron (secondary consumer).
- "Trophic network". It is the complex and real interrelation that is established between the different species that form the different trophic levels. This is in turn made up of numerous trophic chains.

3.2.2 Innovation ecosystems

The concept of "Innovation System" was developed in parallel in different places in Europe and the United States, in the decade of the eighties (Lundvall, 2007), fruit of the new spirit that was breathed from what some called "techno-nationalism," which combined the belief that the technological capabilities of a nation's companies were a key source of their competitive skill, believing that these capabilities were, in fact, meaning, national, and can be built by national action (Nelson, 1993).

The concept of innovation system was an important milestone towards the clarification of innovation processes since the eighties. However, in the found definitions of the innovation system until 1994, little attention is given to details related to the interactions produced between the different actors normally involved in these systems, that is, to the dynamic relationships, focusing more on the innovation process or system in general (Freeman, 1995; Nelson and Rosenberg, 1993; Lundvall, 1992; Carlsson and Stankiewicz, 1991).

The concept of institution is one of the central elements of innovation, according to the different definitions provided by well-known authors in these matters, such as Freeman, Lundvall, Nelson or Rosenberg. So much so that Freeman defines the innovation system as *"the network of public and private sector institutions whose activities and interactions initiate, import, modify and disseminate new technologies"* (Freeman, 1995). For Lundvall (1992) the institutional framework is the second dimension in importance of an innovation system. Nelson and Rosenberg (1993) place special emphasis in their definition on institutions as support for technological innovation. Moreover, Carlsson and Stankiewicz (1991) point to the institutional infrastructure that intervenes in the generation, diffusion and use of technology. That is to say, as can be seen, most of the definitions are stated in terms relative to the institutions, which denotes the important role that these occupy in the innovation systems, and that it requires a more detailed study in which its interactions and relationships are also included, as pointed precisely by Edquist (1997).

In 1997, the OECD presented the report “National Innovation Systems” (Frenkel and Maital, 2014; OECD, 1997). This study puts the focus of attention on the links and interaction within the system, to know how knowledge flows in these ecosystems, among its different actors: companies, universities, etc. That is to say, it is about generating a series of indicators that allow "mapping the flow of knowledge" of a national innovation ecosystem. For policy-makers, an understanding of the national innovation system can help identify leverage points for enhancing innovative performance and overall competitiveness. In this report (OECD, 1997), is mentioned that the approach of the national innovation system had acquired greater analytical importance in the field of technology due to three factors: 1) the recognition of the economic importance of knowledge, 2) the increasing use of systems approaches and 3) the growing number of institutions involved in the generation of knowledge.

With the concept of ecosystem is when it starts to place more emphasis on the activities and interactions of its actors, a more directed approach to understanding the dynamics of systems and their sustainability (Rush et al., 2014). The concept of ecosystem is distinguished from that of system by the use of analogies between ecosystems of ecological-biological type and those of socio-economic type (Iansiti and Levien, 2004). In fact, an organization cannot be considered in isolation, since it is usually immersed in a network of interdependencies where a change produced in one part of the system can affect others (Moore, 1993).

According to Jackson (2011), *“a biological ecosystem is a complex set of relationships among the living resources, habitats, and residents of an area, whose functional goal is to maintain an equilibrium sustaining state. In contrast, an innovation ecosystem models the economic rather than the energy dynamics of the complex relationships that are formed between actors or entities whose functional goal is to enable technology development and innovation”*. The notion of ecosystems provides an attractive metaphor to describe a range of interactions and inter-linkages between multiple organizations (Autio and Thomas, 2014).

In the literature on socio-economic ecosystems there are many authors who refer, in one way or another, to the actors usually found in these ecosystems, actors such as large, medium and small companies, educational institutions, institutes of research, public entities, venture capital, etc. (Pilinkienė and Mačiulis, 2014). As in ecological ecosystems, actors are structured in different roles and functions (Edquist, 1997).

In these ecosystems, whether industrial (Frosch and Gallopoulos, 1989; Korhonen, 2001), business (Iansiti and Levine, 2004; Moore, 1993), entrepreneurship (Isenberg, 2010), digital (Nachira, 2002) or innovation (Adner, 2006; Wessner, 2007; Yawson, 2009), knowledge appears as an element that underlies aspects such as learning, people, technologies and culture. In fact, in a society like the current one, based on knowledge, it does not have to surprise that knowledge forms an essential part of the different systems and ecosystems, as it is reflected through concepts such as the well-known knowledge triangle, with which the relationship between the areas of education, research and innovation is highlighted (Maassen and Stensaker, 2011).

On the other hand, we must be cautious with the use of the term “ecosystem”. As some authors point out (Oh et al., 2016), the notion of "innovation ecosystem" is an interesting development, based on biomimetic thinking, which injects some useful concepts into the economic development dialogue. However, although it is true that it can lead to new scientific truths and reliable methods for knowledge and economic development, the notion in itself does not constitute or provide such truths or methods. Empirical support or rigorous correspondence rules are needed to support the extraction of conclusions when using this type of analogy.

3.2.3 Role of universities in innovation ecosystems

In an economy like the current one, driven by technology, universities must also change at an unknown rate for higher education. While it is necessary to preserve the main mission of educating the next generation and cultivating new forms of knowledge, universities must also assume an increasingly broad role in fostering innovation and as a catalyst for economic development. Universities must face the challenges of the digital revolution in which we find ourselves and play an increasingly important role in ecosystems and innovative economies.

In today's competitive environment, universities must also develop new collaborations with companies, foundations and other research institutions. Large corporations are already recognizing the high value and performance offered by these collaborations. According to the data compiled by the National Science Foundation (NSF) for the USA, industry funds for university research and development have grown by more than 5.5% per year, on average over the past 10 years: from around \$2.4 billion in 2006 to more than \$4, 2 billion in 2016. In Europe, the European Commission has also doubled the university-industry collaborations with the creation of the European Institute

of Innovation and Technology (EIT)⁹. Through its Knowledge and Innovation Communities (KICs), the EIT fosters cooperation between academia, research and business in more than 30 co-located centers in 15 member states.

The role of universities in innovation systems is increasingly crucial (Cai, 2017, Etzkowitz, 2013b). Universities play a proactive role in improving the effectiveness of their regional innovation environment, often in collaboration with industry and government actors. The university's new innovation mission has expanded from a narrow concern to protect and commercialize intellectual property rights to a broader interest in business formation and regional economic development. An entrepreneurial university that interacts with industry and government, in a triple helix, according to different modalities in different societies, is becoming the central focus of the theory and practice of innovation (Etzkowitz, 2013a).

There is a parallel transformation of universities, sometimes as leaders and many others as lagging entities, in a transition towards a knowledge-based economy. It can be expected, therefore, that this new function of economic and social development will be integrated into the university in the same way that research was integrated with education in an earlier era. As each new mission is incorporated into the university, the way in which the previous one is carried out is restructured, until it becomes the university of the future.

The university is incorporating the academic models of teaching and research and is taking them to a new stage of development, integrating the linear models back and forth in a renewed 'social contract' between the university and society in general, to create companies economic and social as "quid pro quo", in many cases, to be able to finance large-scale. According to Etzkowitz, (2013a), *"an 'entrepreneurial university wave' is aggregating from an array of individual experiments that spread both isomorphically and through policy initiative into the latest iteration of an institution of medieval origins"*. An example is the practical experience of the Universidad Politécnica de Madrid (UPM) in the article of León et al. (2018), where it shown that the policy experimentation space provided by EIT Digital has acted as an internal transformation driver for European universities; it has played a key role to accelerate structural reforms once partner universities assumed the need of modifying or reinterpreting "any internal regulation to participate better in the EIT".

⁹ The EIT helps businesses, educational and research bodies work together to create an environment conducive for innovation and entrepreneurship in Europe. <https://eit.europa.eu/>

Universities can be seen as innovation ecosystems contributing towards national innovation capacity, among others, via the commercialization of university research (Rampersad, 2015). In fact, a university can be seen as an innovation ecosystem as it consists of a live set of actors that also engage with the broader regional and national innovation ecosystems through relationships with industry (Herrera et al., 2018; Guerrero et al., 2016). Universities can contribute towards innovation in several ways via consulting, new firm spinoffs, technology licensing, technology and service commercialization, and university technology transfer to either established or new companies (Klofsten et al., 2019). Governments are demanding that universities contribute towards regional innovation and economic development in order to secure public funding for their initiatives (Wessner, 2004). Consequently, there is a shift in universities towards being innovative through high-tech spinoffs, technology commercialization, stimulating economic development and entrenching innovative mindsets in students (Ferraris et al., 2018; Markkula, 2013; Tyler III, 2008).

3.2.4 University-driven innovation ecosystems

University-driven innovation ecosystems are generated when organizations belonging to a university act as tractors to develop and transfer disruptive ideas through the creation of new companies (spin-off and startup), or through partnerships with high-tech consolidated companies. This type of ecosystem usually provides platforms or subsystems where other actors can develop their own products or services (Ardito et al., 2018; Ferraris et al., 2018), in the same way that historically has been done in ecosystems driven by the industry (León, 2013). The cases of MIT in Boston (Massachusetts, USA) and Stanford University in Palo Alto (California, USA) are examples emulated elsewhere in the world. In the European Union, something similar happens in universities such as Cambridge or Oxford, within the United Kingdom. In this sense, the intention of the ecosystems promoted by the university is to attract many other actors to facilitate and increase their innovation capacities and those of the regions and ecosystems with which they are also related.

The influence of public administrations often facilitates the creation of these university-driven innovation ecosystems. The case of Huawei in Shenzhen (China)¹⁰ is a good example of an industry-driven innovation ecosystem, driven by five public authorities over long periods of time. In the European Union, Swedish cases around the University of Lund or Switzerland around Swiss federal

¹⁰ China's Emerging Silicon Valley: How and Why Has Shenzhen Become a Global Innovation Centre
<http://www.europeanfinancialreview.com/?p=12327>

universities such as the Ecole Polytechnique Fédéral de Lausanne (EPFL) in Lausanne or ETH in Zurich are recent examples of innovation driven ecosystems by the university (León, 2013), where the interests of innovation converge between the national or federal authorities and the universities themselves.

3.2.5 Innovation ecosystem management

In 1932, it is the first time that the term "ecosystem management" appeared, when the Committee for the Study of Plant and Animal Communities of the Ecological Society of America recognized that ecosystems, as well as particular species of interest, should be protected (Shelford, 1933). The Committee also realized that inter-institutional cooperation was necessary to succeed and that ecologists should "use all means to educate the public about the value of these ecosystems". Although, at the same time, the idea that the administration could "improve" nature was also questioned (Grumbine, 1994).

Ecosystems are self-regulated systems that provide societies with resources. However, as the demands for these resources have increased, management decisions are replacing the self-regulation of ecosystems (DeFries and Nagendra, 2017). The importance of ecosystem management lies in the fact that it focuses on ecological systems as a whole and not only on some of their parts. The management includes the participation of the public in the process of establishing objectives, integrates conservation into economic activity and represents a change from "linear integral" management paradigm to "cyclical-incremental" or "adaptive" management (Brussard, et al., 1998).

In ecology, contrary to previous technical approaches that applied simple formulas to estimate the sustainable yields of individual species, current research recognizes the inherent complexity of ecosystems and the inability to foresee all the consequences of interventions at different spatial, temporal scales and administrative. Approaches to address such issues include multisector decision-making, institutions that allow management to extend across administrative boundaries, adaptive management, markets that incorporate natural capital, and collaborative processes to engage diverse stakeholders and address inequalities. Ecosystem management must avoid two pitfalls: falsely assuming a domesticated solution and inaction in the face of overwhelming complexity. An incremental approach can help avoid these pitfalls (DeFries and Nagendra, 2017).

Normally, the most significant member of an ecosystem is labeled as "keystone" (Mäkinen and Dedehayir, 2012). In ecological ecosystems, the keystone is usually associated with a vital species,

but it is also a key member in the case of business ecosystems (Iansiti and Levien, 2004). The keystone, also known in other contexts as leader of the platform (Cusumano and Gawer, 2002) or ecosystem leader (Moore, 1993), plays the role of regulating the general function of the ecosystem: its management and governance. Consequently, the actions of the leader influence the success of all other members of the ecosystem. Although the keystones exert substantial power within a given ecosystem and usually have a larger share of the overall gains (Moore, 1993), they tend to represent only a small part or population of the ecosystem organizations (Iansiti and Levien, 2004).

As in ecology, in innovation ecosystems, complexity requires an adaptive and incremental management for decision-making where the different actors involved can participate and re-feed for their own benefit and for the entire ecosystem. In this sense, in university-driven ecosystems, the university must develop a role of "orchestra conductor", ensuring that the ecosystem works in unison and that each organization has a clear role to play, for its sustainability.

With the increase in connectivity, specialization and knowledge-based products, it becomes evident that being part of a larger system is not only a competitive advantage, but also a necessity to participate in the creation of value (Selander et al. 2013). As a result, organizations demonstrate an increasing interest in organizing in these complex ecosystems, with the adoption of a network-centric strategy that allows them to combine their skills to create products that otherwise could not exist (Nambisan and Sawhney, 2011; Adner, 2006). Innovation ecosystems take advantage of the diversity and autonomy of their stakeholders to obtain potential innovative results (Dhanaraj and Parkhe, 2006), which become the central focus of their activities. This new type of collaboration agreements includes a wide range of actors, who closely resemble the biological communities that interact and depend on each other, evolving and responding to the environment in which they exist (Mankevich, 2014).

The dynamics of collaboration and competition in innovation networks are closely linked to issues related to open and closed innovation practices. A starting point for the idea of openness in innovation practices is that a single organization cannot innovate in isolation (Moore, 1993). Organizations must engage with different types of partners to acquire ideas and resources from the external environment to keep up with the competition (Chesbrough, 2003). The disadvantages of openness can also be considerable, although in the literature much less emphasis is placed on this: resources will be available for others to exploit, intellectual property is difficult to protect and the benefits of innovation difficult to take advantage (Mankevich, 2014).

On the other hand, buying pencils is not the same as building buildings or acquiring critical semiconductors. This last case is about "strategic purchases", where it is often even more advisable to do R&D jointly. This is precisely the case of universities and research centers, as strategic knowledge providers. Universities or research centers do not have sales, product development or delivery processes similar to business processes. Its function is not to solve short-term problems with orientation to the detailed specification (all R&D projects are uncertain by nature) and to minimize economic margins. Its function is, as a strategic knowledge provider, to generate R&D in conjunction with other organizations, with a medium and long-term vision, to prepare the next generation of products. In short, create exclusive capabilities for those organizations with which they collaborate. The research groups work with emerging knowledge, which can be incorporated into the market for several years.

Therefore, the management of strategic suppliers such as universities requires collaborative environments and relationships of trust. Open systems or collaborative environments that, in the case of innovation processes, usually require integration of information systems (for example, to develop complex projects concurrently) and, often, supply chain integration.

The solution is to patiently create business ecosystems around universities and research centers. Select those organizations with sufficient managerial and technological capabilities. Generate strong bonds of trust. Trace joint technological roadmaps in the medium and long term. Start to conduct strategic research in partnership, learning from each other, progressively modulating research to make it more oriented. Jointly design new generations of products. Integrate industrial doctorates into this logic (León et al., 2018). Permeabilize the borders and facilitate the "revolving doors" (doors of entry and exit of company personnel to the university and vice versa). Try to have public policies that help accelerate the process, through favorable taxation, preferential financing and direct aid to organizations that decide to follow this path¹¹.

All the aforementioned, requires innovation management, and ultimately knowledge, which allows an adaptive and incremental way to meet all the different milestones needed to achieve the objectives of positioning of universities as strategic knowledge providers, but also as orchestrators of all their ecosystems.

¹¹ <https://xavierferras.com/2015/02/de-la-transferencia-a-la-concurrencia-tecnologica/>

3.3 Knowledge management

According to the definition of innovation of Eurostat (European Union)¹², *“Innovation is the use of new ideas, products or methods where they have not been used before. Innovations are based on the results of new technological developments, new technology combinations, or the use of other knowledge, acquired by the enterprise”*. For the Community Innovation Survey (CIS)¹³, *“an innovation is defined as a new or significantly improved product (good or service) introduced to the market, or the introduction within an enterprise of a new or significantly improved process”*.

Undoubtedly, innovation is presented as one of the most relevant tools for improving the competitiveness of organizations (Filipova and Yuleva, 2018; Kafetzopoulos et al., 2015; Fagerberg et al 2007, Tidd et al., 2001; Porter, 1990). However, there are many obstacles encountered by companies when innovating or adopting an innovation, such as the organizations' own culture, training, policies, environment, etc.

Despite the efforts made, many of the attempts to create new products and services fail in a high percentage. Around 60% of the developments of new products or services are discarded, even before they reach the market. Over the remaining 40%, 40% do not get a sufficient commercial return, so they also fail. Therefore, close to 75% of the capital invested by organizations in the development of new products or services is not finally transformed into innovations (Heidenreich and Kraemer, 2016; Van der Panne et al., 2003; Leonard, 1998; Klein and Sorra, 1996).

In the study of Loewe and Dominiquini (2006), it was concluded that applying partial solutions to the obstacles encountered is not effective, if all aspects related to innovation are not taken into account. In other words, in order to become a successful innovator, it is necessary, according to Loewe and Dominiquini (2006), a systemic approach that addresses the four key causes underlying the ineffectiveness of innovation:

- *Culture and values*. Collaboration, have an open culture and incentives that reward the challenge to the status quo.
- *Leadership and organization*. Visionary leaders and an organization aligned around a common definition of innovation are needed. In fact, one of the respondents, CEO of an

¹² Definition of innovation <https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Innovation>

¹³ Community innovation survey (CIS) [https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Community_innovation_survey_\(CIS\)](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Community_innovation_survey_(CIS))

important aerospace group, stated under his own experience of success that "*without this leadership the efforts to innovate are condemned to failure*".

- *People and skills.* A critical mass of competent people throughout the organization with innovative approaches and appropriate tools.
- *Processes and tools.* There is also a need for a systematic approach and support tools that allow the generation of ideas and their elaboration, as well as the processing and management of portfolios.

According to the results shown in the study of Amara et al. (2016), overall, knowledge obstacles tend to be negatively associated with delivery, strategic, managerial, and marketing innovations. These results carry important managerial implications. Knowledge is positively related to innovation in organizations. However, it affects organizations in a very different way. Organizations create knowledge, and the creation and use of that knowledge is the most important source of sustainable competitive advantages for the organizations themselves (Nonaka et al., 2000). Knowledge management is as important as marketing or finance management. In fact, in the research carried out by Canales and Alvarez (2017), to analyze the effect of knowledge barriers on innovation in organizations, the results indicate that obstacles to knowledge negatively affect the probability of innovating. According to their study (Canales and Alvarez, 2017), in the absence of these obstacles, the probability of innovating would increase by 26%. Therefore, knowledge is considered one of the most important resources, which must be properly managed to obtain its maximum potential.

3.3.1 The importance of knowledge

In the last twenty years, developed countries have moved quickly from a society governed by the accumulation of information to another that could be called knowledge-based society, in which information by itself lacks value if it is not contextualized and analyzed for the benefit of its users. The increase in the importance of knowledge as an economic engine has had great implications for the innovation process and its management, as several studies carried out in this field have shown (Dima et al., 2018; Caiazza et al., 2015; Hidalgo and Albors, 2008; Rodrigues, 2002).

Knowledge is much more than mere information, as it provides added value to the products and services of any organization, thus becoming a very useful element to address complex problems in increasingly dynamic and globalized contexts, such as the innovation ecosystems. Knowledge is the greatest value of an organization, from which great performance can be obtained when properly managed. "*A firm's competitive advantage depends more than anything on its knowledge: on what*

it knows- how it uses what it knows – and how fast it can know something new.” – HR Magazine (2009, p.1.).

According to the literature review of Alavi and Leidner (2001): *“knowledge may be tacit or explicit; it can refer to an object, a cognitive state, or a capability; it may reside in individuals, groups (i.e., social systems), documents, processes, policies, physical settings, or computer repositories. Thus, no single or optimum approach to organizational knowledge management and knowledge management systems can be developed. A variety of knowledge management approaches and systems needs to be employed in organizations to effectively deal with the diversity of knowledge types and attributes”.*

We live in the knowledge-based era, which means that all the activities of an organization, in one way or another, can be managed through the management of their knowledge, be it tacit or explicit. Explicit knowledge is based on universally accepted and objective criteria. It has the character of public goods and it is a knowledge that can be easily coded and transferred. That is, explicit knowledge refers to that type of knowledge that has been or can be articulated, codified and stored in some kind of medium. On the other hand, tacit knowledge is encoded knowledge and resides in the organization’s system. This knowledge is important but difficult to interpret and transfer from one organization to another. It is the type of knowledge that is used mostly by organisational members in the performance of duties. Tacit knowledge is highly personal (held within the holder), subjective, difficult to formalize, articulate and communicate fully, experience based, contextualized, job specific, transferred through conversation or narrative, not captured by formal education or training and may even be subconscious but capable of becoming explicit knowledge (Hislop, 2013; Nonaka and Takeuchi, 1995). Tacit knowledge can be obtained from partner organizations through their close and frequent interactions. Tacit knowledge transfer makes a significant contribution for organizations to develop great innovation capability. Hence, better use of existing knowledge and more effective acquisition and assimilation of new knowledge becomes the business imperative (Thurow, 1996).

3.3.2 Knowledge management literature review

Knowledge management is a very broad topic. However, in the present research work the focus is on the importance of the use of knowledge management to improve the competitiveness of organizations, from the point of view of decision-making and innovation.

Knowledge management has become a very common tool for organizations in recent decades. We live in a globalized and connected world, where there is a continuous transfer of knowledge. Therefore, in today's organizations, belonging to the so-called knowledge-based economies, knowledge is a competitive advantage, and its management is the basis for its sustainability and survival. Good knowledge management provides support for the creation, transfer and application of knowledge in the organization. However, knowledge management is a complex issue. According to Alavi and Lediner (2001):

“Knowledge management involves distinct but interdependent processes of knowledge creation, knowledge storage and retrieval, knowledge transfer, and knowledge application. At any point in time, an organization and its members can be involved in multiple knowledge management process chains. As such, knowledge management is not a monolithic but a dynamic and continuous organizational phenomenon. Furthermore, the complexity, resource requirements, and underlying tools and approaches of knowledge management processes vary based on the type, scope, and characteristics of knowledge management processes.”

The literature of knowledge management is scattered and varied. While much theory exists on knowledge management, little empirical work has been undertaken. Hence, there are large gaps in the body of knowledge in this area (Manfredi et al., 2018; Wallace et al., 2011; Argote, et al., 2003; Alavi and Lediner, 2001). Since 1995, there has been an explosion in the literature surrounding the developing concept of knowledge management. The management of knowledge has generated considerable interest in business and management circles due to its capability to deliver to organizations, strategic results relating to profitability, competitiveness and capacity enhancement (Omotayo, 2015). In the study of Liao (2003), he concludes that knowledge management technologies tend to develop towards expert orientation, and knowledge management applications development is a problem-oriented domain. These outcomes indicate that knowledge management is became a complex strategy tool for decision-making in organizations.

Alavi and Leidner (2001) draw the following conclusions from their analysis of the different perspectives that many authors in the literature attribute to knowledge:

- Much emphasis is placed on understanding the difference between data, information and knowledge, as well as extracting implications of these differences.

- Since knowledge is personalized, so that the knowledge of an individual or a group is useful for others, it must be expressed in such a way that the recipients can interpret it.
- Stacking information has little value. Only information that is actively processed in the mind of an individual, through a process of reflection, enlightenment or learning, can be useful.

In Table 1 is depicts the varied knowledge perspectives and their implications for knowledge management.

Perspective	Description	Implications for knowledge management (KM)
Knowledge vis-à-vis data and information	Data is facts, raw numbers. Information is processed/interpreted data. Knowledge is personalized information.	KM focuses on exposing individuals to potentially useful information and facilitating assimilation of information.
State of mind	Knowledge is the state of knowing and understanding.	KM involves enhancing individual's learning and understanding through provision of information.
Object	Knowledge is an object to be stored and manipulated.	Key KM issue is building and managing knowledge stocks.
Process	Knowledge is a process of applying expertise.	KM focus is on knowledge flows and the process of creation, sharing, and distributing knowledge.
Access to information	Knowledge is a condition of access to information.	KM focus is organized access to and retrieval of content.
Capability	Knowledge is the potential to influence action.	KM is about building core competencies and understanding strategic know-how.

Table 1. Knowledge perspectives and their implications for knowledge management (Source: own elaboration from Alavi and Leidner, 2001)

The current knowledge economy requires that organizations be able to create new business structures and concepts so that the management of their resources remains competitive. The latest

approaches to strategic management tend to consider strategic alliances as sources of knowledge. A strategic knowledge management is related to the processes and infrastructures that organizations use to obtain, create and share knowledge for the generation of new strategies and make decisions. A strategic attitude is necessary to achieve a sustainable competitive advantage (Ferreira et al., 2018). On a practical level, organizations are realizing the importance of managing knowledge to remain competitive and grow. Because of this, companies around the world are beginning to dynamically manage their knowledge and, consequently, innovation (Ferreira et al., 2016).

From industry perspective, in recent years, many documents highlight that knowledge management is acquiring a fundamental role in the global economy and a crucial importance for the competitiveness of large companies and small and medium enterprises (Centobelli et al., 2017; Massaro et al., 2016). Nowadays, a growing number of research projects and studies show how companies can take advantage of the knowledge management to promote significant innovations and cultural changes that positively influence the sustainability of the organization. In this sense, the case of small and medium enterprises (SMEs) is especially interesting and deserves to be a focus of attention. In fact, one of the things that characterize SMEs, in general, and specially startups, is the scarcity of resources. For this reason, startups must necessarily take advantage of intangible assets, such as knowledge and human capital, in order to scale.

In the last two decades, Europe and Canada have experienced a startup revolution. During the last decade, other countries than the United States have successfully developed ecosystems for new technology companies. While it is true that Europe and Canada are almost comparable in numbers of newly created technology companies, there is still a great concern about their growth performance. With the United States creating the vast majority of success stories, the challenge in Europe and Canada has focused on success in the later stages of the business development process. This is the so-called 'scale-up' challenge (Duruflé, et al., 2017).

In reference precisely to the issue of scalability, in a context of economic and social development in which startups play such an important role, high growth companies have aroused in recent years a deserved interest in their commitment to innovation, intensity in knowledge, the ability to create new markets (or motivate the evolution of existing ones) and the potential to generate employment and increase productivity (Könnölä, et al., 2017). In their study, Daunfeldt et al. (2015) find that knowledge intensive firms are more overrepresented among the high growth companies. In this

sense, the creation and dissemination of knowledge is crucial for high growth companies, because they tend to be more innovative within their sectors, even if they are low technology (e.g. Starbucks, Walmart and IKEA) (Moreno and Coad, 2015). That is one of the main reasons why knowledge management is a tool of enormous transcendence for the development of high growth companies.

In the literature review conducted by Cerchione et al. (2016) and Centobelli et al. (2017) shows that the vast majority of articles analyzed between 1990 and 2016 are focus on knowledge management in SMEs, while only a few documents are responsible for analyzing knowledge management in networks populated by SMEs. Therefore, a research gap is identified in studies with a focus on the analysis of knowledge management of SME networks. However, this issue is outside the scope of the present investigation, so it will not be addressed.

Among the varied documents found on knowledge management in relation to startups, it stands out the factors that positively or negatively influence the adoption of knowledge management in startups (Centobelli et al., 2017). These factors can be classified into the following seven categories:

- 1) Human and cultural factors (education, skills and knowledge base of individuals).
- 2) Geographical factors (geographic proximity between business partners).
- 3) Management and organizational factors (organizational tensions, support of senior managers).
- 4) Relational factors (trust, exchange processes and individual exposure to external knowledge).
- 5) Specific start factors (contacts with the existing business community).
- 6) Strategic factors (predictive frameworks).
- 7) Technical and technological factors (technical and technological knowledge of startup founders).

In summary, the literature highlights that the process of knowledge management can have a positive impact on startups in the following aspects (Centobelli et al., 2017): (1) Economic and financial performance; (2) Environmental performance; (3) Human performance; (4) Market performance; (5) Organizational performance; (6) Relational performance; and (7) Technical and technological performance. In particular, not taking into account all the possible advantages of the adoption of knowledge management for startup performance, in its different aspects, could affect the objectives related to its scalability.

Finally, regarding to startups, from the point of view of knowledge management tools, literature review stress that startups usually do not have specific resources to monitor and follow the innovation processes affecting knowledge management (Centobelli et al., 2017). Therefore, there is room to improve, with respect to knowledge management performance in startups. The empirical evidence analyzed in the literature points out that the impact of the use of knowledge management practices in the performance of startups can be extremely significant and, at the same time, improve a great variety of performances. In particular, knowledge management contributes positively to the global sustainable growth of new companies by improving economic, financial, environmental, human, market, and organizational, relational, technical and technological performance.

On the other hand, there are fewer studies focusing on public sector knowledge management than those focusing on knowledge management in the private sector. However, analyzing the evolution of articles about knowledge management within the public sector, results show an increase. The public sector is an important and specific field of research within the management of knowledge (Massaro, et al., 2015). Knowledge management has the potential to greatly influence the processes of public sector renewal. So much so, that within the public sector knowledge management is an enabling element for an improvement in the efficiency of all its areas. However, developing a culture of knowledge management within the public sector is a greater challenge than the private sector. Amayah (2013, p.456) supports this argument, noting that *"organizational goals in public organizations are typically more difficult to measure and more conflicting than in private organizations, and they are affected differently by political influences"*. The public sector has specific labor divisions that do not help the exchange of knowledge, making the delivery of knowledge in the public sector much more difficult than in the private sector (Gau, 2011). In addition, due to organizations of the public sector work in a unique context, in which their stakeholders and accountability differ significantly from those of the private sector, the public sector organizations should not import knowledge management tools and models from private organizations (UNPAN, 2003).

Although universities and research centers are mainly public bodies in many countries, *"the degree of impact of university activities on industrial innovation and the nature of the linkage used depend on the industry concerned, as well as the provision of appropriate policy for knowledge transfer"* (Gertner et al., 2011, p. 626). For that reason and because universities are cognitive intensity institutions where the primary function is based on knowledge, knowledge management is one of

the main objectives of universities. There is a growing belief that knowledge management in universities helps to build the future of a dynamic learning environment, as well as the development and improvement of activities related to the efficiency of knowledge exchange, and the overall performance of the organization (Naser et al., 2016).

3.3.3 The importance of knowledge in decision-making

The application of knowledge to decision making has a significant impact on the performance of the organizations. When we recognize that knowledge is a resource to gain organizational competitiveness, knowledge management becomes a method to administer and apply knowledge to improve the performance of the organization (Yim et al., 2004).

According to Peter Gray (2001) *“knowledge can generate economic value when it is used to solve problems, explore opportunities and make decisions”*. Although the role of knowledge management for decision support is well recognized, there is a gap between existing knowledge management theory and practice in real-life decision-making (Kondori et al., 2013). Knowledge management can contribute to decision-making not only by sharing past experiences, but also by providing knowledge and decision-making structures, inside and outside the domain of the problem. Many authors have highlighted the importance that knowledge management has in decision-making. The positive impact of the knowledge management infrastructure on the quality of decisions and on speed has been demonstrated empirically (Ciambotti et al., 2017). Therefore, knowledge and time are seen to be two strongly connected resources (Ragab and Arisha, 2013), something critical for the competitiveness and survival of organizations.

3.3.4 The role of knowledge and knowledge management in innovation

Innovation depends largely on the availability of knowledge. So much so, that the complexity of innovation has been increased by the amount of knowledge available today by organizations (Du Plessis, 2007). According to Darroch (2005), *“a firm capable in knowledge acquisition, knowledge dissemination and responsiveness to knowledge is more innovative”*; effective knowledge management makes contributes to innovation and performance. The innovation process depends on knowledge (Gloet and Terziovski, 2004). In fact, *“innovation, that is the application of knowledge to produce new knowledge”* (Drucker, 1993, p. 173).

At the empirical level, there is evidence that effective knowledge management is developed by organizations with a tendency to develop incremental innovations (Darroch, 2005). In more recent studies, Inkinen et al. (2015) provide empirical evidence on how various knowledge management

practices influence the performance of innovation. Their results are based on data from surveys collected in Finland during 2013. In their study, the authors (Inkinen et al., 2015) consider that companies are able to support the performance of innovation through the strategic management of the knowledge and competence, as well as compensation practices based on knowledge and information technologies. Their study demonstrates, therefore, the importance of knowledge management for the performance of innovation. Also, in the analysis conducted by Obeidat and Al-Suradi (2016) in the consulting companies of Jordan, it is shown that there is a positive and significant impact of the processes of knowledge management in innovation.

3.4 Innovation management

Innovation is presented as one of the most important tools in the performance of organizations' competitiveness (Fransman, 2018; Farinha et al., 2016; Fagerberg et al., 2007; Iansiti and Levien, 2004). Innovation management is particularly important, especially at a time when competitiveness crosses borders, due to key issues such as globalization and digitalization (Tidd et al., 2005).

Innovation management has been associated with knowledge management, in such a way that innovation management practices have been defined as those routines used for the development and application of knowledge (Darroch, 2005; Coombs and Hull, 1998). In this sense, two schools of thought related knowledge and management of innovation (Dankbaar, 2003). On the one hand, Drucker (1969) suggests that the management of innovation requires the application of knowledge to the work done by workers in their work. On the other hand, Burns and Stalker (1961) describe the need for a context where structures are more flexible and less bureaucratic, for the promotion of creativity within organizations.

In addition, Lundvall (1992) identifies two types of management that encompass the different definitions and approaches found for this field in the literature. On the one hand, the discipline that aims to study strategies and conditions that stimulate creativity and introduce it into the dynamics of the organization, something that coincides with the vision of Burns and Stalker. On the other hand, with a vision closer to the vision of Drucker's school of thought, the set of activities carried out by the managers to accelerate the transformation of ideas into innovations, with the inclusion of the necessary collaborators during the process and looking for these innovations offer benefits to each of the agents involved.

Therefore, the management of innovation for some authors focuses on ensuring the existence of a business strategy or culture capable of promoting innovation, maximizing the generation of ideas

and the innovative potential of the organization (Spieth et al., 2016; Alliance, 2007). On the other hand, when the focus of management is not on the promotion and insertion of the innovation process of the organization, but rather on the management of the activities that support it. In the latter case we are faced with a wide variety of actions to be conducted by any organization such as the management of creativity and generation of ideas, R&D, technologies, technological collaboration, projects, corporate surveillance, etc. (Hidalgo et al., 2002). It is precisely these activities that shape the necessary actions to guarantee the generation of a context that fosters the development of innovation and the attainment of the necessary skills for its management (Goffin and Mitchell, 2016; Adams et al., 2006; Tidd et al., 2001). Therefore, the two identified aspects of innovation management are directly related and complementary to many authors (Dankbaar, 2003), and its application allows to insert, in a rational and effective way, the innovative process within the organization (Lundvall, 1992).

Innovation requires continuous monitoring of the factors that may affect its development, both external and internal. Ultimately, this could depend on the sustainability and survival of the organization. Innovation management has seen a plethora of supportive tools and techniques emerge, mostly originating from academic research into a few organizations and generalized into consulting offerings (Dodgson et al., 2013). The following points will analyze in detail the evolution of innovation management through definitions, models and techniques used over time.

3.4.1 Definition of the innovation management

In the literature, it can be found multitude of definitions on the management of innovation, and depending on where you wanted to put more or less focus on the study, it can be seen the following areas of interest in order of preference: processes, strategy, organization, leadership and culture, people, projects, portfolios and external relations (Igartua, 2009).

It should be noted that, long before the current dimension of strategic resource has been conferred on innovation management, the evolution of innovation management in organizations has undergone important changes, as organizations have understood the role that represented innovation in its competitiveness and development (Morcillo, 2007):

- Management of R&D in the 60s. It focused on granting a management to the technological resources of the organization.
- Innovation management in the 70s. Thinking about managing it as a tool to be able to innovate.

- Strategic management in the 80-90. Giving it a certain strategic character and trying to integrate it at a functional level within the organization.
- Strategic direction of innovation since 2000. Generating a strategic dimension of innovation in organizations.

Table 2 shows examples of definitions that represent the evolution and orientation carried out by the concept of innovation management to the present day.

Reference	Definition
(Chiesa et al., 1996)	Innovation management requires the management of four key processes: concept generation, product development, process innovation, and technology acquisition, supported by the facilitating processes: deployment of human and financial resources, the appropriate use of systems and tools, and the leadership and management of managers.
(Goffin and Pfeiffer, 1999)	The management of technological innovation requires the strategy of innovation, the management of creativity and ideas, portfolio management, project management and people management.
(Hidalgo et al., 2002)	The management of technological innovation is the process aimed at organizing and directing the available resources, both human and technical and economic, with the aim of increasing the creation of new knowledge, generate ideas to obtain new products, processes and services or improve existing, and transfer those same ideas to the manufacturing and marketing phases.
(Goffin and Michell, 2005)	The management of innovation requires the management of five areas: ideas, their prioritization, the implementation of these, all with the support of an innovation strategy, and an adequate management of the organization and people.
(Hansen and Birkinshaw, 2007)	Innovation management can be defined as the active and conscious organization, control and execution of activities that lead to innovation.
(Hidalgo and Albors, 2008)	In comparison with traditional mechanistic and control management, innovation management implies a fundamental change in the strategic perception of the organization, tending consequently to consider the following management challenges: Managing human capacities in a

	strategic way; Establish relationships with external and internal partners; Create adaptive and interactive organizational structures; Balance between balance and chaos - process efficiency versus destructive innovation.
(Volberda, et al., 2013)	Management innovation consists of changing a firm's organizational form, practices and processes in a way that is new to the firm and/or industry, and results in leveraging the firm's technological knowledge base and its performance in terms of innovation, productivity and competitiveness.
(Tidd and Bessant, 2018)	Innovation management is inherently inter-disciplinary, but it is much more than simply applying business and management disciplines to innovation, and over time the field has developed a distinct body of knowledge

Table 2. Definitions of innovation management (Source: elaboración propia)

Therefore, innovation has been gaining over the years a greater transcendence for organizations and their management a strategic nature of vital importance to be able to compete.

3.4.2 Innovation management models evolution

Innovation is a complex process, consisting of a set of technical, organizational, productive and commercial stages that lead to the successful launch of new manufactured products or new services to the market (Hidalgo et al., 2002). The nature of the characteristics and activities of this process can generate a lot of uncertainty within the innovation (Jalonen and Lehtonen, 2011; Escorsa and Pasola, 2003). To emphasize the uncertain character of this innovation process, other authors use the innovation journey (Eveleens, 2010). Therefore, the first step in managing innovation is to understand how the innovation process can be successfully influenced.

Measuring the innovation process is critical for both professionals and academics. In the literature related to the measurement of the innovation process there is a great diversity of approaches, prescriptions and practices that can be confusing and contradictory (Adams, et al., 2006). The optimization of the management of innovation processes is configured as an important challenge to improve the innovation capacity of organizations (Cordero, 1990). Lundvall (2013, p. 33) emphasized that *“a core in innovation studies is the conceptualisation of innovation as an interactive process involving many actors and extending over time”*. Following such understanding, an

innovation process can be regarded *“as one that starts with combining elements of existing knowledge and ends with new knowledge as an important output”*.

Innovation is a complex, diversified activity, with many interacting components that act as sources for new ideas, so it is very difficult to discover the consequences that a new event of this nature can cause and hence its uncertainty (Escorsa y Valls, 2003). That is why many authors try to develop new models capable of analyzing the innovation process and explain its functioning, although it is difficult to find a universal model capable of explaining and much less guiding a phenomenon as dynamic and unpredictable as is the process of innovation in organizations. So much so, that some authors have presented works where they conclude that to date has not created an innovation process model capable of being generalizable (Hobday, 2005; Forrest, 1991), adding doubts and questions about the proper functioning of each one of the most relevant models.

Here it is important to note that not all models have been created to replace previous ones. In fact, many models coexist in the years without major problems, they even use elements from other models, since they are generated and adapted to the different needs of the organizations and specific circumstances of their context and time. However, it is true that at a general level there is a gradual attempt to refine and improve the models from one generation to the next, as Rothwell (1992) identifies in his works when classifying the different models found in the literature in several decades and that are well accepted by many other authors.

In the literature there seems to be some consensus regarding the models that have predominated between the 1950s and mid-90s, when trying to define their different phases, stages or tasks necessary to carry out the innovation process in an organization. Noteworthy Rothwell (1992), which classifies the different models as shown below:

- Linear or First and Second Generation Models (Years 50-70)
 - o Technology-Push Model or First Generation (from 1950 to the mid-1960s)
 - o Market-Pull or Second Generation Model (from the mid-60s to the early 70s)
- Mixed or Interactive or Third Generation Models (from the early 70's to the mid 80's)
- Integrated or Fourth Generation Models (from the early 80's to the early 90's)
- Models in Network or Fifth Generation (decade of the 90)

Subsequently, since the 1990s and up to the present, new models, approaches and systems have continued to emerge, because of the new needs of organizations and the context, among which the “Open Innovation Model” (Chesbrough, 2003) stands out due to its special relevance, which is a

before and after for its novel approach, creating a new paradigm that differentiates between the models that are constituted within the "Closed Models" approach and those that do it as "Open Models".

3.4.2.1 Linear models

"Linear models" are defined by Rothwell (1992) as "First and Second Generation models". These models are characterized by conceiving the process of innovation as a linear process where everything happens sequentially, starting from the source of innovation (scientific knowledge, technological or market demand) and going through different phases until finally reaching commercialization of the product. Its greatest virtue is precisely its simplicity, which allows to explain in a simple way how the innovation process takes place. That is why this type of models has served as the basis for the development of many other models.

The first of the "Linear models" was the so-called "Technology-Push" (also known in some cases as Science-Push), which according to some authors was based on the thesis of Schumpeter (1934). This model was predominant from 1950 to the mid-60s. According to the model, innovation emerges with basic research and, through a sequential process of design, production and marketing, the product is finally put on the market to be sold. As Rothwell (1992) himself argues, this model was frequently used to justify the large R&D expenditures carried out by companies and governments during those years in favor of improving the economic growth of their respective regions.

Figure 4. Technology-Push model (Source: Elaboration from Rothwell, 1992)

The second of the "Linear models" is the so-called "Market-Pull" (from the mid-60s to the early 70s). According to some authors, it rescues the ideas of Schmookler (1962) and Freeman (1974). It is with this model that begins to pay more attention to the needs of consumers in the innovation process. As its name suggests, in this model they rewarded the needs of the market, which served as the driving mechanism of technological innovation. This mechanism was also based on a sequential process that started from the needs of the market; based on these needs, a development and production was carried out that finally ended with the sale of the product.

Figure 5. Market-Pull model (Source: Elaboration from Rothwell, 1992)

“Linear Models” have been criticized for their sequential nature and the simplification they make of the innovation process, which is little resemblance to a reality where the same sequence is not always followed, some or many of the phases are not necessary, new stages appear due to unforeseen or contextual effects and even loops, feedbacks or overlaps are created between one and other phases of the innovation process (Velasco and Zamanillo, 2008). Nor does it allow for the insertion of elements of either model (Market-Pull and Technology-Push), something that could actually happen in reality.

In addition, this type of models does not consider other agents in the environment in the innovation process, as important as customers, suppliers, competitors, government agencies, etc. (Hobday, 2005). If it is true that innovation occurs in the organization, it is also true that the knowledge on which it is based can come from different sources (Padmore et al., 1998), so it seems relevant to consider them. Therefore, we can talk about five sources of information for innovation: 1) Internal to the organization, 2) Providers, 3) Equal organizations (competitors or not), 4) Clients and 5) The public sector (Velasco et al., 2006). That is why this type of models falls within the group of so-called “Closed Process Models” or simply “Closed Models”, where the process of innovation is developed internally by the organization.

Regarding the type of innovation to which these models can be applied, observing the phases included in the process, these seem to be destined to generate product innovations and, in particular, radical ones. Therefore, innovations such as process, organizational, or incremental (widely used in the case of SMEs), do not seem to fit into these models so that many of the options presented by innovation are lost.

Finally, it should be noted that the disaggregation of the different activities of the innovation process suggests that each of these phases can be carried out in an entirely independent way: which could allow an organization to carry out some phases, while another will carry out some of the phases remaining. That is to say, one could come to understand the possibility of carrying out collaborations during the innovation process (something rational and that is certainly carried out many times by organizations). However, collaborations usually entail the existence of a feedback, very necessary

among the different activities, that with this type of linear models, as indicated above, it would not be possible to represent.

3.4.2.2 Mixed or Interactive models

As many studies have shown (Myers and Marquis, 1969), linear models were too simple to explain many of the aspects involved in the innovation process. Therefore, the need for new more complex models arises, capable of representing how innovation occurs in a more detailed way, as well as to understand the logic of this process, with the aim of trying to reduce as much as possible errors and misuse of resources, previously committed by linear models (Rothwell, 1992).

An interesting approach is offered by Morcillo (2010), who calls these new models, “Integrated Innovation Process Models”. These models integrate the innovation sources of the previous “Linear Models”, maintaining the “Closed Model” approach and trying to take advantage of the best of each of the models that precede them.

The first of the models belonging to this new approach are the “Mixed or Interactive Models” (early 70's to mid-80's), named by Rothwell (1992) as “Third Generation”, which highlight the importance of the retroactivity generated between the different phases of the innovation process. These models emphasize the interaction of technological capabilities and market needs. Specifically, the characterization of this type of models is reached through two models: the “Marquis model” and the “Kline model” (Hidalgo et al., 2002).

Marquis says that ideas are not always generated from basic research but may come from other departments or areas of the organization. In particular, his studies conclude that many of the ideas come from the commercial department, which is in direct contact with customers and from those who receive their needs and suggestions, and hence new ideas to develop.

The “Marquis Model” involves a series of stages that start from the idea and its technical feasibility and demand: Can it be carried out at a technical level? Is there a market niche for this product? Subsequently, if it is answered satisfactorily, a prototype is developed with which to know in detail the production costs and associated margins: Is the commercialization of this product profitable? Thus, if the answers to these questions are affirmative, we can move on to the aspects of design, production and marketing, to put the product as soon as possible in the market. The main methodological contribution of this model is based on the representation of a direct and permanent contact between the different areas involved in the process, as well as the possibility of going back

to research, whether basic or applied, in case the organization does not have the necessary technology to make possible the commercialization of the idea.

The Kline Model (Kline and Rosenberg, 1986), called "Chain-Link model", tries to incorporate the complexity of the innovation process, proposing five paths or paths that connect the three most relevant areas of the process: research, knowledge and central chain of the innovation process. The five routes or paths are:

- The central path begins with an idea that materializes in an invention, which in turn responds to a market need. Subsequently, the invention goes through a design stage, creating a prototype that is tested in the development phase. If everything goes well, it goes to the manufacturing phase, to end with its commercialization.
- The second path consists of a series of feedbacks.
- The third way is the link between knowledge and research with the central chain.
- The fourth path is the connection between research and invention.
- The fifth path is based on direct connections between the market and research.

The model allows different feedbacks between the different phases and paths followed by the innovation process. Likewise, the model makes it possible for there to be innovations whose source is not always research. One of the most important differences of this model with the "Linear model" is that it allows the interaction of science and technology in all the stages of the model and not only in its beginnings. In addition, innovation is conceived as a way of solving problems, allowing incremental and novel solutions, which implies a very different approach to the "Linear model" that was more focused on the creation of new products, that is, on innovations of radical type¹⁴.

Based on the Marquis and Kline models, the authors Rothwell and Zegveld (1981) create the "Mixed model", which represents a sequence of interactive stages with each other, and the relationship of the different phases with technology, organization and its context.

¹⁴ A radical or disruptive innovation is one that has a significant impact on a market and on the economic activity of firms in that market, while incremental innovation concerns an existing product, service, process, organization or method whose performance has been significantly enhanced or upgraded.

Figure 6. Mix model (Source: Elaboration from Hidalgo et al., 2002)

It is noteworthy that the introduction of feedback and loops improve to a certain extent the sequentiality of the "Linear Models", since it makes it possible to choose different trajectories or paths to follow during the innovation process. In addition, that these models allow the development of innovations of more types than the previous models, thanks precisely to the loops and feedbacks introduced that allow to relate all the activities of the process, so it manages to correct one of the key deficiencies of the "Linear Models".

Even assuming improvements with respect to the previous "Linear models", this type of models are also subject to criticism and present certain important deficiencies to be mentioned. In the first place, Morcillo (1997) states about these models that even with the feedbacks included, they maintain the linearity of the innovation process (the beginning of a stage is conditioned by the completion of the previous stage), which affects the effectiveness of feedback systems, in reference to the dissemination of information.

On the other hand, adding numerous feedback processes between the different activities involved in the process can add delays in decision-making. In fact, the duration of the process is still excessive, which can lead to the failure of certain product launches, arriving late to the markets. In addition, the model does not refer to work in interdisciplinary teams, which does not guarantee the much-needed functional integration (Velasco et al., 2006).

Another important criticism is the lack of relevance that these models offer to the relation of the process with its organizational environment (Hobday, 2005), something that already happened with the "Linear models" and that this new type of models continues without solving. These models also do not show relationships, nor how they affect the innovation process important elements at the internal level of the organization, such as managers, stakeholders, etc., or factors of their environment such as laws, policies or culture.

Therefore, the "Mixed Models" solve some of the vulnerabilities presented by the "Linear models", although they still maintain some of their deficiencies and even introduce new ones. Thus, the next generation of models, the "Integrated models", are created precisely with the idea of trying to solve some of the problems of these "Mixed models", and more specifically their sequentiality.

3.4.2.3 Integrated models

During the 80s, companies began to focus on the core of their business and on essential technologies. Along with these new trends, the global strategy requires establishing new strategic alliances, often promulgated and supported by the governments themselves. Furthermore, the increasingly short product life cycle makes the speed of its development a key factor in competing, forcing companies to adopt strategies based on time (Rothwell, 1992).

At the beginning of the 90s, and as a result of the consideration that development time is a key variable that must be optimized to compete in the markets, it begins to be considered from an operational perspective that the stages of the innovation process they must be considered as non-sequential, that is, overlapping and even simultaneous or concurrent (Hidalgo et al., 2002). Rothwell (1992) calls the models within this new approach "Fourth Generation models" (from the 80s to the early 90s).

Thanks to this new approach of concurrence of the stages, it is possible to introduce a new product in the market much faster than competitors do, although that does increase the risk associated with the innovative process. Therefore, this new concurrent development generates certain risks, such as the possibility of creating useless products or the design of components or elements whose operation is incompatible with the rest. For this reason, for the efficient management of this model it is recommended to put into practice the following success factors:

- A disciplined process supported by the systematic application of planning and control techniques.

- A multifunctional project team that works in a coordinated manner in all aspects of the product as the development progresses.
- Eliminate barriers between the different functional areas of the organization.
- Responsibility shared by the group.
- Good ability to resolve conflicts.

With this new model, the development of the innovation process is conducted by a multidisciplinary group, whose members work interactively throughout the process and without following a series of sequential steps (Takeuchi and Nonaka, 1986). It is also important to note the relevance given in this model to the interaction with suppliers, who are included in the process. Thus, the innovative company creates strong links with suppliers and customers, trying to shorten the time of development and product launch, while responding more quickly to the opportunities detected in the market (Morcillo, 2010).

Figure 7. Integrated model (Source: Elaboration from Hidalgo et al., 2002)

Although this model solves some of the deficiencies presented by the previous models, such as the sequentiality of the innovation process, some factors are still ignored, so this model is not exempt from criticism. The most obvious problem is that the model continues to focus mainly on the development of product-type innovations, leaving aside process innovations. It is also noteworthy that even with the inclusion of suppliers in the process, other external factors, such as government agencies, competitors, etc., are still left out of these models.

3.4.2.4 Network models

According to the Rothwell classification (Rothwell, 1992), the "Network models" or "Fifth Generation" (from the 90's) are based on the "Systems Integrations and Networking Model". The interactive nature of the innovation process implies the need for companies to cooperate with other organizations in order to carry out research and technological development activities (Mowery and Rosenberg, 1989). In addition, this model indicates that learning and accumulation of knowledge occurs both within the company and between the agents involved, thus defining innovation as a process whose development is carried out in a network (Hobday, 2005).

Figure 8. Network model (Source: Elaboration from Hobday, 2005)

This generation of models proposes to imbricate systems and networks in order to guarantee flexibility and increase the speed of development to better adapt to market opportunities. Internally, the organization pays more attention to the management and planning of technological resources, as well as to information systems. That is why these models are characterized by the use of sophisticated electronic tools that allow companies to increase speed and efficiency in the development of new products.

Externally, the establishment of agreements and alliances with research organizations is favored, giving entry to the open conception of innovation processes (Morcillo, 2010). Similarly, in Velasco et al. (2006) point out that this type of model proposed by Rothwell (1992) points to an idea about innovation that, with a more strategic and broad character, is subsequently collected by the European Commission (1997), where it indicates that innovative companies are associated with a

very diverse set of agents through collaborative networks and information exchange, forming the so-called "Innovation System". Therefore, it can be talked about national, regional or sectoral Innovation Systems. In short, and regardless of its scope (national, regional or sectoral), this new approach points out the importance of external sources of information to the organization, such as customers, suppliers, government, educational centers, technology centers, etc. According to Freeman (1985), an innovation system is defined as the networks of institutions in the private and public sectors, whose activities and interactions initiate, transmit, modify and disseminate new technologies.

Figure 9. Innovation System (Source: Elaboration from Hidalgo et al., 2002)

Lundvall (2007) argues that the concept of "Innovation System" was developed in parallel in different places in Europe and the United States, in the decade of the eighties. There is no doubt that, in the early eighties, the collaboration between Christopher Freeman and the IKE group in Alborg was important in coining and shaping early versions of the concept. Although the basic ingredients and inspiration could be found in the work of many other scholars of innovation before them. The diffusion of this concept throughout different countries (first in Japan by Freeman) and until now, has been carried out by different authors, starting with Freeman and later with Dosi (1990), Lundvall (1992), Nelson (1993), etc.

Models used for the analysis of open innovation processes at a strategic level are "Triple Helix models" (Etzkowitz and Zhou, 2017; Leydesdorff and Etzkowitz, 1996), where the three main actors that work together are universities (as producers of knowledge), companies (as creators of business)

and Public Administrations (as regulators and generators of environments for innovation). Thus, the three groups become strategic partners taking as a reference the spiral of innovation, as is depicted in Figure 9, which establishes relationships of interdependence among them (Morcillo, 2010).

Returning to the "Network models", in terms of criticism, the main one is that it has not been demonstrated that the adoption of information technologies, so important in these models, generate the suggested benefits (Hobday, 2005). Therefore, the weight and relevance of information technologies (ICT) in the model is strongly criticized, as well as the fact that ICTs cannot replace social interaction and trust (social capital).

3.4.2.5 Open Innovation Model

Open Innovation supposes a new paradigm in terms of how the innovation process itself develops, going from a process that was originally "closed", or carried out internally by companies, to one developed in conjunction with its environment, where the aspects of integration and flexibility are affected. In this way, by opening up to the outside and matching all the cognitive and technological options offered by the environment, companies make their organizational borders become increasingly porous (Morcillo, 2010).

Figure 10. Open Innovation model (Source: Chesbrough, 2003)

This new paradigm is at the forefront of Henry Chesbrough, Professor and Executive Director of the Open Innovation Center at the "Hass School of Business", University of California, Berkeley. Therefore, more than a model that can serve as a guide for an organization to develop its innovation, it is about the representation of a new paradigm that allows a better understanding of how innovation is carried out, in its inherent complexity.

To arrive at this new approach, open innovation processes are based on a series of principles:

- Innovation is not a question of just one, of a single functional department or of an isolated center, but is the product of a joint effort.
- Demystify the idea that knowledge is concentrated in certain places or specific fields of activity.
- It is necessary to create communication mechanisms that facilitate the connection of different sources and their socialization.
- We must favor the integration of all agents, centers and organizations of the knowledge system, through the constitution of networks.
- Also, define intellectual property policies to avoid the emergence of ownership and control relationships that end up jeopardizing the viability of the innovation processes initially created.
- Admit that innovation is a good that is bought, transferred and reinvested.

According to Chesbrough (2007), innovation is increasingly becoming an open process thanks to the growth of the division of labor (concept promulgated in the first place by the Scottish economist and philosopher Adam Smith in his book "*The Wealth of Nations*" of 1776). Nowadays, when a company develops a novel idea, it does not take it directly to the market, but decides to associate or sell it to another organization, which finally is the one who commercializes it. To achieve the maximum results of this new innovation system, companies must open their business models to actively seek and explore ideas of external origin, also allowing internal technologies not used by the organization to flow abroad, where other companies can be able to unlock and activate their latent economic potential (the real case of the Xerox company exposed in Chesbrough's work "*Open Innovation*" of 2003 clearly shows the power of these words).

Generalizing, business models develop or must develop two important functions: create value and capture a portion of that value. Precisely, open models enable the organization to be more effective in creating and capturing that value. These models help create value by taking advantage of many ideas, including a variety of concepts from outside the organization. They also allow the capture of value using key assets, resources or the position of a company, not only in its own operations but also in the businesses of and in other companies (Chesbrough, 2007).

In other words, the main idea that underlies Chesbrough's open innovation model is based on enriching the innovation process that results from introducing new alternatives and options, either

working in collaboration with other organizations, taking advantage of their new approaches, ideas and resources, as well as the possible transfer of the idea so that it evolves in virtue of a new environment and resources to which it may be exposed. In fact, the result of success is not assured as it depends on the path followed, concept of "Path dependence" or dependence on the path promoted by the economist Paul David (David, 1988). It defines the dependence of the road when the result of a process depends on the entire sequence of decisions made by the actors and not only on the conditions of a particular moment. According to this theory, both the initial point and the accidental events that occur along the way have significant effects on the result. Thus, increasing the exposure of an idea to more elements can lead to the emergence of new paths that become successful, increasing its probability, such as the case of the Xerox Company with the Adobe or 3Com sub-companies, created precisely through the exposure to this new approach (Chesbrough, 2003).

In this way, Chesbrough advises that to counteract the trend of increasing development costs and the increasingly short life cycles of products, organizations experiment with new creative ways to open their business models using ideas and technologies from abroad in the internal development of their products, allowing internal intellectual property to be commercialized also externally.

In short, this new model or new paradigm ends with some of the deficiencies found in previous models, especially those related to the interaction with external factors of the organization. Thus, it is presented as a very dynamic model, thus saving previous problems derived from the sequentiality of the innovation process. In addition, by avoiding talking about specific departments included in the process, the application of this model is open to innovations of very different types, such as process, product, organizational innovations, etc.

Regarding criticism of the model, perhaps the clearest is that, for an organization that intends to innovate, this model will not serve as a guide with which to know concretely the path to take to arrive successfully at an innovation. On the other hand, innovation is a concept associated with risk and uncertainty, so the model fits well with the essence of the concept and truly reflects the complexity and dynamism involved in the development of an innovation process. Therefore, it is implied that the process followed by an organization to innovate will be different from any other, even within the same organization there will be very different processes and paths depending on the conditions, due to a multitude of internal and external factors of the organization.

Finally, it is important to add that, although innovation is by nature a random process, it should be the result of a deliberate process guided by human intuition, intelligence and foresight. That is why

it is essential to understand and manage the innovation process, so that there is as little margin as possible for chance (Velasco and Zamarillo, 2008). Therefore, we must make an effort to improve the knowledge we have about the innovation process and help explain certain behaviors that can later help professionals responsible for innovation management when making decisions. Many models, methodologies and tools based on the open innovation approach continue appearing continuously trying to explain the innovation process.

3.4.3 Innovation management techniques (IMT)

The model selected by an organization to manage innovation, such as those seen in the previous section, establishes at a strategic level the different activities that should be conducted by the organization for a correct management of innovation. However, at the operational level, the techniques and tools that are used to carry out these actions are different. This set of techniques and tools are known as innovation management techniques (IMT).

A management technique is a document, framework, procedure, system or method that helps an organization define or achieve a specific objective (Brady et al., 1997). Innovation management techniques (IMT) can be defined as the range of tools, techniques and methodologies that help organizations, in a systematic way, to adapt and meet the challenges presented by the market (Phaal et al. al., 2006). These definitions are well accepted and summarize in a clear and simple way the initial objectives of the use of this type of tools by organizations. However, the latest approaches and thoughts presented by recent studies in reference to the subject, deepen more in terms of its relationship with the concept of innovation itself. For its part, the Center for Technology Management (2008) presents and distinguishes two categories of tools, which are framed with the two aspects of innovation management identified at the beginning of the point of innovation management:

1. Tools oriented to the types, classification and structure of innovation (to the innovation activities themselves).
2. Tools focused on the promotion of innovation in the structures and culture of organizations.

According to Hidalgo and Albors (2008), IMT is a set of tools, techniques and methodologies that support the process of innovation in organizations and systematically help them to respond to new challenges in the markets. IMT are critical to increase competitiveness and its application generates in organizations the ability to introduce new technologies in products and processes, as well as the changes needed in the organization itself.

D'Alvino and Hidalgo (2012) analyze the relationship between the use of IMT and the degree of development of the innovation process in the service sector, as well as the most used tools in this sector and highlighting that innovation leaders are precisely those organizations that make greater use of IMT. That is to say, at present, the IMT are constituted as a set of tools of great relevance for the development of the process and the management of the innovation in the organizations, and its application has been demonstrated that it helps to improve the assimilation of this process and the integration of the different participating actors.

The application of IMT involves efforts on the part of the organization that require more time, motivation and money, something that often hinders its application. This is combined with the fact that in most organizations there is no culture of innovation (Büschgens et al., 2013; Naranjo Valencia et.al, 2010), understood as the values, convictions and behaviors acquired in favor of the development of innovation in the company: a very internal barrier is established important for the use of this type of techniques.

Another difficulty for the application of IMT is the little or no capacity that many organizations have to identify innovations and manage them (Mehrabani and Shajari, 2012), either because they do not have the necessary capacities a priori or because the daily task makes it very difficult to dedicate time to topics that in principle they are more focused on the medium-long term. The use of IMT often involves support for new training schemes, something that requires great effort on the part of the organization as well. Only organizations whose goals are focused on the need for change, try to acquire those necessary skills (if they have them a priori), to help them understand and identify innovations that can be of benefit to their businesses.

One of the keys to the use of IMT is that it is necessary to understand and accept the failure as an integral part of the innovation process (García-Quevedo et al., 2017). The risk and uncertainty that innovation entails is often an insurmountable obstacle for many organizations (Teece and Leih, 2016, Bullen et al., 2006), for the culture that normally exists against change and the little recognition given to entrepreneurs in this area. Finally, it should be noted that bureaucracy is a clear inhibitor of the innovation process (Suzuki and Demircioglu, 2017; Demircioglu and Audretsch, 2017), so reducing it is a direct benefit for the use of this type of techniques and tools by of the organizations.

The European Commission (2005), after an exhaustive study of the literature and the analysis of the results of a survey of 15 member states of the European Union, Japan and the United States, obtains

the IMT classification of Table 3, grouped together, as shown, in ten different categories: 1) Knowledge management, 2) Development of creativity, 3) Market intelligence, 4) Process improvement, 5) Cooperation and networks, 6) Innovation project management, 7) Human resources management, 8) Design management, 9) Interface management and 10) Business creation.

IMT types	Methodologies and tools
Knowledge management	Knowledge audits
	Knowledge maps
	Document management
	Industrial Property Management
Creativity development	Brainstorming
	Lateral thinking
	TRIZ
	Scamper method
Market intelligence	Technology watch
	Patent analysis
	Business intelligence
	CRM
	Geo-marketing
Process improvement	Benchmarking
	Workflow
	Process reengineering
	Just in Time
Cooperation and networks	Team work
	Equipment configuration
	Supply chain management
	Clusters
Innovation project management	Project management
	Project appraisal
	Project portfolio management
Human resources management	Tele-work
	Corporate intranets
	On-line recruitment
	e-Learning
	Competency management
Design management	CAD-CAM
	Rapid prototyping
	Usability techniques
	Value analysis
Interface management	R&D interface management – Marketing
	Concurrent engineering
Business creation	Business simulation

	Business Plan
	Spin-off

Table 3. Innovation Management Tools (IMT) classification (Source: European Comission, 2005)

In more recent studies, IMTs are presented as very relevant tools in open innovation strategies (León et al., 2019; Igartua et al., 2010), which help to align the objectives shared by the different participating agents, improve supplier networks, the quality of projects and the ability of organizations to introduce and manage new technologies.

3.5 Network theory and analysis

3.5.1 Network theory

Networks are reshaping the global business architecture. A distinctive feature of the early twenty-first century is the incremental presence of types of social, digital, electronic and organizational networks. These ubiquitous networks, not limited to geographical areas or areas, are mainly fostered by the great advances in communications, information technology and transport, and encouraged by traditional organizational structures through a continuous growth of the use of "management technology", necessary by the increasing pressures of global competition (Parkhe et al., 2006).

A central characteristic of society, as a network, is that both the dynamics of domination and the resistance to domination are based on the formation of networks and on the offensive and defense strategies of the network, either forming separate networks or reforming existing networks. In fact, this can be seen in the historical one, in past societies like that of the industrial society (Castells, 2011).

Network theory is the study of graphs as a representation of either symmetric relations or asymmetric relations between discrete objects. Network theory has applications in many disciplines, such as ecology, economics, operations research, sociology, etc¹⁵. Network theory has the potential to offer information on such varied issues as the Internet, "sleepers cells" in terrorist groups, epidemiological studies of the spread of AIDS and the impact of technology on the organizational structure and performance, among others (Parkhe et al., 2006).

In general, there are two types of results that network research has tried to explain. The first includes behaviors, attitudes, beliefs and (in the case of collective actors such as organizations)

¹⁵ https://en.wikipedia.org/wiki/Network_theory

internal structural characteristics to make a certain choice. Network research has often been framed in terms of similarity of choice, such as in explaining which pairs of nodes make similar choices. The second result of network research is success, which includes performance and rewards, either at the node level or the entire network. Work in this area is known as the literature of social capital (Borgatti and Halgin, 2011).

3.5.2 Network analysis

A network consists of a set of actors or nodes, as well as a set of links of a specific type that links them. The pattern of links in a network produces a specific structure, where the nodes occupy positions within that structure. Much of the theoretical richness of network analysis consists of characterizing network structures and node positions, as well as relating them to group and node results (Borgatti and Halgin, 2011). Network Analysis help in solving some common problems in many disciplines and visualizing them at a much grander scale and abstraction.

Knowledge in the social and behavioral sciences can be improved by focusing on the tributes of individual actors (individuals, groups and organizations), but also in the causal forces derived from the cognitive maps, values, ideas and ideals of the actors. In addition, can be improved by focusing in the many relationships that may exist between the actors. The fundamental concepts in the analysis of networks are the following: actor, relational link, dyad, triad, subgroup, group, relationship and network (Wasserman and Faust, 1994).

3.5.2.1 Value networks

Understanding the transactional dynamics is vital for purposeful networks of all kinds, including networks focused on creating knowledge value. Dynamics, which is visible through the value network perspective, is relevant when describing business models at a company level (Westerlund et al., 2014). According to (Casadesus-Masanell and Ricart, 2010), a business model consists of a set of managerial choices and their consequences. Each choice may result in different outcome; thus, they drive dynamism. A value network is a business analysis perspective that describes social and technical resources within and between businesses¹⁶. Value network generates economic value through dynamic and complex exchanges between companies, suppliers, strategic partners, etc. Value networks exhibit interdependence. These value exchanges can be mapped as flow diagrams

¹⁶ https://en.wikipedia.org/wiki/Value_network

showing goods, services, revenue streams, as well as knowledge flows, and creation of value (Allee, 2000).

The nodes in a value network represent roles. The nodes are connected by interactions that represent tangible and intangible deliverables. These deliverables take the form of knowledge or other intangibles or financial value. Two elements are included in intangible value: knowledge and benefits. Intangible knowledge exchanges include strategic information, planning knowledge, process knowledge, technical know-how, collaborative design and policy development; which support the product and service tangible value network (Stabell and Fjeldstad ,1998).

The purpose of value networks is to create the most benefit for the actors involved in the network (Kong, 2003). In order to succeed, knowledge must be shared to create the best situations or opportunities. Since value networks are instrumental in advancing business and institutional practices, a value network analysis can be useful in a wide variety of business situations. Resource deployment, delivery, market innovation, knowledge sharing, and time-to-market advantage are dependent on the quality, coherence, and vitality of the relevant value networks, business webs, and business ecosystems (Tapscott, 2000). Mergers, acquisitions, expansion to new markets, new product groups, new partners, new roles and functions; anytime relationships change, value interactions and flows change too (Stabell and Fjeldstad ,1998).

Value network analysis offers a way to model, analyse, evaluate, and improve the capability of a business to convert both tangible and intangible assets into other forms of negotiable value, and to realise greater value for itself (Allee, 2008). Purposeful networks, such as organisations, consist of specific roles and value interactions oriented toward the achievement of a particular task or outcome. Other kinds of networks cross organizational and industry boundaries, such as innovation networks, with the shared purpose of creating a particular social good or outcomes, such as improving education. Value network analysis was first developed in 1993 and was adapted in 1997 for intangible asset management. Value network analysis has been tested in applications from shop floor work groups to business webs and economic regions. It draws from a theory based in living systems, complexity theory, system dynamics, knowledge management, and intangible asset management (Allee, 2008).

3.5.2.2 Social Network Analysis (SNA)

Many analysts and researchers are using social network analysis to try to understand networks as economic entities with some limited focus on intangible outcomes and exchanges. Social network

analysis (SNA), sometimes referred as organizational network analysis when applied to organizations, is being used in some organizations to understand knowledge flows (one kind of intangible) and the network patterns of expert communities (Allee, 2008). Both value network analysis and SNA draw from exchange theory and address the question of how social relationships convert into other forms of value (Allee, 2009). A SNA modelling language moves network analysis to being a tool for decision-making.

Therefore, the framework of analysis and decision-making presented in this paper for the university-driven innovation ecosystems, will consist of applying the SNA on the graph generated from (Tejero and León, 2016), and taking into account all the learning of the value networks (Allee, 2009; Allee, 2008; Allee, 2000). With this framework, it is possible to obtain metrics that can drive to answers to specific questions such as the current dynamism of the innovation ecosystem.

Some benefits of using SNA, including (Cross et al., 2004):

- SNA can help identify opportunities in networks that span functions, geographies, or process steps.
- Driving innovation in new product development, R&D, or market-facing functions. SNA can isolate how and where leveraging expertise in a network will either support or impede innovation efforts.
- SNA pre-change can identify key players to work through and retain. During the change, it can inform key interventions. After the change, it can ensure appropriate integration.
- SNA can help to rapidly form and improve effectiveness of communities by working through the network to more efficiently improve collaboration and business results.
- SNA can illuminate the effectiveness of external ties to strategic partners or clients in terms of information flow, knowledge transfer, and decision-making.
- SNA provides a set of powerful techniques for the study of social interactions empirically. Specifically, SNA allows for measuring the features of a network and the position of the actors of an innovation ecosystem (Cronin, 2016). It is a quantitative method that helps us obtain the social structure from the relationships established among social entities such as people, groups and organizations (De Nooy et al., 2018; Aryani et al., 2018; Ávila-Toscano, 2009).

SNA can be applied, among other things, to analyse large data sets of patent registrations to examine collaboration in research and development or to analyse citations of academic publications

to study scientific collaboration and impact. For a large number of nodes, it is difficult to manually and systematically visualize and analyse networks, so computer software is normally employed to analyse network data (Aryani et al., 2018; Akhtar, 2014; Studer et al., 1998). Referring to data collection, rational data is collected by observation, questionnaires, surveys or ethnographic methods, and processed through formal procedures based on graph theory and matrix theory.

3.5.2.2.1 Measures related to the structure of the network

Many measurement techniques have been developed to characterize and compare network structures and roles (De Nooy et al., 2018). Some techniques allow the comparison of the network structures together: for example, the investigation of network structure effectiveness for the achievement of goals. The first set of measurement techniques that we utilize is based on the network general structure analysis and the level of integration that characterizes the network; where the network components are identified as well as the density and cohesion of the whole network and the components are analysed (Scott, 2017; Sanz Menendez, 2003).

SNA has developed a set of categories, procedures, and algorithms that give us information about network structure, such as the following:

- Density of the network. This measurement is used to establish the relations between points and lines of the network graph and represents the number of links that are established between the nodes in relation to a maximum number that could be established if all the actors were connected directly by one line with all the others. Its definition is as follows: $Den = 2L / (n(n-1))$, where L is the number of lines and n is the number of nodes.
- Unipolarity. It is the first measure of the set of measures that represent the network cohesion (Cavalcanti, 2017). This measure indicates the value of the degree of the most central actor in relation to the maximum possible centrality that actor could have (n-1). Its formula is as follows: $U = D / (n-1)$, where n is the number of actors. U is obtained by dividing the gross value of the graph degree (represents the ability to communicate directly with others), D (the highest degree of an actor in the graph), by the highest possible degree (it would be that of an actor having relation to all the others).
- Integration. It corresponds to the sum of the degree of all actors in a graph. Its formula is as follows: $I = \sum d [n * (n - 1)]$, where d is the degree of each actor and n is the number of actors in the graph.

- Centralization. It is the sum of the differences in the degree of all points with the unipolarity value. Its formula is as follows: $C = \sum (D - d) / [(n - 1) (n - 2)]$, where d is the degree of each actor, D is the highest degree of an actor in the graph and n is the total of actors.

3.5.2.2.2 Measures related to the centrality of actors in the network

The centrality (non-directed networks) or prestige (Barekati et al., 2015) (directed networks), is a measure of an actor's position in the overall structure of the social network. These metrics are used to identify the key players in the network. They show how relationships are concentrated in a few individuals, giving an idea of their social power (Cordón, 2013).

The analysis of centrality is represented through the following properties: degree, closeness, betweenness, and EigenCentrality. These metrics are a form of being able to be defined and to become operative the centrality (Freeman, 1978).

- Degree. Represents the ability to communicate directly with others. It is defined as the number of other actors to which an actor is directly attached or adjacent (the normalized degree is the ratio of real relations to the total of possible relations). The degree of an actor would be, $CD(n_i) = \sum_j (x_{ij})$
- Closeness centrality. Represents the ability to reach directly many of the other members of the network, without intermediaries. Property by which an actor may have relationships with other actors, but through a small number of steps in the network. A node will be more central the smaller the number of steps it has to give through the network to relate to the rest (Sanz Menendez, 2003).
- Betweenness centrality. Represents the control of others' communication and their ability to restrict it. According to Sanz Menendez (Sanz Menendez, 2003), betweenness is defined as the level at which other actors must pass through an actor to communicate with the other actors. The value of betweenness for an actor measures the shortest paths between any two actors in the graph, which pass through it as a vertex. They often have high betweenness values the most central actors of the network according to their closeness, or those that link different subgroups or blocks (and which are the cut-off points between them).
- EigenCentrality. Like degree centrality, EigenCentrality measures a node's influence based on the number of links it has to other nodes within the network. EigenCentrality then goes

a step further by also taking into account how well connected a node is, and how many links their connections have, and so on through the network.

4 PROBLEM OR OPPORTUNITY. UNIVERSITY INNOVATION MANAGEMENT

4.1 Conceptual schema of the chapter

Figure 11. Conceptual schema of the Problem or Opportunity Chapter (source: own elaboration)

Blue color is used to show the main topics of the chapter. The main concepts of the topics are shown in **black color**. Finally, **orange color** is used to show the key concepts of the main concepts.

4.2 Factors or causes that affect universities development and sustainability

Universities are entities exposed to society changes. For that reason, the importance of innovation management for higher education organizations has never been more critical. A variety of factors have combined to present new challenges for universities, particularly for public universities. According to Clark (2016), these challenges consist of:

- 1) Demographic changes, combined with a change in the needs and desires of the students. Incoming students have different needs and wants in regard to technology than they have

in past generations. These students have been collaborating electronically since a very young age.

- 2) A gradual decrease in state funding for public education that has persisted since 1980.
- 3) The entries of new private and for-profit institutions have created an intense level of competence.
- 4) The rapid changes in technology.

In addition, as mentioned in the "Theory background" chapter, the role of universities in innovation ecosystems is presented as crucial (Cai, 2017). Apart from the education and research missions carried out previously by the university, a new mission of innovation is added to them, framed within of the so-called "Knowledge Triangle" (Maassen and Stensaker, 2011). This new mission requires moving from activities of protection and commercialization of intellectual property to a greater number and variety of activities more related to business and economic development, which requires new management approaches (Etzkowitz, 2013b).

Finally, although the data is expanding in universities, most of the data in regards to the innovation ecosystem and associated relationships are still scattered across individual office desktops, departments, and come in various formats, therefore, making data consolidation and retrieval difficult (Daniel, 2015; Daniel and Butson, 2013).

Figure 12 shows schematically the causes or factors that demonstrate the need of a new integrated innovation management for universities to support their evolution.

Figure 12. Ishikawa diagram of factors or causes that affect to universities and reflect a new integrated innovation management need (Source: own elaboration)

Whether these factors represented in Figure 12 are seen as opportunities for improvement or threats, the need to adopt a new integrated system of innovation management of the universities is identified. Specifically, this system should enable the use of the latest technological changes, for the proper storage and management of data (Technological), but also to manage innovation and the transfer of R&D (Political) results, which allow improving ecosystem performance to counteract the lack of funds received, obtaining advantages to compete with the new public and private actors that are appearing in the sector (Economic), and thus adapting to demographic changes and the new needs of students (Social).

Each of these causes or factors, seen as threats or opportunities (if it is acted accordingly for its elimination or mitigation), is shown in more detail below.

4.2.1 Demographic changes

What does demography have to do with higher education? Demographic trends in the population of a country, or throughout the world, can have an impact on the cost, size, dynamics and demographics of higher education systems and their outcomes (Vincent-Lancrin, 2017).

Nathan Grawe (2018), in his book "Demographics and the Demand for Higher Education", begins by pointing out persistent pessimism about the imminent collapse of higher education, under the weight of impending demographic change. In fact, according to many demographers (Johnson, 2019), changes in the size and composition of the population attending the university do not benefit our universities. One example are the projections of the decrease in the number of high school graduates and the consequent increase in competition between universities sharpens the problem for student recruitment.

The pace and dynamics of population growth are key for educational planning. The size of the school-age population and, therefore, the potential demand for education, affect educational decisions and the educational systems themselves. While the higher education system is being transformed, from being something only accessible by a few, by the elite, to having massive access with incoming students representing "at-risk" populations (Klemencic and Fried, 2015), which usually require increased attention and interventions in order for them to succeed, the rapid expansion usually requires structural changes (Mizikaci and Baumgartl, 2015).

Demography has become an issue of concern in many countries. The population of some OECD countries is aging rapidly, especially in Japan, Korea and southern and eastern Europe (Vincent-Lancrin, 2008). On the contrary, in countries like Mexico and Turkey, the population continues to grow, despite a decrease in the fertility rate. While demographic issues have not featured prominently in higher education debates in recent decades, current demographic trends are generating unprecedented concern.

The EU population projections reveal the demographic impacts: data on birth rates, migration and mobility combine and coincide with a decline in the youth population over the next 50 years (Mizikaci and Baumgartl, 2015). In many countries, not only in the EU, the size of the elderly population is increasing faster than birth rates, which presents a problem for many issues, including education.

All other things being equal, demographics directly affect the enrollment of students in higher education, since the size of younger age cohorts is a partial determinant of the number of students. Given that in OECD countries, approximately 80% of students in higher education have, on average, less than 25 years, the relative impact of younger age groups has a great influence on the levels of enrollment of students. If higher education entry rates, together with survival rates, the average duration of courses and other factors related to students (age, etc.) remain unchanged, the countries in which those cohorts decrease in size they will normally experience a drop in their student enrollments (Vincent-Lancrin, 2008).

These demographic changes will have an impact on higher education institutions in the not too distant future, for example, by enrolling fewer students and native employees than of foreign origin. In fact, regarding the teaching staff, one of the difficulties caused by the rapid expansion of higher education systems is that their teaching staff cannot always be recruited or replaced when needed, due to the lack of qualified human resources. The opposite case is also not without problems. As an example, when higher education systems are significantly reduced, we are faced with an overproduction of doctorate graduates if the non-university sectors fail to absorb them. According to the trend detected, in the OECD countries, this last scenario of reduction of higher education systems seems unlikely (Vincent-Lancrin, 2017; Vincent-Lancrin, 2008).

The growth in student enrollment is conducive to changes in the teaching staff and the employment of younger teachers. This allows the recruitment of new teachers without waiting for the current ones to leave. The permanent teaching staff, as demonstrated by Willekens (2008), experiences

cyclical changes in their age structure. In most OECD countries, teachers in higher education, on average, are an aging workforce, with an average of 55 years, in those for whom data are available (Vincent-Lancrin, 2017).

4.2.2 New students needs and pace

An important transformation in higher education is based on the evolving nature of the student. The traditional student profile was young, with little status and enrolled in conference-based programs on the campus of their university. This student profile is changing rapidly. Throughout the world, higher education institutions are witnessing a large increase in the enrollment of older people. With the evolutionary concept of lifelong learning, today's student may be working part-time or looking to continue their education after taking a break from work. These are adults who work and who have unique learning requirements (Yeravdekar et al., 2018).

“Non traditional” students in higher education

Figure 13. “Non traditional” students in higher education (Source: Yeravdekar et al., 2018)

In this sense, higher education must also respond to changes in the labor market to provide students with skills that will help them to maintain themselves throughout their working lives.

The increase in student mobility is also seen to increase by leaps and bounds. As higher education systems are interconnected around the world, universities should be encouraged to include more global components and contexts in the curriculum and teaching. Universities must become spaces for open learning.

On the other hand, nowadays, incoming students have different needs than past generations. Concerning technology, in average, child of today has had a cellphone since age 10. In addition, more than half of these children use a smartphone to access social media and interact with their peers every day (Boerma, 2014).

4.2.3 Rapid changes in technology

The dynamic and continuous changes in technology have provided new opportunities, although many institutions have struggled not to apply these changes (Merchant, et al. 2014; Al-Qahtani and Higgins, 2013).

As proof of the dynamism and continuity in the changes can be seen in the availability and use of bandwidth, which has quadrupled in just 10 years. In the last decade, we have also seen the rapid conversion of DVD to Blu-Ray discs, and these to streaming. For its part, high-definition video has quadrupled in resolution and virtual reality is ready to become a new standard for interacting with digital media (Clark, 2016).

During this decade, the fast evolution towards the so-called “digital economy” and the exponential growth and availability of innovative solutions based on “digital platforms” embedded in the so-called collaborative economy are affecting all public and private entities by disrupting the value-chains of all economic sectors. Digital platforms are, in turn, closely linked to concepts of increasing impact and unclear borders such as “collaborative economy”, “digital economy”, “multi-sided markets”, and, in a broader context, its relationship with the “digital ecosystems of innovation” that, together, determine the rhythm in the creation of new companies, and the disappearance or transformation of many others (León et al., 2017).

In fact, the European Commission itself recognizes that these platforms are essential to promote innovation since they increase the variety of products, efficiency and competitiveness apart from helping to increase social participation¹⁷. For end users, digital platforms allow them to provide solutions with a high level of customization and a large number of solutions of all kinds that allow not only meet different needs but do so by personalizing the service.

A clear advantage of digital platforms over other structures is their catalytic role in fostering innovation. The platforms offer the possibility of distributing innovations on a massive scale, and also allows reducing the costs and risks of carrying out this innovation (which are transferred to the developers, since in search of their own benefit they help the platform grow with each innovation). Additionally, it allows the supply of market niches outside the common mass of the market that, without platforms, would not be well supplied.

¹⁷ <https://ec.europa.eu/digital-single-market/en/policies/online-platforms>

Platforms play a fundamental role in digital ecosystems. They are the "medium" in which these ecosystems are developed, as well as becoming the infrastructure that supports the interactions between users, developers and other interest groups. According to the report of León et al. (2017), the irruption of the platforms and their associated digital ecosystems generates three fundamental changes in the economy of the digital society:

1. Innovation is transferred from the organization to its consumers (users and/or developers) who take a much more active role in the value chain.
2. The added value that the organization provides grows more than linearly due to the network effects that derive from the platforms, which are able to attract developers and users that generate new markets on the platform.
3. The organization is affected by requiring a greater emphasis on connecting the "sides" (who has something to offer and who needs it), guaranteeing trust in the transactions and exploiting the new source of income that is the "data".

Studies on future projections for higher education suggest that technological advances will be the main factors to be taken into account. Technology will continue to shape and reform the learning process. Therefore, universities must be prepared for a future with technology. In fact, technology has fundamentally changed post-secondary education and learning (Yeravdekar et al., 2018).

4.2.4 Data is not stored properly

According to Rob Kitchin (2014), "Data have strong utility and high value because they provide the key inputs to the various modes of analysis that individuals, institutions, businesses and science employ in order to understand and explain the world we live in, which in turn are used to create innovations, products, policies and knowledge that shape how people live their lives". Therefore, data are a key resource in the modern world.

The amount of data that exists today, in the so-called era of knowledge, as well as the difficulty to use such amount of data correctly and really useful for decision making, makes it necessary to explore new tools and ways of action in all the levels of our society, but especially in the universities, for its adaptation to the new current needs and its future sustainability.

Data is the new old, the new oil (Humby, 2006). However, although data are growing in universities, the most of them are still scattered across desktops, departments, they come in various formats and, therefore, making it difficult to retrieve or consolidate (Daniel and Buston, 2013). The ability to

analyse diverse information sets is needed, regardless of where they originate, and consolidating data stored in silos within institutions, managing and governing the data while securing sensitive information across databases (Daniel, 2015). In other words, data warehousing can be an effective approach to unlock the value of Big Data in higher education.

The promise of data-driven decision-making is now being recognized broadly, and there is growing enthusiasm for the notion of “Big Data” (Labrinidis and Jagadish, 2012). Big Data is providing a new means to dynamically and efficiently manage all the activities of an organization and obtain additional profits, through greater productivity, competitiveness and market knowledge (Kitchin, 2014).

4.2.5 Emergence of new competitors

Traditionally, economic development was a question associated with the industrial sector. However, in the era of a knowledge-based society, this economic development has become increasingly dependent on the existence of cooperation between industry and knowledge production organizations, as is the case of universities (Lundvall, 1992). For that reason, in the coming years, universities must overcome their traditional approach, as independent academic institutions, since higher education will be increasingly integrated into the economy and the society in general. As globalization and technological advances gain momentum, universities must assume an increasingly active leadership role in both local and global spheres (Yeravdekar et al., 2018).

Traditional higher-education value-chain is being challenged with the introduction of new actors in the higher education process and the emergence of IT-based disruptive learning models, which impact on university performance and governance.

With the emergence of new technologies, new actors have also emerged in the space of higher education. Organizations such as EdX and Coursera have partnered with prestigious universities such as Stanford or MIT to teach courses in new formats, such as the well-known MOOC (massively open online courses) (Clark, 2016). While these offer benefits to universities, such as prestigious or valuable marketing tools of these institutions, many of the universities have not yet participated in these new associations (Hampson, 2012).

With the support of technology, collaboration has been a central theme in the way research is conducted in some of the leading institutions of higher education. Academy, industry and government are collaborating together to research and develop innovative solutions to solve

business challenges (Etzkowitz, 2013a). In addition to the commercialization of research for the industry, such collaborations take advantage of the synergies and complementarities of scientific and technological capabilities and simulate additional funds for research. With the backing of technological advances, researchers can network with each other through virtual groups and use data analysis to extract huge amounts of open source data that are available in different countries for their research results.

Therefore, a relevant approach concerning universities' evolution is the recognition of the possibility or convenience that their educational services could be provided through long-term partnerships with public and private external entities not necessarily located in the same country. These developments point out towards new "hybrid models" where universities operate their core academic activities in symbiosis with their enabling partners. The rationale behind this evolution is two-fold:

1. To be able to quickly adapt the academic offer to emerging market needs by relying on agreements with external experts and capabilities when internal resources were not enough or when they were not ready. This approach allows universities to find shortcuts to avoid the substantial time required in the public system to convert a new degree in a reality.

Additional human and material resources can be offered by other entities; then, universities do not need to base their offer of academic degrees only on internal capabilities. One of the easiest well-known approaches for that is the provision of "on-line" degrees by using advanced tools (e.g. to develop or acquire software platforms, pre-designed educational contents or even access to remote labs!) and through the participation of external experts individually identified or through the signature of agreements with service providers (León et al., 2018).

The need to accelerate innovative academic offer where administrative conditions delay purchase and hiring processes of faculties are overregulated is forcing more active universities to combine the provision of educational services with selected partners and to distribute potential benefits among all participants. This trend is being progressively adopted in case of post-graduate studies oriented to specialised professionals.

2. To increase the efficiency and performance of the education process by focusing public universities in those areas where they can offer a substantial added-value (e.g. knowledge

certification, grading, postgraduate courses with advanced equipment to bridge them with research, etc.) and not in other areas where private entities could perform better.

In fact, a reaction is required from public universities, since the growth of the private sector in higher education in Europe, in terms of the number of institutions and the proportion of enrollments, reflects a quite significant increase. The global demography of private higher education is such that the main center of the sector is East Asia, with approximately 80% of all students enrolled in private universities in Japan, South Korea, Taiwan and the Philippines. It is surprising that in the United States it is only 20%, while in Western Europe it is around 10% and in the European countries of post-communist transition, and in some post-Soviet republics, the percentage can reach up to 30%. Finally, in Latin America more than 50% of enrollments belong to the private sector, in countries such as Brazil, Colombia, Peru and Venezuela (Kwiek, 2016).

One case where this approach applies is the provision of technical platforms for students to access to media contents, interact with peers through specialised social networks, schedule virtual tuition, etc. As any other entity, universities can implement these services but usually they have not internally the right profile neither the experience for that. Why not to rely on external partners?

Figure 14 offers a high-level view of the main drivers for change which condition decision-making by universities. Some drivers are internal to the university in order to improve their positioning (e.g. in international rankings and with their partners) and efficiency (e.g. best use of human and material resources). Others are external drivers motivated by shifts in interest or priorities of stakeholders (e.g. the creation of a new faculty).

Figure 14. Drivers for higher educational change (Source:own elaboration)

Figure 14 refers to a change of university model where emphasis shifts from ensuring “competitiveness” (as an isolated goal) to create the most adequate “higher education ecosystem” (as a shared goal). Behind that approach is the recognition that other partners will be needed for one university to be globally competitive.

With respect to innovation, the role of universities in innovation systems is increasingly crucial (Etzkowitz, 2013). Therefore, in the same way, an important issue that is present in the reforms related to higher education underway all over the world is the one on how to coordinate and facilitate in an effective way that universities can better interact with other actors to promote innovation, which consequently leads to a transformation within higher education (Cai, 2017). This transformation in higher education has been conceptualized in a variety of concepts, such as "academic capitalism", "entrepreneurial university", "model 2 of knowledge production", "higher education as an industry" and "the third mission of university".

4.2.6 The third mission

According to many authors (Loi and Guardo, 2015), an invisible revolution, known as "third mission", is happening within the universities. Consequently, canonical missions associated with research and teaching have been integrated with this new mission focused on territorial development.

The third mission of the universities refers to all those social, business and innovative activities that are carried out by universities, in addition to the usual tasks of teaching and research (Zomer and Benneworth, 2011). In a broad sense, the third mission represents the contribution that universities provide to the social and economic development of the territories (Saad and Zawdie 2011).

The different activities through which it is possible to transfer knowledge or technology by universities can be classified into two main types: commercialization activities and academic engagement (Perkmann et al., 2013). Commercialization activities represent a measurable and immediate means by which universities contribute directly to the economy and society. On the other hand, academic engagement, which ranges from a formal agreement, such as contracts, to activities of a more informal nature, such as meetings or conferences, is defined as a collaboration related to knowledge, which is conducted among academic researchers and non-academic organizations (Bozeman et al., 2013).

In relation to this “third mission”, at the end of the last century the European Union (EU) was well-aware of the urgent need to reinforce the role of European universities in the construction process

of the so-called “European knowledge society” where not only knowledge generation and wide absorption was essential but also its application and use would demand highly skilled citizens and professionals. This is the basis of the well-known concept of “knowledge triangle” (Maassen and Stensaker, 2011) where universities meet together with other entities like enterprises and public research centres. Conceptually, the so-called “knowledge policies” ranging from education, research and innovation policies should be jointly designed and implemented by governments and institutions to be successful in an integrated way.

Figure 15 depicts a global view of the effort made by the EU where the European Higher Education Area, the European Research Area (ERA), and a broad range of innovation activities firmly tied to regional policies and (since 2014) deeply embedded in the framework programme (H2020) coexist together. To realize that political ambition, the European Union is pushing since 2010 a long-term process of structural reform of European universities to improving their global competitiveness.

Figure 15. The EU in the knowledge triangle (Source: own elaboration)

4.2.7 A gradual decrease of funding for public education

There is a trend of decreasing funding from states for public education that has persisted since 1980 (Clark, 2016). In particular, recent studies (Pruvot et al., 2017) indicates that since the 2008 financial crisis, the divide between higher education systems that could increase public funding and those that were forced to reduce the level of investment is getting wider in Europe. The findings of the Public Funding Observatory Report 2017, published by the European University Association or EUA, also show that while 2012 was the year of “deepest crisis” for universities in Europe with the largest number of systems cutting funding, any recovery that can now be detected is slow and fragile: “only 14 systems had higher funding in 2016 than in 2008 and eight of those have a faster growth in

student populations compared to the increase in funding. Nineteen systems still had lower levels of direct public funding than at the time of the financial crisis” (Pruvot et al., 2017).

Associated to the internal drivers, there is also a trend in public universities from a growing pressure for higher efficiency and performance in their operation as a basis for public funding (performance-based funding, PBF) (Debackere et al., 2018). In recent words from the European Commission’s services (SWD, 2017) the situation is stated as follows:

“In recent years, there has been a general shift towards systems that pay universities based on the outputs they produce (number of graduates, number of research publications etc.), rather than purely on the basis of established costs. At the same time, a number of countries have introduced performance contracts between the state and higher education institutions, which established specific targets, the achievement of which may be rewarded with funding. Output-based funding formulas and performance agreements with funding linked are types of ‘performance-based funding’ (PBF)”.

Most PBF schemes focus on the quality of research and its scientific impact although recently additional criteria are being used, especially in relation to societal impact. In principle, PBF schemes are backwards-looking systems for allocating funding so in practice, few of them consider potential future performance.

This trend is not only linked to public universities in order to be rewarded (or not) with additional public funds (in many cases, it is a redistribution of pre-existent resources within a group of universities); it is also related to another megatrend to convert public universities in “sustainable” entities capable of managing efficiently public budgets and able to attract external funds.

It is worthy to mention that a large part of the open discussion around universities is framed in the USA under the “cost perspective”, fuelled by the value of expensive college degrees. The problem boosted from the dramatic increase of unpaid loans for university studies and the feeling from middle-class families that this time it will be much more difficult to give their children a university education as they had in the past.

This cost-value trade-off analysis is also behind the boosted phenomena of cheaper MOOCs despite its well-known weaknesses to ensure continuity over time (statistics said that only 7% of students are finishing on-line degrees) and poor adequacy to be applied to some technical or engineering degrees where large equipment is needed, or the difficulties to address soft skills.

Anyway, many European universities are also testing the use and adequacy of on-line learning modules in combination to face-to-face models (i.e. blended learning) to be able to reduce costs, address additional demands for students' flexibility and to get the same degree of quality and performance than in the traditional education process (i.e. to get the same level of fail graduates and employment rates of graduates) (Dion et al., 2018; Pisoni et al., 2018).

Consequently, the common set of economic pressures has led the various sectors of higher education to adopt entrepreneurial models of financing and service (Breneman, 2005). Commercialization of R&D resources is seen as a possible solution to the problem.

4.2.8 Pressure to exploit R&D resources

The nature of universities is changing as reduced public funding reflects a public debate about their role in society (Guerrero et al., 2015). Nowadays, although government subsidies promote new initiatives for the collaboration of academia and industry, the increasing pressures on public funding sources for universities has generated a strong incentive for universities to also look for alternative sources of income for their basic research and equipment through means such as the commercialization of research and the exploitation of intellectual property rights or the granting of patent licenses (Ankrah and Omar, 2015).

Public universities, and some public research centres, are receiving considerable pressure from public administrations to develop specific internal mechanisms in order to exploit the results of R&D projects funded by governmental programmes. For the efforts made in science and technology, taxpayers (and governmental officers on behalf of them) expect to see returns from their taxes in terms of better quality of life and increased visibility. As a result, universities are motivated to protect their research results (via patents or other IP tools) and to move protected items to the market as an institutional strategy to "exploit" the research results (Perkmann et al., 2013). Technical universities are even more pressed of acting in the direction of exploitation, because the relevance of applied research in their project portfolio make them more capable to react to public administration pressure.

In recent years, more and more attention has been paid to the international creation of new companies that involve the creation of spin-offs, as a combination of technology and knowledge generated by universities (Guerrero et al., 2015). From the perspective of business creation, entrepreneurship can contribute to the university-driven innovation ecosystems' generation,

development and sustainability in many ways. In fact, entrepreneurship is seen as a major engine for economic growth and job creation (Valliere and Peterson, 2009; Wong et al., 2005), also by and for universities (Eesley and Miller, 2017).

On the other hand, following the traditional approach of academic entrepreneurship, in a knowledge-based economy, research activities such as the generation, transfer and commercialization of new knowledge are another function that must be taken into account. Examples of traditional mechanisms for commercialize knowledge include copyrights, patents, licenses and trademarks.

4.3 A new integrated innovation management in higher education is required

In view of the challenges identified in above sections, the universities of the future must be prepared to face unprecedented challenges, but also to take advantage of unprecedented opportunities for innovation. Innovation is the main determinant of the dynamics of the evolution of capitalism (Schumpeter and Fels, 1939). Innovation is fundamental to generate a development strategy, being combined with local business dynamics, knowledge generation, skills development, technology transfer and the region's policies (Arciénaga Morales et al., 2018).

However, despite the efforts of many countries to promote innovation, there is still a gap between academic research and its transformation into products and services useful for citizens and, ultimately, society. In the USA, this gap has been called "Valley of Death" (Wessner, 2008). In Europe, it has been given the name of "European Paradox" (European Commission, 1995); that is, the failure perceived and measured by European countries to translate scientific advances into commercial innovations (Dosi et al., 2006). In fact, the evolution of public universities in the EU has been dissimilar since 2000 and a number of diverse models and situations can be found in the EU Member States.

Main problems in the European paradox or "innovative gap" are precisely the lack of administration of specific information and knowledge. Therefore, innovation management must be interpreted as a valid and necessary tool to solve this innovation gap. It is therefore critical that institutions consciously engage in the practice of innovation management, so that new opportunities to advance student and faculty success are leveraged appropriately and more quickly.

The new mission of the university, in terms of innovation, requires a series of changes or adaptations that allow integrating all the new activities required with existing ones. For all these reasons, the

need of a new integrated innovation management is identified for an evolutionary change that allows universities to be consecrated as strategic knowledge providers for innovation.

Base on the eight big challenges identified above, it arise a set of main aspects that should be considered. Table 4 described these main aspects. Taking into account the challenges and their respective main aspects related, a serial of objectives are defined to be conducted by an university. In particular, these specific objectives should be addressed by the university to face the eight challenges, transforming them to an opportunity to be ready for new times.

Challenges (eight big challenges)	Main aspects to be consider	Objectives
Demographic changes	<ul style="list-style-type: none"> • Too many students enrolled due to the democratization of education. • Very few students enrolled due to the existence of a lot of competition. • Lack of qualified personnel on time depending on the demand. • Overproduction of graduates that the market cannot absorb. 	To have a system that allows a service management adequate to the demand: planning and management of human and material resources, coordination with the market, etc.
New students needs and pace	<ul style="list-style-type: none"> • A large increase in the enrollment of older people. • Evolutionary concept of lifelong learning. • The increase in student mobility is also increasing by leaps and bounds. • Universities should be encouraged to include more global components and contexts in the curriculum and teaching. 	To have a system that allows students a learning aligned with their pace and needs, being able to access when and where they want.

Rapid changes in technology	<ul style="list-style-type: none"> • The availability and use of bandwidth has quadrupled in just 10 years. • The rapid conversion of DVD to Blu-Ray discs, and these to streaming. • High-definition video has quadrupled in resolution and virtual reality is ready to become a new standard for interacting with digital media. • The platforms offer the possibility of distributing innovations on a massive scale, and allows reducing the costs and risks of carrying out this innovation. 	To adopt the new technologies to take advantage of the huge possibilities that they can offer.
Data is not stored properly	<ul style="list-style-type: none"> • The amount of data that exists today is huge. • The difficulty to use such amount of data correctly and really useful for decision-making. • The most of data is still scattered across desktops, departments, it come in various formats and, therefore, making it difficult to retrieve or consolidate. • The ability to analyse diverse information sets is needed, regardless of where they originate, and consolidating data stored in silos within institutions, managing and governing the data while securing sensitive information across databases. 	To apply a digital transformation of the university, in order to have knowledge digitalized and stored properly.

<p>Emergence of new competitors</p>	<ul style="list-style-type: none"> • The growth of the private sector in higher education in Europe, in terms of the number of institutions and the proportion of enrollments, reflects a quite significant increase. • Traditional higher-education value-chain is being challenged with the introduction of new actors in the higher education process and the emergence of IT-based disruptive learning models, which impact on university performance and governance. • With the emergence of new technologies, new actors have also emerged in the space of higher education (e.g. EdX and Coursera). • As globalization and technological advances gain momentum, universities must assume an increasingly active leadership role in both local and global spheres. • Economic development has become increasingly dependent on the existence of cooperation between industry and knowledge production organizations. • Academy, industry and government are collaborating together to research and develop innovative solutions to solve business challenges. 	<p>To change the university model where emphasis shifts from ensuring “competitiveness” (as an isolated goal) to create the most adequate “higher education ecosystem” (as a shared goal).</p>
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	<ul style="list-style-type: none"> • Educational services could be provided through long-term partnerships with public and private external entities not necessarily located in the same country. • To be able to quickly adapt the academic offer to emerging market needs by relying on agreements with external experts and capabilities when internal resources were not enough or when they were not ready. • To increase the efficiency and performance of the education process by focusing public universities in those areas where they can offer a substantial added-value (e.g. knowledge certification, grading, postgraduate courses with advanced equipment to bridge them with research, etc.) and not in other areas where private entities could perform better. 	
The third mission	<ul style="list-style-type: none"> • The role of universities in innovation systems is increasingly crucial. • An important issue that is present in the reforms related to higher education underway all over the world is the one on how to coordinate and facilitate in an effective way that universities can better interact with other actors to promote innovation. 	To allow an innovation management in combination with education and research, as well as the collaboration with other actors to promote innovation and launching of new products and services to the market.

	<ul style="list-style-type: none"> • In relation to this “third mission”, at the end of the last century the European Union (EU) was well-aware of the urgent need to reinforce the role of European universities in the construction process of the so-called “European knowledge society” where not only knowledge generation and wide absorption was essential but also its application and use would demand highly skilled citizens and professionals. 	
A gradual decrease of funding for public education	<ul style="list-style-type: none"> • There is a trend of decreasing funding from states for public education that has persisted since 1980. • While 2012 was the year of “deepest crisis” for universities in Europe with the largest number of systems cutting funding, any recovery that can now be detected is slow and fragile: “only 14 systems had higher funding in 2016 than in 2008 and eight of those have a faster growth in student populations compared to the increase in funding. Nineteen systems still had lower levels of direct public funding than at the time of the financial crisis” (Pruvot et al., 2017). • There is a trend in public universities from a growing pressure for higher efficiency and performance in their operation as a basis for public funding (performance-based funding, PBF). It is 	To get higher efficiency and performance in their operation to convert public universities in “sustainable” entities capable of managing efficiently public budgets and able to attract external funds.

	<p>also related to another megatrend to convert public universities in “sustainable” entities capable of managing efficiently public budgets and able to attract external funds.</p> <ul style="list-style-type: none"> • Many universities are testing the use and adequacy of on-line learning modules in combination to face-to-face models (i.e. blended learning) to be able to reduce costs, address additional demands for students’ flexibility and to get the same degree of quality and performance than in the traditional education process (i.e. to get the same level of fail graduates and employment rates of graduates). 	
Pressure to exploit R&D resources	<ul style="list-style-type: none"> • Public universities, and some public research centres, are receiving considerable pressure from public administrations to develop specific internal mechanisms in order to exploit the results of R&D projects funded by governmental programmes. • For the efforts made in science and technology, taxpayers (and governmental officers on behalf of them) expect to see returns from their taxes in terms of better quality of life and increased visibility. • Universities are motivated to protect their research results (via patents or 	To adopt entrepreneurial models of financing and service, with focus on innovation, mainly through exploitation of R&D resources and business creation.

	<p>other IP tools) and to move protected items to the market as an institutional strategy to “exploit” the research results.</p> <ul style="list-style-type: none"> • From the perspective of business creation, entrepreneurship can contribute to the university-driven innovation ecosystems’ generation, development and sustainability in many ways. In fact, entrepreneurship is seen as a major engine for economic growth and job creation. 	
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Table 4. Challenges and objectives for an integrated innovation management system (Source: own elaboration)

5 OBJECTIVES

5.1 Conceptual schema of the chapter

Figure 16. Conceptual schema of the Theory Background Chapter (source: own elaboration)

The **blue color** is used to show the main topics of the chapter.

5.2 Objectives description

Based on the review of the challenges related to innovation management in universities described in Chapter 4 and taking into account the theory background presented in Chapter 3, the overall objective is stated as follows:

- *"To improve the innovation processes in universities to allow them to remain as strategic suppliers of knowledge and innovation"*

As previously commented, innovation is a key aspect in the most of organizations today. Universities are not an exception so their innovation process should be aligned with the current demands from society. In addition, the innovation in Universities is not only a powerful tool by also a results by itself, since is one of the main knowledge generation tool. As exposed on chapter 4, there are several factors that makes the current innovation processes implemented by (mostly public) universities insufficient to achieve the required alignment with society needs. The general objective of this research work is to start changing this situation to maintain one of the main roles of universities: generation of knowledge in all its dimensions, including the innovation one.

Specific objectives

To achieve the general objective several specific objectives have been defined. These objectives state the research actions to be performed specifying the aspects of the innovation process to be improved. The specific objectives have been defined as follows:

1. *"To analyze the situation of the innovation processes of public universities to understand the most valuable factors and main challenges"*.
2. *"To Propose a new framework of action for an evolutionary integrated management of innovation that allows an improvement of innovation processes in universities as analyzed previously"*.

A framework of action is understood as the set of tools and actions for the design, development and implementation of an integrated innovation management system that allows universities to offer services as the obtained from the first specific objective.

Since the development of a framework of action have a large number of possibilities, it is required a definition of a strategy from the very beginning that allows to follow specific approaches. In this research work will be checked two different strategies (approaches):

- Continuity Strategy. Determine the structure, tools, techniques and actions necessary for the development of a model that, **based on the current configuration and resources used by universities**, allows the creation of an integrated innovation management system adapted to new challenges.
- Disruptive Strategy. Determine the structure, tools, techniques and actions necessary for the development of a model that, **based on the factor analyzed on specific objective 1**, allows the creation of an integrated innovation management system adapted to new challenges.

In particular, from the challenges, are defined the following operative objectives for universities evolution:

1. To have a system that allows a service management adequate to the demand: planning and management of human and material resources, coordination with the market, etc.
2. To have a system that allows students a learning aligned with their pace and needs, being able to access when and where they want.
3. To adopt the new technologies to take advantage of the huge possibilities that they can offer.
4. To apply a digital transformation of the university, in order to have knowledge digitalized and stored properly.
5. To change the university model where emphasis shifts from ensuring “competitiveness” (as an isolated goal) to create the most adequate “higher education ecosystem” (as a shared goal).
6. To allow an innovation management in combination with education and research, as well as the collaboration with other actors to promote innovation and launching of new products and services to the market.
7. To get higher efficiency and performance in their operation to convert public universities in “sustainable” entities capable of managing efficiently public budgets and able to attract external funds.
8. To adopt entrepreneurial models of financing and service, with focus on innovation, mainly through exploitation of R&D resources and business creation.

6 ACTION FRAMEWORK

6.1 Conceptual schema of the chapter

Figure 17. Conceptual schema of the Theory Background Chapter (source: own elaboration)

Blue color is used to show the main topics of the chapter. The main concepts of the topics are shown in **black color**.

6.2 Rationale and benefits of the implementation

The challenges faced by universities to remain as strategic suppliers of knowledge, demonstrate the need to take on new changes. An integrated management of innovation is presented as a solution to face these challenges, but also to take advantage of all the opportunities that they envision through the specific objectives defined above. The challenge is great, but there are different options to face that go through adopting approaches that are more conservative, starting and reusing as much as possible the resources available to universities today. For the most daring, and perhaps ambitious, adopting a more radical, more disruptive approach may initially present a multitude of

drawbacks. However, nowadays are times to adopt changes. Courageous attitudes are required to face these adversities thinking about future solutions, since the higher education sector is clearly a strategic element of our society, where it should always be seen in the long term.

Indeed, universities and research centers do not have sales, product development or delivery processes similar to the firms. Its function is not to solve short-term problems with orientation to the detailed specification and to maximize economic margins. Its function is, as a strategic knowledge provider, to generate knowledge in conjunction with other organizations, with a medium and long-term vision, to prepare the next generation of products and services. In short, create exclusive capabilities for those organizations with which they collaborate. The research groups work with emerging knowledge, which can be incorporated into the market for several years.

Anyway, the choice of one or another alternative will depend on each university, its idiosyncrasy and its possibilities. Then, in following points of this chapter, the two approaches are shown, beginning with an incremental approach, to end with a more disruptive approach, looking to the future.

Before presenting both approaches in depth, arguments are presented to: 1) justify why a university should take the decision to take a step like the one proposed, to undertake the adoption of an integrated system of innovation management; 2) show why each of the two proposed approaches would be more useful (incremental and disruptive), as well as on which points each of its components would be more beneficial; and 3) assessing and comparing the benefits that solutions can offer in the face of complexity that would require its implementation.

6.2.1 Rationale for implementing an integrated innovation management system

The current problem facing universities, disaggregated in the previous challenges presented in Chapter 4, urges the need for change, which allows the management of knowledge generated, transferred and consumed in their respective ecosystems, to improve decision-making with special focus on innovation.

At present, although each university has its own management system, often developed by the university itself, these systems are usually ineffective or have great inefficiencies both in knowledge management and in academic, economic, financial or human management. A key aspect in this problem is the treatment of information, starting from what could be considered as more serious,

that is, not keeping certain data that are relevant to the decision-making processes, up to what implies the application of a biased analysis of the information.

The existence of this problem can be reflected in the various initiatives that are emerging in recent years, for example, in some European countries. In the case of Spain, the Hércules project, promoted by the CRUE¹⁸, identifies the need for a new university research management system that allows not only solve the problem of information management, but also connect to the different universities. The objective is none other than to homogenize the way that universities have to manage information to improve not only at the individual level, but to enable the joint exploitation of that information; which would allow to establish synergies between universities, but also with business organizations.

Through the two approaches proposed in this research, it would be possible to solve the problem detected. The proposal of two approaches has no other objective than to facilitate the adoption by the universities of an integrated innovation management system, gradually. Of course, the ultimate goal would be that a university, when fully implemented, would be fully integrated with its ecosystem, but would also have a homogeneous information infrastructure that would allow it to scale-up because of the appearance of more relevant information for its use and use in their decision-making.

6.2.2 Benefits of the implementation of an integrated innovation management system

The achievement of the specific objectives listed in Chapter 5, either by adopting a more or less radical approach, would allow the following improvement opportunities to be developed for a given university:

1. An efficient management of human and material resources.
2. Services adapted to the new needs of students.
3. Capacity for the adoption of new technologies.
4. Storage, access, management and analysis of knowledge for decision-making.
5. Knowledge of the market of competitors and expansion of the possibilities of collaboration.
6. An integrated management of innovation, education and research to maximize innovation opportunities in their different aspects.

¹⁸ <http://tic.crue.org/hercules/>

7. An efficient management of budgets, as well as expansion of the options to obtain external financing.
8. Creation of new commercialization models of the R&D results generated by the university.

In particular, taking into account the different options and tools available in each of the approaches (incremental and disruptive), the challenges identified above could be addressed, as summarized in Table 5.

Dimensions (TYPES)	Main challenges (PROBLEMS)	Expected results (OPPORTUNITIES)	New integrated innovation management system (OPTIONS AND TOOLS)	
			Incremental approach	Disruptive approach
SOCIAL	Demographic changes Information	An efficient management of human and material resources	Digital platform	Advanced Digital platform
			IMTs (Human Resources management)	IMTs (Human Resources management)
			IMTs (Innovation project management)	IMTs (Innovation project management)
				Knowledge graph
	New students needs and pace	Services adapted to the new needs of students	Digital platform	Advanced Digital Platform
			IMTs (e-Learning)	IMTs (e-Learning)
TECHNOLOGICAL	Rapid changes in technology	Capacity for the adoption of new technologies	Digital platform	Advanced Digital platform
			IMTs (technology watch)	IMTs (technology watch)
				Advanced technology

				intelligence services
	Data is not stored properly	Storage, access, management and analysis of knowledge for decision-making.	Digital platform (Digital transformation of University databases)	Advanced digital platform (Ontology + knowledge graph)
ECONOMIC	Emergence of new competitors	Knowledge of the market of competitors and expansion of the possibilities of collaboration	Digital platform	Advanced Digital platform
			IMTs (Market intelligence)	IMTs (Market intelligence)
			IMTs (Cooperation and networks)	IMTs (Cooperation and networks)
			IMTs (Open innovation)	IMTs (Open innovation)
			Network analysis (new taxonomies, ecosystem graph and SNA)	Advanced technology intelligence services
				Knowledge graph
	Gradual decrease of funding for public education	An efficient management of budgets, as well as expansion of the options to obtain external financing	Digital platform	Advanced Digital platform
			IMTs (Cooperation and networks)	IMTs (Cooperation and networks)
				Advanced technology intelligence services
POLITICAL	The third mission	An integrated management of innovation, education and	Digital platform	Advanced Digital platform

		research to maximize innovation opportunities in their different aspects	IMTs (Knowledge management)	IMTs (Knowledge management)
			IMTs (Innovation project management)	Innovation project management
				Knowledge graph
	Pressure to exploit R&D resources	Creation of new commercialization models of the R&D results generated by the university	Digital platform	Advanced Digital platform
			IMTs (Knowledge management)	IMTs (Knowledge management)
			IMTs (Innovation project management)	IMTs (Innovation project management)
				Knowledge graph
			IMTs (Creativity development)	IMTs (Creativity development)
			IMTs (Design management)	IMTs (Design management)
			IMTs (Interface management)	IMTs (Interface management)
			IMTs (Business creation)	IMTs (Business creation)
			IMTs (Market intelligence)	IMTs (Market intelligence)
				Advanced technology intelligence services

Table 5. Challenges and options to face them (Source: own elaboration)

In later sections of this chapter, the different options listed in Table 5 are shown in detail, through their description and implementation for concrete and real case studies. Before going into detail of

these options and tools, a comparison is presented below between the complexities of the implementation of these solutions, with respect to the benefits that could be obtained.

6.2.3 Comparison of implementation benefits vs implementation complexity

As can be seen in Table 5, the implementation of the different approaches, as well as the tools associated with each case, involves as a minimum having a basic infrastructure: a digital platform, which will connect with the knowledge structure and enable the incorporation of other applications and functions, such as IMTs, advanced technology intelligence services, etc.

The implementation of both the incremental approach and the disruptive approach will bring about a certain complexity (see Table 6). In the case of the incremental approach, the objective is for the digital platform to enable the connection and use of the knowledge base available to the university. However, the basic infrastructure implemented (digital platform + knowledge base) will not be, in principle, prepared to facilitate the incorporation of new functions and applications, adding more complexity to this later part of the process. Therefore, in the incremental approach the focus will be on making the digital platform compatible with the knowledge base, which will facilitate the first part of the process, but will generate a subsequent complexity when new applications and functions are incorporated into the infrastructure.

	Incremental approach	Disruptive approach
Initial complexity	Low initial complexity since compatibility of the digital platform with the available knowledge base is sought.	High initial complexity since in the basic architecture a new knowledge base and advanced digital platform is created.
Later complexity	High complexity later since the basic architecture (digital platform + knowledge base) does not facilitate the incorporation of applications and functions.	Low complexity later since it seeks to facilitate the incorporation of applications and functions.

Table 6. Implementation complexity for incremental and disruptive approaches (Source: own elaboration)

In the case of the disruptive approach, the objective is to create an advanced digital platform that facilitates the subsequent incorporation of applications and functions into the formed architecture (better integration of the ecosystem with a more homogeneous and scalable format). This, however, will entail a greater initial complexity, requiring having to break with the standards and resources used by the university, to start new ones more adapted to the current ones.

As was mentioned before, once the infrastructure is available (digital platform + knowledge base), it is possible to incorporate the different tools available for both approaches. In the case of the advanced digital platform of the disruptive approach, in addition to the different IMTs, it will be possible to implement advanced technology intelligence services. In addition, thanks to the knowledge infrastructure created using ontologies, the generation of knowledge graphs both for obtaining new knowledge, and for easy monitoring and management, in the face of decision-making.

In the case of the digital platform generated through the incremental approach, in addition to the possibility of incorporating the different IMTs available, it is possible to use analysis of the behavior of the ecosystem actors using SNA (Social Network Analysis). However, unlike the disruptive case, the knowledge structure and digital platform do not allow the direct application of SNA. It is therefore necessary to apply new taxonomies that allow the representation of information in a format that enables the application of SNA techniques. The latter, obviously, adds a degree of complexity in the implementation and use of these tools, which coincides with what was previously expressed in Table 6.

Figure 18 summarizes the comparison of the complexity of implementation compared to the benefits that can be obtained for both approaches. The colors represent the degree of interest that this can have for a given university, according to the complexity and associated benefits.

Figure 18. Graduation of complexity vs benefits for the implementation of the incremental and disruptive approaches (source: own elaboration)

6.3 Incremental approach

6.3.1 Conceptual schema of the chapter

Figure 19. Conceptual schema of the Theory Background Chapter (source: own elaboration)

Blue color is used to show the main topics of the chapter. The main concepts of the topics are shown in black color. Orange color is used to show the key concepts of the main concepts. Finally, the case studies and results are shown by the green color.

6.3.2 Incremental approach description

As it was advanced in Chapter 3, innovation management techniques (IMT) can be defined as the range of tools, techniques and methodologies that help organizations, in a systematic way, to adapt and meet the challenges presented by the market (Phaal et al. al., 2006). In addition, IMTs are methodological approaches that help improve the competitiveness of organizations through the diagnosis of the organization's capacity and providing innovation into its structure (Skalkos and Bakouros, 2011).

Simplifying the innovation process a lot, as shown in Figure 20, this usually consists of the following phases or activities: Discovery, Technology demonstration, Development and Commercialization (Jackson, 2011).

Figure 20. Innovation process (Source: Jackson, 2011)

For each of the phases or activities of the process, there are IMTs that allow its management. Table 7 shows the relationship of the different types and tools of IMTs shown in Chapter 3 that have a possible application for the management of the corresponding phase or activity of the innovation process.

IMTs		INNOVATION PROCESS PHASES			
Types	Techniques	Discovery	Technology demonstration	Development	Commercialization
Knowledge management	Knowledge audits	XX	X	XX	XX
	Knowledge maps				
	Document management				
	Industrial Property Management				
Creativity development	Brainstorming	XXX	X	-	X
	Lateral thinking				
	TRIZ				
	Scamper method				
Market Intelligence	Technology watch	XXX	X	XX	XXX
	Patent analysis				
	Business intelligence				
	CRM				
	Geo-marketing				
Process improvement	Benchmarking	-	XX	XXX	-
	Workflow				
	Process reengineering				
	Just in Time				
Cooperation and networks	Team work	X	X	XXX	XX
	Equipment configuration				
	Supply chain management				
	Clusters				
Innovation project management	Project management	X	XX	XXX	-
	Project appraisal				
	Project portfolio management				
Human Resources	Tele-work	X	XX	XX	X
	Corporate intranets				
	On-line recruitment				
	e-Learning				
	Competency management				
Design management	CAD-CAM	X	XX	XXX	X
	Rapid prototyping				
	Usability techniques				
	Value analysis				

Interface management	R&D interface management – Marketing	-	XX	XXX	X
	Concurrent engineering				
Business creation	Business simulation	-	X	XX	XXX
	Business Plan				
	Spin-off				

Table 7. Innovation Management Techniques (IMT) classification with respect to innovation process (Source: own elaboration based on European Commission, 2005 and Jackson, 2011)

Of course, IMTs alone cannot solve the problems, ensure direct financial improvement, and correct the mistakes and the organizational problems of any organization. IMTs are only one part of the equation, but it is necessary to combine them with other methodologies and tools. The basic steps of each IMT methodology are the following: 1) collection of data, 2) analysis, 3) composition, and 4) report (Hidalgo and Albors, 2008). Therefore, taking into account the first step of data collection, to be able to use IMTs it is necessary to have a structure that provides the data of quality to be able to use this type of tools with the highest possible performance and success: the digital platform.

The relative value of the data is associated, above all, with the higher levels in which the applications developed on or provided by the digital platforms are capable of capturing, storing, analyzing, and valuing the data obtained from the interactions of the users or of internet devices of things. Most of the business models that new or consolidated digital organizations offer at this time use data transactions as a basis for creating value. It is not strange, therefore, that national and international regulations establish appropriate rules of the game to ensure the protection and good use of private data, as well as offering other public data in an open format so that, in turn, stimulate the creation of new value-added businesses on them (León et al., 2017).

Figure 21. Representation of an integrated innovation management system for universities using an incremental approach (Source: own elaboration)

Figure 21 depicts a representation of the pursued objective. It is expected that a system of these characteristics can offer its users valuable and varied information, as represented in Figure 21 with the "gold nuggets" with the label of "info". To fulfill this purpose, the system is composed of the following parts:

- **University databases** (and other sources of information belonging to the university). Given that this incremental approach is based on the resources available to the university to build the new integrated system of innovation management, the databases and other resources of the university should be taken into account and feed the system.
- **Digital platform.** As advanced in Chapter 4, new technologies play a double role in the development of universities, as threatening factors, but also as opportunities. Given that what is intended with the proposed system is to face the challenges, the use of digital platforms by universities can be a great step forward towards the objectives pursued, as they argue in their work, towards a change, which can be progressive, in its value chain.
- **IMTs.** The traditional idea that innovation was a closed approach process has been replaced by the current open model of innovation where social networks are formed between the different actors involved and where knowledge plays a crucial role (Bullinger et al., 2004),

as it could be seen in Chapter 3. Precisely, successful IMTs are those for which knowledge is a relevant part of the innovation process (Skalkos and Bakouros, 2011), that is, they participate actively in knowledge management, as shown previously in Table 7. In Figure 21, it can be seen a "layer of IMTs" that extract information from the digital platform, where they can best take advantage of all the knowledge generated within the system for analysis and management, as it combines the data received from the data bases of the university, the data related to the behavior and performance of the network (reflected from the ecosystem graph and SNA) and, consequently, from the ecosystem. In following points of this chapter, two new IMTs created to help manage one of the most relevant aspects within open innovation models will be shown: the selection of partners and the creation of profiles of other actors for the comparison and obtaining of good innovation practices.

- **APIs.** The application programming interface or APIs¹⁹, are formal specifications on how a module of a software communicates or interacts with another. In other words, APIs are a set of commands, functions and computer protocols that allow developers to create specific programs. The "solutions" developed on the APIs offered by the technical platforms can fulfill the role of final applications (directly instantiated by the users) or, on the contrary, also offer "high level APIs" on which the developers can generate very specific applications for a specific domain (León et al., 2017).
- **Ecosystem.** The ecosystem is a source of invaluable information for the integrated innovation management system. That is why the digital platform must maintain "a windows open" to the interaction and management of the ecosystem, the relationship with its actors, etc. In fact, as seen in Chapter 4, digital platforms enable interaction with the actors of the ecosystem, which exponentially increases the quantity and quality of data that can be obtained from this interaction for later use in decision-making.
- **Network analysis** (new taxonomies, ecosystem graph and SNA). Given that collaboration with other actors is crucial to face new challenges, understanding the behavior of both the network of the actors as a whole, and of each actor at a particular level is something basic and necessary. This type of information can enable decision-making to improve the ecosystem; for example, by indicating the need to add new policies that attract certain types of actors to the ecosystem, acting to improve their productivity as well as balance, fostering collaboration, eliminating bad operations or dysfunctions, etc. In below sections are

¹⁹ APIs https://en.wikipedia.org/wiki/Application_programming_interface

described in detail these new parts of the new proposed system, their usefulness and operation, for a better understanding.

6.3.3 Recommended steps for the implementation of the incremental approach

Although each university has its own characteristics (situation, dependency, resources, interests, strategy, etc.), this section shows a series of recommended, basic and rational steps to be able to conduct the successful implementation of an integrated system of Innovation management of incremental type.

Figure 22. Recommended steps for the implementation of the incremental approach (Source: own elaboration)

As discussed in the previous point, this incremental approach will be based on the resources and databases currently available to universities, for their adaptation and integration with the proposed new system. In particular, the steps necessary for its correct achievement are described below:

1. **University databases.** It is necessary to begin with a review, classification and ordering of the different information resources available to the university, which allow its connection and integration with a digital platform. For this, it is recommended to analyze, from a point of view or process of "digital transformation", how much information and what quality is available in digital format, as well as what information, even if not digitized, would be necessary or interesting for the institution digitize.

2. **Digital platform.** As shown in Figure 21, the digital platform will be the container and intermediary element of all communications, between the different parts or elements of the new integrated innovation management system. For this reason, and once all the necessary information resources and interest of the university are available in digital format, the digital platform will be fed with all that information (as well as other ecosystem information), allowing its classification and ordering, to make a better use and access to their data. In fact, this change is very important, because as will be seen in later sections within this chapter, through the digital platform will enable the change and improvement of the current value chain of services offered by the university for and with its different stakeholders, towards new ones conferred in the digital dimension.
3. **IMTs.** The availability of a well-powered digital platform with information from the different sources of information of the university, will allow the implementation and use of different IMTs. In particular, depending on the degree and quality of the digital platform implemented and recorded information, it will be possible to use different techniques such as those shown in Table 7. Thanks to this new "digital knowledge base", it will be possible to use tools for better management of the knowledge (knowledge maps, industrial property management, etc.), market analysis, clients, technology and competence (technology watch, CRM, etc.), human resources management of the university (e-learning, on-line recruitment, competency management, etc.), among others. The use of one or other IMTs will ultimately depend on the university and its opportunity.
4. **APIs.** The use of APIs allows endless possibilities of creating new services or connection with other existing applications that can get the most out of the knowledge of the system.
5. **Network analysis.** The application of new taxonomies for the representation of the different actors of the university-driven innovation ecosystem in graph format, as well as the use of analysis tools such as SNA (for an extension of the behavior and interaction information of the different actors, between them and with their environment), will confer a new degree of action to the university for its analysis and decision-making in the ecosystem. Specifically, the new information obtained through the monitoring and analysis of networks will allow, as will be shown in later sections, the creation of new metrics and indicators (in addition to the use of others of a more general nature), for better monitoring, analysis and, consequently, significant improvement in decision-making.

In the identified parts of the integrated innovation management system depicted in Figure 21, ecosystems have already been discussed (Chapters 3 and 4). The APIs, on the other hand, have been briefly described when listing the parts of the integrated innovation management system; being "software pieces" customized according to specific needs, it is not deepened in its description within this work. In the following points of this chapter, two new IMTs for the management of vital aspects of open innovation will be presented. Then, the university seen as a digital platform, in the context of Europe, will be presented in greater detail (with the objective, in addition to an improvement of its management, to offer its services and interaction with the ecosystem). Also will be shown below, the part dedicated to representation and network analysis of the ecosystem modelled, through two new taxonomies and SNA or Social Network Analysis techniques.

6.3.4 IMTs for Open Innovation contexts

The following points show new methodologies recently created within an international project conducted by Universidad Politécnica de Madrid with Facebook Connectivity Lab, which respond to major current challenges in the context of open innovation, such as open innovation partners' selection and open innovation models profiling.

6.3.4.1 New methodology developed for partner's selection in Open Innovation contexts

Open innovation for R&D activities conducted by multinational organizations is usually carried out at the international level looking for specific knowledge and complementarity of partners. One of the critical factors for success in open innovation activities is the "right selection of adequate partners" both for conducting bilateral activities or as a part of R&D consortia where several entities perform the activity (León et al., 2019). Potential partners differ profoundly in their interests and legal structure (e.g. universities, research centers, SMEs, large companies, etc.), and must be carefully compared to select the most appropriate one.

The use of open innovation (OI) models for R&D activities (Chesbrough and Euchner, 2011) is generally done internationally, with the aim of obtaining specific knowledge and the complementarity of potential partners in priority geographical areas. One of the critical factors for success is "the right selection of appropriate partners" for specific open innovation activities (Bengtsson et al., 2015), both to carry out bilateral R&D activities between the organization and the external partner, or as part of consortia where the R&D activity is carried out by several entities that perform different roles and tasks. Here it is necessary to highlight that this case of open innovation

is different from the more conventional case and known as "subcontracting" of some activities following detailed specifications. In open innovation, both parties share risks and assume certain degrees of uncertainty (Brunswick and Chesbrough, 2018).

In the implementation of open innovation models, leading organizations must identify and select the most effective external partners worldwide, according to their adaptation to the technical challenge to be solved and their availability to use open innovation schemes (Bengtsson et al., 2015; De Faria et al., 2010). Sometimes, the leading organization should focus on geographic areas where the interest of the open project is greater (for example, closer to the target market or where there is a concentration of potential partners) or, on the contrary, to focus on highly specialized partners (when they need specific technical knowledge, regardless of contextual restrictions).

Leading companies that conduct open innovation schemes with universities or research centers (Warnke et al., 2016) are aware that an incorrect selection of external partners may endanger all open R&D activity (Greco et al., 2016). In addition, an incorrect selection of partners introduces a high risk factor in the efficiency of open innovation models, which must be identified, characterized and mitigated, if necessary, with specific measures. This situation requires a very careful definition of specific and efficient management procedures adapted to the type of organization, external partners and OI activities.

The methodology showed below use a semi-quantitative approach to measure the "differences" (a metrics based on "proximity" is defined) to analyze and compare between different partners from several dimensions: previous experience in open activities, technical proximity, cultural compatibility, etc. The goal is to select external partners with the "minimum distance" to the leading organization. The proposed selection metrics were applied to some open research projects launched with university partners in three Latin American countries (Mexico, Chile, and Peru) where the UPM was conducting open innovation activities framed in a larger UPM-FBCL agreement²⁰. This new methodology is framed within the IMT types "Cooperation and networks" and "Innovation project management", which were shown in the Table 7.

²⁰ This work has been done in the context of the Sponsored Research Agreement (SRA) between Facebook Connectivity Lab (FBCL) and the Universidad Politécnica de Madrid (UPM) in the research project: "Analysis and Development of International Open innovation models and networks".

Organizations opening R&D activities assess the adequacy of the partner regarding its readiness to be involved in one open activity in two steps:

- 1) *Closeness to the organization*. Use of public information on the potential partner (obtained without a bilateral formal contact to get it). The leading organization will interpret results in their own context without sharing information with external partners.
- 2) *Technical adequacy to the challenge*. Readiness to address one activity by transferring to previously partners identified the minimum information to accomplish the task (if necessary, by signing specific NDAs²¹ to share information).

The task of selecting the best partners (i.e., to choose the most adequate external entity to find a solution of a given technical challenge open to the community of external partners) with previous knowledge and experience closer to the stated technical problem, and with the right set of skills (even the cultural ones) is conceptually defined as a framework for guiding the selection process. To support this process, the concept of “distance-based metric” between the organization leading the OI and the potential partner is proposed, as a semi-quantitative technique to test the adequacy of a partner for a specific type of open R&D activity. The selection process is performed by measuring at what extent some target entities are ready to participate in the open technical activity proposed by the leading organization. The selection approach postulates that the adequate partner should be the entity with the smallest distance to the OI leading organization for one specific challenge. Figure 23 depicts this concept for one simple case of technical challenge.

²¹ Non-disclosure agreement.

Figure 23. Logical distance between the leading organization and external partners with respect a given challenge (Source: León et al., 2019)

The distance between a firm and a partner to solve one specific challenge is interpreted in this document as a variable depending on several factors. The factors related to the “closeness to the organization” are the following:

- (G) “*General level of technical knowledge*” of the partner on the interests or activities developed by the leading organization. It includes the technologies that are well known by the partner related to the activities or interests of the leading organization. Value assignment: Maximum value (5) when the technical knowledge of the partner with respect to the interests or activities developed by the leading organization is low or very low; Minimum value (1) when the partner's knowledge fully covers the interests or activities developed by the leading organization.
- (R) “*Relationship with the partner*”, based on previous experiences by the partner with the leading organization and the Hub (an organization that may acts as intermediary between the leading organization and the partner, if exists) and cultural diversity. The intention with respect to the cultural diversity is to capture at what extent the diversity in working procedures, values for cooperation, etc. between the leading organization and the partner could condition the success. Value assignment: Minimum value (5) when the relationship is practically nil or ill-formed and cultural diversity is not relevant at all; Maximum value (1) when the relationship is very close and cultural diversity is key.

Table 8 describes the values of P1 to P4 based on the above identified factors for the closeness to the leading organization.

	(G) General Level of technical knowledge		(R) Relationship		"Closeness to the organization" value
P1 (Partner 1)	WC1 ²²	1-5	WC2	1-5	$\sum$ columns
P2 (Partner 2)	WC1	1-5	WC2	1-5	$\sum$ columns
P3 (Partner 3)	WC1	1-5	WC2	1-5	$\sum$ columns
P4 (Partner 4)	WC1	1-5	WC2	1-5	$\sum$ columns

Table 8. Data from partners' closeness to the leading organization (source: León et al., 2019)

On other hand, the identified factors related to the "*technical adequacy*" to the challenge are as follows:

- (S) "*Specific level of technical knowledge*" of the partner on the problem(s) behind the proposed technical challenge (usually in terms of the category of the technical challenge). It includes the technologies that are well known by the partner, the methods used to develop related products/services, the researchers' skills, the demonstrated experience in research projects, highly cited articles, patents filed, etc. Value assignment: Maximum value (5) when the technical knowledge of the partner needed to solve the challenge is low or very low; Minimum value (1) when the partner's knowledge fully covers the needs to solve the challenge.
- (C) Characterization of the "*solution's complexity*" concerning the given challenge proposed by the leading organization; to do that, the partner requires to access to challenge information to be able to elaborate a technical solution's proposal. Furthermore, it includes aspects like cultural bias to find a solution (including ethical aspects), previous experience in academia-industry cooperation, internal access to resources (both human and material), etc. Value assignment: Maximum value (5) when the technical solution proposal presented by the partner is poor; Minimum value (1) when the technical solution proposal is close to the leading organization expectations or overcome them.
- (T) "*Time/deadline*" to provide a solution to the open technical challenge based on the partner's capabilities or, if necessary, by joining forces with other entities in order to complement knowledge or facilities. Time to provide a solution to an open challenge is also related to the available resources put on the table by the partner, and it also depends on the available budget and facilities. Value assignment: Since this value is expressed in terms of percentages of "improvement" with respect to deadline, 1 (minimum value) means that the development time corresponds to the deadline (or even lower), 2 between 100-90%, 3 between 90-80%, 4

²² Weights for closeness to the leading organization (WC).

between 80-70% and 5 (maximum value) less than 70% (it is far away of the leading organization's expected time).

- (B) “*Budgetary resources*” allocated to the partner by the leading organization (both in kind and in cash) and the difference with respect to the budget requested by the partner to develop the proposed solution. To simplify the discussion, we assume that some maximum budget to address the challenge is known by potential partners²³. Value assignment: In the same way that the factor time/deadline, due this value, is expressed in terms of percentages of “improvement” with respect to the maximum budget, 1 (minimum value) means that the request budget corresponds to the maximum allowed budget (or even lower), 2 between 100-90%, 3 between 90-80%, 4 between 80-70% and 5 (maximum value) less than 70% (it is well above the estimated budget).
- (E) “*Engagement with stakeholder*” of the possible partner with respect to target of the challenge. This factor tries to capture at what extent the engagement with stakeholder is important to get the success of the challenge. In concrete, this factor will be based not only on the knowledge of the target (geographical area, people, regulation, etc.), but also contacts with public entities, e.g. local government, and private organizations (providers, support, etc.). Value assignment: Maximum value (5) when the engagement with stakeholder is not relevant for the success of the project; Minimum value (1) when the engagement with stakeholder is key for the success of the project.

Table 9 describes the framework to define the relative distances of partners *P1* to *P4* based on the above identified main factors for the identified challenge.

	(S) Specific Level of technical knowledge		(C) Challenge solution complexity		(T) Time versus deadline		(B) Resources requested v max budget		(E) Engagement with stakeholder		“Technical adequacy to the challenge” value
P1 (Partner 1)	WT1 ²⁴	1-5	WT2	1-5	WT3	1-5	WT4	1-5	WT5	1-5	$\sum$ columns
P2 (Partner 2)	WT1	1-5	WT2	1-5	WT3	1-5	WT4	1-5	WT5	1-5	$\sum$ columns
P3 (Partner 3)	WT1	1-5	WT2	1-5	WT3	1-5	WT4	1-5	WT5	1-5	$\sum$ columns
P4 (Partner 4)	WT1	1-5	WT2	1-5	WT3	1-5	WT4	1-5	WT5	1-5	$\sum$ columns

Table 9. Data from partners' proposed solutions to a challenge (source: León et al., 2019)

²³ It is true that one organization's strategy is to hide this figure (keep it unknown for potential partners, at least, at the beginning of the negotiation process).

²⁴ Weights for Technical adequacy to the challenge (WT).

Then, the “logical distance” between one leading origination and one partner for one specific technical challenge is expressed as:

$$d_i (\text{leading organization, challenge, } P_i) = \text{Square root } ((\text{“Closeness to the organization factors”} \times \text{Weights})^2 + (\text{“Technical adequacy to the challenge”} \times \text{Weights})^2) = \sqrt{((WC1 \times Gi) + (WC2 \times Ri))^2 + ((WT1 \times Si) + (WT2 \times Ci) + (WT3 \times Ti) + (WT4 \times Bi) + (WT5 \times Ei))^2}$$

Figure 24 depicts an example of the numbers obtained from the application of this method to six potential partners.

	(1) Closeness to the firm		(2) Technical adequacy to the challenge					Closeness value (Gi x WC1 + Ri x WC2)	Technical value (Si x WT1 + Ci x WT2 + Ti x WT3 + Bi x WT4 + Ei x WT5)	Distance di (firm, challenge, Pi)	Bubble size
	(G) General level of technical knowledge	(R) Relationship	(S) Specific level of technical knowledge	(C) Solution's complexity	(T) Time / deadline	(B) Budgetary resources	(E) Engagement with stakeholder				
	(WC1)	(WC2)	(WT1)	(WT2)	(WT3)	(WT4)	(WT5)				
Weights	0.5	0.5	0.2	0.2	0.2	0.2	0.2				
PARTNER 1	5	1	2	4	2	5	2	3.0	3.0	4.2	6.8
PARTNER 2	2	3	5	5	5	3	5	2.5	4.6	5.2	5.5
PARTNER 3	4	5	5	5	3	5	1	4.5	3.8	5.9	4.9
PARTNER 4	2	4	5	3	5	5	1	3.0	3.8	4.8	5.9
PARTNER 5	1	2	1	5	1	1	1	1.5	1.8	2.3	12.2
PARTNER 6	4	3	5	5	5	5	5	3.5	5.0	6.1	4.7

Figure 24. Detail of the evaluation data for the example of “distance” between the leading firm and external partners with respect to a given challenge (Source: León et al., 2019)

Figure 25 depicts the result of application of partner’s selection tool to the twelve potential partners pre-selected from Chile, Mexico and Peru, within the UPM-FBCL project, in order to assess the main factors: closeness to the firm and technical adequacy to the challenge.

Figure 25. Result of the application of partners' selection tool to LATAM universities within the UPM-FBCL project (Source: León et al., 2019)

Thanks to this IMT, the most suitable partners were selected to conduct the projects in Chile, Peru and Mexico, within the framework of collaboration and projects between UPM and Facebook (León et al., 2019). Some lessons learned from this experience:

- The creation of the adequate framework between the leading multinational organization launching open innovation R&D activities and the primary node entity to expand open innovation networks at international level requires substantial effort, time and high level of mutual trust.
- The identification of the right individual interface is a key factor for success. It requires to identify an internal empowered person (the open innovation champion) to remove institutional obstacles and to speed-up agreements from the technical and managerial perspectives.
- As it clearly stated in multiple cases of OI implementation, if champions were well-known (e.g. they had previous cooperation and scientific mutual recognition), time and effort is substantially reduced.
- Extrapolation of proximity with respect to one specific research group to the whole entity is not immediate. Mutual trust and confidence are firmly anchored in personal acquaintances between two entities' research groups, but it does not necessarily apply to other research

groups in institutions with considerable autonomy degree for research and innovation cooperation.

- The selection of an entity as an intermediate node implies a double qualification process: 1) to be able to conduct some specific open R&D activities bilaterally with the OI leading firm and 2) to control the execution of projects to other entities in the next level.
- Benefits of the proposed proximity-based metrics approach would grow-up over time if abundant data were collected during OI experiences. Then, it is necessary to embed a set of pilot projects monitoring management procedures as part of the OI methodology definition effort. To address this issue, the monitoring effort carried out by the UPM was decomposed in two components: 1) technical monitoring to ensure the smooth development of the contracted tasks and 2) OI monitoring to extract enough lessons to share with Facebook Research. This second component had as primary goal to extrapolate the approach used to other LATAM partners in the same countries, in other LATAM countries and in other geographies where international OI networks were needed.

6.3.4.2 New methodology for profiling and comparison of Open Innovation models

Since 2003 when Prof. Chesbrough coined the term “open innovation” (Chesbrough, 2014; Chesbrough et al., 2006; Chesbrough et al., 2003) to refer to a *“new way of understanding the fast and deep evolution of many companies looking for external talent and partners to conduct their work in a more efficient and flexible way”*²⁵, many variations and implementations have been tried and partly or fully implemented by very diverse type of public and private entities over the world²⁶.

The rationale behind the movement towards the adoption of open innovation models was similar in all cases: many organizations (both public and private) realized that they cannot find internally all the knowledge they need to develop on time advanced products and services to keep competitiveness in a context of fast market and technology evolution; then, they liked to get more

²⁵ The formal definition used by Henry Chesbrough was as follows: *“the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively”*. A more recent definition from the same author (Chesbrough et al., 2014) is as follows: *“a distributed innovation process based on purposively managed knowledge flows across organizational boundaries, using pecuniary and non-pecuniary mechanisms in line with the organization's business model”*

²⁶ A simple search of the term *“open innovation”* in Google obtained 549.000.000 results (September 10, 2018). This huge number of results shows the wide diffusion of the term but also that behind it many differences and subtle variations are hidden. Probably, specialization approaches of the whole field of open innovation will emerge in the near future (e.g. for SMES, in the public sector, for R&D, etc.) in order to adapt specific procedures and lessons learned in different contexts.

flexibility in internal processes in order to identify and take advantage of complementary or disruptive results and market opportunities by cooperating with external partners. The same approach was applied in motivating and supporting their own staff to launching new tech-based business units too.

Today, many large entities feel that higher visibility within potential partners and the need to improve world-wide positioning in one industrial sector became driving factors to embrace open innovation in “non-core activities” (Fu et al., 2017; Morikawa, 2016; Albano, 2016; Chesbrough and Brunswicker, 2013; Van de Vrande et al., 2009). These concepts were applied not only to ICT or industrial sectors but also in pharma sectors (Schuhmacher, 2018).

The discussion about the “old-new” features of the open innovation term²⁷ and the relevance and impact on the organization strategy and processes has advised scholars to define and use the concept of “openness degree” (described below) as a key feature for characterizing open innovation processes within an entity when a single set of processes is not applicable for everything.

Notice that the case of “Wikipedia” could be considered as the maximum level of openness degree because all the contents uploaded is generated by external voluntary (non-paid) “collaborators”. This extreme case is not the usual one when companies like to enter in the market with their own products and services (with or without external partners) and respond on the quality of products and services in front of users and regulatory bodies²⁸.

In the case of open innovation activities involving the interaction between industry and academia, the operating contexts of both types of entities are very different and substantial effort is needed to set-up a common cooperation framework, where both parties should obtain clear benefits from the activity. This context is highly asymmetric where leadership of the cooperation is in the hands

²⁷ Several scholars have criticized the concept of open innovation with the argument that companies were never using a pure “closed model” and then the division between open and closed is somewhat artificial. Chesbrough reacted saying that some factors have deeply changed *“influencing the conditions under which innovation takes place (e.g., increased mobility of workers, more capable universities, declining U.S. hegemony, and growing access of startup firms to venture capital), giving rise to a new paradigm. It does not imply that individual elements of open innovation were absent in the earlier paradigm, but rather that they now combine to form a new paradigm to manage innovation”*. Probably, this sentence is true when open innovation models were fully implemented in a given firm and less evident in cases where openness degree is lower, or the process is restricted to one unit or department with marginal impact on the global business model. Don’t forget that open innovation is also used for marketing purposes.

²⁸ The issue of quality control in open innovation schemes has received attention. In the case of Wikipedia, the implementation of an open quality control where contributors refine contributions is an essential ingredient of its success.

of the firm, while the academia (the attention will be focused here on universities) plays a reactive role participating in some open innovation activities launched and funded by the firm.

The diversity in open innovation models and the different capabilities to successfully conduct them, advises us to define and use a more detailed concept of “open innovation profile” as a basis for comparison between potential open activities. Profiling process means that some dimensions are more relevant than others to increase the success of the activity and a prior knowledge of them constitute the basis for good management. One of the intuitive concepts behind this profiling is the “openness degree” (Lazzarotti et al., 2011). It refers to the quantification of the level of open activities found in one organization.

Based on Table 10 (Öberg and Alexander, 2018), it could be suggested that openness could be considered as the combination of several low-level dimensions (Henkel et al., 2014; Chesbrough and Appleyard, 2007). A network or ecosystem that is not formalized (for instance, different actors come and go from the network or ecosystem) and includes different competences that participate in shared activities, would indicate the most far reaching openness, but is not necessarily the most adequate one for research and innovation purposes.

<u>Openness</u>	<u>Description</u>	<u>Scholars</u>	<u>In the paper defined as</u>
Breadth	The more different the competences, the more open.	Idrissia et al. (2012)	Heterogeneity in skills of contributors (they are not the same type of actors).
Depth	The deeper the knowledge, the more open.	Idrissia et al. (2012)	Expertise of contributors is high.
Freedom, lack of formalization	The freer the collaboration, the less formalized, the more open.	Herzog (2008), Aslesen and Freel (2012)	Arrangement based on voluntary participation. Contracts not main deal.
Number of phases	The more phases the parties are included in, the more open.	Lazzarotti and Manzini (2009)	More than one phase covered in the innovation process.
Number of actors	The more parties, the more open.	Lazzarotti and Manzini (2009)	More than two actors involved.

Table 10. Dimensions of “openness” (Source: Öberg and Alexander, 2018)

Table 10 considers five dimensions of openness that are relevant to classify specific cases from a holistic view of the company capacity to embracing open innovation. Specifically, it proposed to add

three additional dimensions to assess the impact of the use of open innovation schemes on one given organization, which are not included in the previous five ones:

- Percentage of external funding sources. It refers to the source of the money to work in an open innovation way. Typically, this case occurs when one company is “forced” to work in open innovation projects due to constraints imposed by public administrations funding the project (e.g. putting as a compulsory condition to be funded to conduct the research work in cooperation with an academic research entity).
- Percentage of R&D projects framed in open innovation projects. It refers to the relative importance in the firms’ activity. If only a 1% of projects follow the open innovation logic, the impact of the whole company is very low (usually, an ad hoc management procedure is set-up for that project while not disturbing the rest of management).
- Percentage of R&D economic resources. It complements the previous one from the economic volume involved. Only one open innovation project could involve a large percentage of the R&D resources; then, its impact will be high.

Then, based on the eight identified dimensions, the “open innovation profile” of a specific R&D department can be represented as a “radar diagram”. Figure 26 depicts two fictitious cases that correspond to two companies that exhibit very different openness degrees (blue and red ones). Each dimension has an associated value (qualitative grade between a maximum and a minimum) which is a semi-quantitative approach to the dimension.

Figure 26. Open innovation profiles (Source: own elaboration)

In the example of Figure 26, the red case corresponds to one company where open innovation plays a major role in its institutional strategy with impact on a relatively large number of projects and resources; even when the source for funding of the open activities, comes from the company itself and it is broadly focused.

The blue case refers to one company where a limited number of projects by involving a few numbers of resources is using open innovation (maybe stimulated or imposed by an external funding source as a public administration as happens with the EU in consortia-based projects²⁹). Furthermore, the way of using open innovation is constrained by external procedures (low level of freedom) and with a limited number of actors.

The “values” associated to each dimension corresponds to the result of a qualitative process; in practice, values could be obtained by using a collective process where several persons with different background and positions could provide their own views (and weighted opinions are used for giving values for the dimension). This is typically performed through a panel activity.

Can be postulated that the innovation profile dictates the most appropriate management structure. Then, the characterization of the open innovation profile of one specific activity is the basis for managing it within an organization. The same set of management procedures cannot be optimized for open innovation activities with very different profiles and grouping of activities is necessary for complexity control.

If the interest of the characterization process is focused on one specific type of open activity (e.g. R&D), it could be necessary to identify additional factors. In the case of R&D, the maturity of the technology and its external access should feed-up the valuation of “breadth” and “depth” dimensions. The consequence is the need to manage several subsets of internal procedures within a given company when the open innovation activities to be managed are very diverse. Guidelines for choosing one specific set is a matter of decision at the company level.

Figure 27 shows the whole process of the methodology designed and followed for the profiling process and comparison of the companies’ profile.

²⁹ Be aware that the EU is enforcing the use of consortia-based models to push the creation of a common European views. For that reason, consortia should be composed by entities from a number of different Member States.

Figure 27. Methodology used to the comparison of Open Innovation models of companies (own elaboration)

In the above figure, we can see that the process begins with data obtained from secondary sources of information. In order to improve the methodology, primary sources of information can be used to feed-up the process and getting more objective and adjusted results: 1) assignment of values to each company profile (based on answers provided by the own companies) and 2) definition of the comparison of the companies (ranking), prioritized by the leader organization interests and approach.

The open innovation information of the companies can be collected from company's websites, reports, etc. The process followed is detailed from the variables definition, where the open innovation models of the organizations can be defined using the following dimensions:

- *Breadth*

- Variable description: This is referred to the variety of competences and skills that usually the participants of innovation projects have. Therefore, the higher amount of skills and competences of the contributors in innovation projects (more heterogeneous, broader), the more open the innovation model is.
- Maximum value = 5; Maximum value description: The amount of skills and competences of the contributors in innovation projects is usually very high.
- Minimum value = 1; Minimum value description: The amount of skills and competences of the contributors in innovation projects is usually very low.

- *Depth*

- Variable description: This is referred to the level of expertise of the contributors of innovation projects (if they are more specialized in the topics treated in the project,

they have more knowledge about those topics, so they can offer more options to collaborate/work into the project). Therefore, the higher level of expertise of the contributors in innovation projects (more deep), the more open the innovation model is.

- Maximum value = 5; Maximum value description: The level of expertise of the contributors of innovation projects is usually very high.
- Minimum value = 1; Minimum value description: The level of expertise of the contributors of innovation projects is usually very low.

- *Freedom*

- Variable description: The freer the collaboration in innovation projects (less formalized; for instance, arrangement based on voluntary participation), the more open the open innovation model is.
- Maximum value = 5; Maximum value description: Innovation projects are usually formalized in a very high level.
- Minimum value = 1; Minimum value description: Innovation projects are usually formalized in a very low level.

- *Nº of R&D development phases covered*

- Variable description: The more phases the parties are included in innovation projects, the more open is the innovation model.
- Maximum value = 5; Maximum value description: The number of phases included in innovation projects is usually very high.
- Minimum value = 1; Minimum value description: The number of phases included in innovation projects is usually very low.

- *Nº of actors involved*

- Variable description: The more parties involved in innovation projects, the more open is the innovation model.
- Maximum value = 5; Maximum value description: The number of actors involved in innovation projects is usually very high.
- Minimum value = 1; Minimum value description: The number of actors involved in innovation projects is usually very low.

- *% of external funding sources*

- Variable description: It refers to the source of the money to work in an open innovation way. Typically, this case occurs when one company is “forced” to work in open innovation projects due to constraints imposed by public administrations funding the project (e.g. putting as a compulsory condition to be funded to conduct the research work in cooperation with an academic research entity).
- Maximum value = 5; Maximum value description: The amount of external funds in innovation projects is usually very high.
- Minimum value = 1; Minimum value description: The amount of external funds in innovation projects is usually very low.
- *% of economic resources*
 - Variable description: It complements the previous one from the economic volume involved. Only one open innovation project could involve a large percentage of the R&D resources; then, its impact will be high (the open innovation model is more open).
 - Maximum value = 5; Maximum value description: The percentage of the R&D resources framed in open innovation projects is usually very high.
 - Minimum value = 1; Minimum value description: The percentage of the R&D resources framed in open innovation projects is usually very low.
- *% of R&D projects*
 - Variable description: It refers to the relative importance in the firm’s activity. If only a 1% of projects follow the open innovation logic, the impact on the company is very low (so, the open innovation model is less open).
 - Maximum value = 5; Maximum value description: The percentage of R&D projects framed in open innovation projects is usually very high.
 - Minimum value = 1; Minimum value description: The percentage of R&D projects framed in open innovation projects is usually very low.

The definition of values to the variables of companies is important to describe the extreme values for each variable, in order to facilitate its measurement and comparison. The rationale used in the above definition:

- Minimum value
 - Value: We define the minimum value as 1 point for all variables.

- Description: this value it related to... (it is depending on each variable)
- Maximum value
 - Value: We define the minimum value as 5 point for all variables.
 - Description: this value it related to... (it is depending on each variable)

The competitive matrix tool can be used to generate the open innovation companies' comparison matrix. A competitive profile matrix³⁰ classifies a firm's major competitors and its meticulous strengths and weaknesses in relation to an illustration firm's strategic point. Using this matrix is possible to evaluate the company as well its competitors by giving weights and rating to their critical success factors, then identify their strategic competitive position with their competitors. Thus, the company that gets a higher weighted score would have the strong competitive position compared to its competitors.

		Wal-Mart		Kmart		Target	
Critical Success Factors	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Advertising	0.25	3	0.75	3	0.75	4	1
international Expansion	0.20	4	0.80	3	0.60	2	0.40
Financial position	0.15	4	0.60	2	0.30	3	0.45
Price competitiveness	0.15	4	0.60	3	0.45	3	0.45
Customer Loyalty	0.10	3	0.30	2	0.20	3	0.30
Product Quality	0.10	3	0.30	2	0.20	4	0.40
Market Share	0.05	3	0.15	1	0.05	3	0.15
Total Score	1.00		3.50		2.55		3.15

Table 11. Competitive profile matrix (Source: MBA-lectures³¹)

In the specific case of the UPM-FBCL project, using the competitive profile matrix approach and assigning weights to the eight variables defined above, it is possible to generate a comparison matrix of open innovation models. The matrix then multiplies each value of the variables by the respective weight assigned, so all organizations can appear prioritized by Facebook's interests. In this stage of the process, a preliminary order of the weights (importance of variables) can be conducted, assigning values to the weights based on a priority order of the variables. The values of the weights

³⁰ Competitive profile matrix <http://mba-lectures.com/management/strategic-management/977/competitive-profile-matrix-for-wal-mart.html>

³¹ <https://mba-lectures.com/tag/competitive-profile-matrix-cpm>

must be retrieved from Facebook in order to gain their desired level of interest within each dimension; for instance, using secondary sources of information about Facebook. A preliminary assignment of the weights can be as follows:

Variable	Priority order (importance)	Weight
Breadth	1	0,22
Depth	2	0,19
Freedom	3	0,17
Nº of R&D development phases covered	4	0,14
Nº of actors involved	5	0,11
% of external funding sources	6	0,08
% of economic resources	7	0,06
% of R&D projects	8	0,03

Table 12. Example comparison matrix of companies' Open Innovation models based on a "priority order" defined (own elaboration)

Using the information gathered about companies, values can be assigned to the variables of each company and their respective profiles drawn. An example of comparison between two companies is shown below (the data of these examples are invented), to illustrate its purpose and possibilities:

Figure 28. Invented example of Amazon's profile (source: own elaboration)

Figure 29. Invented example of Nasscom's profile (source: own elaboration)

Example of profiling: Amazon vs Nasscom

Variables (for Open Innovation profiling)	Weight (by Facebook)	Amazon		Nasscom	
		Value	Weighted score	Value	Weighted score
Breadth	0,15	2	0,75	2	0,3
Depth	0,10	3	0,4	3	0,3
Freedom	0,15	5	0,6	1	0,15
Nº of R&D Development phases covered	0,25	1	1	2	0,5
Nº of actor involved	0,10	3	0,5	5	0,5
% of external fundin sources	0,05	4	0,15	4	0,2
% of economic resources	0,15	2	0,75	2	0,3
% of R&D projects	0,05	1	0,15	3	0,15
Total Score	1.0	-	4,3	-	2,4

1st

Table 13. Example of comparison matrix between two companies' Open Innovation models using invented data (source: own elaboration)

In Table 13, it can be seen that Amazon could be closer to the Facebook's interest, due to the weights assigned to the variables. Since the ranking of companies are created based on secondary sources, the methodology can be improved using more objective and real information from primary sources. In this sense, it is possible to design a questionnaire, in order to send to the companies and receive a better picture about their open innovation models. A sample of the questions is shown below, in the Figure 30.

*Obligatorio

Questions

1) How broad is your open innovation model? (Breadth) *

This is referred to the variety of competences and skills that usually the participants of my innovation projects have. Therefore, the higher amount of skills and competences of the contributors in my innovation projects (more heterogeneous, more broad), the more open the innovation model is. (5) MAXIMUM VALUE: The amount of skills and competences of the contributors in my innovation projects is usually very high. (4) Value: The amount of skills and competences of the contributors in my innovation projects is usually high. (3) Value: The amount of skills and competences of the contributors in my innovation projects is usually more or less balanced. (2) Value: The amount of skills and competences of the contributors in my innovation projects is usually low. (1) MINIMUM VALUE: The amount of skills and competences of the contributors in my innovation projects is usually very low.

1 2 3 4 5

☐ ☐ ☐ ☐ ☒

Figure 30. Question belonging to the questionnaire (source: own elaboration)

Using the information gathered about each company through their responses to the questionnaire, the updated and final profiles of the companies can be updated. Based on the new profiles, which are updated using the information provided by the companies through their answers to the questionnaire, a ranking of the companies can be generated. Table 14 shows a ranking belonging to one of the iterations within the UPM-FBCL project.

Company	Country	Sector	Breadth score	Depth Score	Freedom Score	No of R&D development covered phases	% of external funding sources score	% of economic resources score	% of R&D projects	Total Score
LG Electronics	S. Korea	Manufacturer	3	3	4	2	3	1	1	2.25
Intel Corporation	USA	Microelectronic	5	4	3	2	2	1	3	2.88
Accenture	USA	IT services	4	4	3	3	4	1	2	2.88
Vodafone	United Kingdom	Telco operator	3	3	3	4	3	1	3	2.88
BBVA	USA	banking	4	4	3	3	4	1	4	3.25
NASSCOM	India	Innovation services	4	5	2	2	3	5	3	3.38
IBM	USA	IT services	5	5	5	4	4	2	3	3.75
Telefónica	Spain	Telco operator	4	4	3	4	5	4	4	4.00

Table 14. Ranking of companies' Open Innovation models based on survey responses in UPM-FBCL project (source: own elaboration)

6.3.5 University as a platform

Mainly, attention should be paid to the way that European public universities could perform better their social mission in the future. For that objective, the equivalent of the “value-chain model” widely used as a useful analysis tool in other economic sectors (Gereffi and Fernandez-Stark, 2016, Normann and Ramirez, 1993), can be also applied to analyse the evolution of the high-level academic sector.

The analysis in this section will be focused on European public universities, although many of the insights could be also applied to private universities, which have inherited similar approaches. In fact, this distinction is blurring. The present public university-based education value-chain model used by European universities can be summarised as follows:

1. **The academic offer** of European universities is defined by themselves, but within the legal framework set-up by governments, to ensure quality and social/governmental recognition of their graduates. The flexibility degree to define in detail the academic offer depends on national and regional regulations (ranging from national-wide to simple university recognition of their own academic degrees³²), on the internal capacities and adequate market analysis to attract students, and on the academic offer to give students the maximum employability once graduated.
2. **Academic degrees** are implemented by individual universities, by using their own staff and implemented in their proprietary (non-shared) premises, with facilities for teaching and research obtained from several sources: University premises visibility is a must to attract students. Academic offer jointly designed by two or more universities to receive a single university degree is still an exceptional case in undergraduate courses, although it is becoming more common for master’s degrees (León, Leceta and Tejero, 2017).
3. **The awareness and marketing of the academic offer** to potential targeted students is made by universities themselves to cover the annual offered places. This process has a limited impact on the budget of the public universities due to the low tuition fees imposed by governments and because there was an implicit market segmentation, where the allocation of students to specific universities is based on geographical concepts of proximity.

³² This factor constitutes a key distinction between Anglo-Saxon and continental models of universities. In several European countries, the legislation indicates how to obtain an academic degree confers the graduate “professional rights” delegates to society (many engineering, architecture or medicine degrees provide that). In other cases, there is a clear separation between academic skills and professional rights.

4. **Student's decision** is made at the individual level based on his/her own interest to choose one university degree (criteria range from short-term views based on affinity and wishes on specific degrees, and long-term views based on potential employability and professional development related to the chosen degree). The final decision is also modulated by the qualifications obtained by students during high-school studies (or specific entry exams conducted by universities themselves when and where this system applies) and a number of factors like individual students' marks, geographic proximity, tuition fees, reputation of the university or chosen degree (rankings and/or word of mouth), and family pressures or economic constraints.
5. **Enrolment** in university courses in one university is got after fulfilling academic requirements (i.e. "numerus clausus" if it were the case, for the selected university degree) and the effective payments of tuition fees. Some control of physical presence of the students is also regulated although national cultural bias allows students' freedom to assist. For master's degrees, much more flexibility is available and advisable. Furthermore, the possibility to study in two or more universities to receive a single degree has increased in the EU with the expansion of the ERASMUS programme³³, with benefits beyond academic results. This issue relates to the internationalisation model of the university where students are not only local ones³⁴.
6. **Education processes** are conducted by using a mix of learning methods (e.g. face-to-face lectures, use of technical labs, seminars, project-based learning, groups' assignments, and the follow-up of on-line modules, blogs, etc.) individually applied to the most appropriate thematic subjects. A wise combination of these subjects constitutes the full academic year (with an allocation of 60 ECTS), and some academic years compose the curriculum for university degrees (3-4 years for university degrees and 1-2 years for master degrees depending on national regulations). In all cases, the responsibility of providing the subjects' contents relies on the university.

³³ https://en.wikipedia.org/wiki/Erasmus_Programme

³⁴ Knight (2015) describes a range of different internationalisation models including the classic model where the university engages internationally in a range of initiatives while remaining anchored in a national context, the satellite model where internationally based facilities extend the reach of the universities' activities into other countries and the co-funded model where multiple partners collaborate in the creation of hybrid universities.

7. **Grading** is performed individually by students through a set of evaluation processes which are conducted at individual level (group level evaluation can be also applied as a complementary grading process during the academic year) to assess if the pre-defined set of learning outcomes were well apprehended by enrolled students. Recent emphasis is placed on the application of continuous evaluation systems instead of the more traditional procedure based on written exams (usually concentrated at the end of each academic semester).

Figure 31 depicts the main interactions between the seven main steps of the higher education value-chain.

Figure 31. Simplified higher education value-chain (Source: own elaboration)

Two main actors, universities and public administrations, take the lead in the value-chain while other actors play complementary roles. Nowadays; the support for “external advice” offered by industry or other type of entities, or the participation of external experts in regular courses still have marginal weight in public university processes.

The wise combination of several technical drivers (derived from the wide availability of ICT-based solutions in the educational market and higher confidence in their advantages) and non-technical drivers (derived from the need of optimisation of resources and deeper society engagement where social networks and big data analytics will play a prominent role) for the evolution of universities will make the current situation an opportunity for public universities to increase their value for further socioeconomic growth.

Under this approach, it is expected that some of the educational services offered today by universities through conventional processes will be provided as renewed “educational services accessed through sophisticated education platforms open to the cooperation with other stakeholders”.

A “university education platform” is conceived in this work as a conceptual tool where a number of seamless IT-powered higher education services are smoothly provided by a set of interrelated public and private stakeholders, which are coordinated by a public university playing a key role to generate skilled high-quality professionals on behalf of society demands with loose requirements of physical and timing synchronisation.

This operational definition of “university education platform” widens the conventional approach of university activity in two main directions:

- 1) The need to design and provide higher education services with the deep participation and commitment of other stakeholders in the university ecosystem, and
- 2) The intensive use of IT solutions as a key element of the value chain to optimise resources and to be able to offer high-level customised services for students.

The “university education platform” concept is borrowed from recent developments of the “collaborative economy” (COM, 2016b; COM, 2016c) where many actors are able to create added value in a number of economic sectors by introducing deep changes in traditional value-chains through the use of digital platforms.

This “university education platform” concept cannot be confused with simply providing all higher educational activities through a digital platform. The concept of “university platform” is richer and more complex because it needs to be interpreted in a dynamic university ecosystem regardless the technology used to provide services.

Figure 32 reflects the transition process from the actual context and the future context, where the university education platform concept became a reality. The left side of Figure 5 expresses the current situation where the academic offer is conceived, made public and implemented (by following the rules set-up by the governmental and regulatory context) by using the university internal structure. The right side of Figure 5 depicts a more complex scenario, where the university academic offer is jointly implemented by the university with a set of partners’ entities (ranging from other universities to specialised firms located anywhere). Now, the concept of “university education platform” reflects education partnership agreements where human and material resources are wisely combined in a transparent way to enrolled students.

Figure 32. Transition towards a university platform concept (Source: own elaboration)

Obviously, this approach implies the implementation of a sound quality and reputation control by the public university, which will keep the responsibility to grade students and it respond to that to the quality governmental agencies. Notice that this approach is compatible with double diploma models currently use when two or more universities participate in the process.

The model of provision of higher educational services through a “university education platform” implies that many activities directly performed in the past by universities as part of the value chain will be moved to one shared university-education platform.

Notice that the concept of “university education platform” is not only linked to a simple ICT-powered digital platform; however, the evolution of ICT digital platforms constitute the most relevant enabler and it offers great opportunities to implement the concept in an efficient way as it will be discussed later on. Main changes with respect to the present situation of higher educational services that are powered by the use of advanced digital platforms are the following ones:

- Full adoption of digital marketing and awareness techniques. Both business schools and private universities had fully understood years ago that the use of “digital marketing” techniques constitutes a key factor to increase their attractiveness for potential students at international level. Today, the same approach is being (slowly) realised by public universities over the world where the attraction of students at local level is not guaranteed anymore (due to local or on-line competition, but also by demographic reasons).

Then, they need to increase their footprint in other regions or countries to ensure full enrolment in all offered degrees. This approach is not only based on web 2.0 sites but also full use of social networks to be able to convey personalised messages to prospective students after careful

customer segmentation process and big data analytics to process current data with historical trends for fine tuning. This activity will deserve the allocation of substantial funds and efforts with skills, which are not easily found in traditional universities.

- Full digitisation of the enrolment and follow-up process. Universities made efforts in the past to reduce clerical work by developing (or purchasing) ad hoc customer relationship management (CRM) software packages, and full e-administration solutions feeding up a broad range of mobile services. Then, the starting point is better although the integration of a large set of independent software packages or applications is still a problem. Nevertheless, the maintenance of proprietary systems became a source of heavy legacy problems to migrate to new IT systems; then the trend to find integrated common (shared) solutions is increasing although no common university IT reference architecture has been adopted.

The use by students of device-independent access to all types of administrative procedures and personal data (even their grading marks on real time) is becoming part of common services offered by universities. The emerging use of AI-based personal assistants for enrolled students will offer them another level of personalised support not available in the past, and universities can also support their strategic decision-making by extracting behavioural patterns from big data analytics.

- Crowdfunding platform to increase external funding. An additional issue also borrowed from the collaborative economy field is the use of “embedded crowdfunding platforms” in order to get additional funds to support education costs (e.g. student’s fellowships). In the USA where tuition costs could be very expensive, this approach is getting momentum³⁵. European universities are far from promoting the use of crowdfunding in practice while tuition fees remain very low.

Another extra value of this kind of embedded platform came from its role to increase the engagement in society where open activities of the university could be also promoted through small economic contributions from citizens (even from ex alumni networks). The combination with other mechanisms based on social networks will also promote better knowledge of the activity and strengthening the role played by universities in society.

³⁵ U Fund, University High School’s annual fund (<https://www.universityhighschool.org/giving/the-u-fund/>) is the single most important source of yearly fundraising income to make up the difference between tuition and the actual cost of the education provided.

When applied to public universities this approach could require specific regulations and rewarding to taxes schemes.

- Full adoption of blended learning models. Universities are compelled to explore innovative learning models to offer customised services and higher efficiency for teaching activities by using pre-defined modules from their partners' networks (León, Leceta and Tejero, 2016).

Then, face-to-face lectures (initially in university premises but in the future also in partners' premises) are combined with on-line access to educational material probably shared by university networks to save efforts. The case of EIT Digital Master School³⁶ is an example in this process where on-line material is made available in a common repository, where partners' universities can extract and incorporate in their own ad hoc courses, the selected on-line material adequate to their needs.

- Individual grading based on customisation and gamification of students' knowledge assessment where both timing and procedures are adapted to individual needs and are desynchronised from general scheduling.

This approach was very difficult to implement in the past for large number of students enrolled in the same course where grading synchronisation was the norm. However, today is becoming a feasible solution provided by advanced IT systems and additional flexibility can be offered to students. The full deployment of this approach could require regulatory changes to be able to coexist with conventional grading systems.

Several of the above-mentioned activities were embedded in Figure 5 under the term “university platform” by assuming that students will not be necessarily aware of some of the partnerships used to provide the education processes. The implementation of this approach dramatically benefits for the deployment of one or more digital platforms to provide access to data repository and analytics, uniform user interfaces, customisation and individual tracking of learning process.

Inside the “university education platform”, several campus activities (both physically and on-line) are included. In this context, it is worthy to analyse the value of keeping physical university campuses, which have constituted the most visible element of a traditional university. It is possible to think that the model presented above could make them unnecessary relics of the past (even motivated by economic reasons in owned state management).

³⁶ See for further details <https://masterschool.eitdigital.eu/>

Within the umbrella of “university campuses”, universities usually provide facilities for developing a large number of activities: project-based learning between groups of students, free exchange of ideas among students and faculties outside curricular-based activities, promotion of debates and rich cultural life (in crucial years where the personality of students is being shaping), but also to be able to carry out other additional activities like business incubators, students’ competitions, open days for citizens’ visits, etc. Furthermore, in a model where partnerships become a driving force, campuses constitute a common space to be shared with other partners to increase mutual commitment and alignment. Then, physical presence of joint labs, university-industry chairs, living labs, demonstration or pilots with industry partners, etc. also constitute added-value activities for interdisciplinary and cross-cutting university education approaches. The difference in the case of university platform-based model is that campuses activities are not necessarily restricted to university premises because the concept of “campus” refers to a shared space with other partners.

Today, very large innovative companies located in the Silicon Valley (see Google or Facebook cases) are creating their own “corporate campuses” by mimicking the same approach that universities were using for decades: a shared space where students and faculties live in order to facilitate knowledge generation and transmission. The idea of creating a “corporate campus” (not only corporate physical premises as usual) came because industry leaders trust in a model where employees can learn from others, exchange ideas, and to increase creativity, if possible, with other entities, as universities are doing.

The right approach is not to remove university campuses or to move them far away but to convert them in “smarter campuses” fully embedded in society. If advanced IT solutions could also provide a sense of “virtual proximity” to other external spaces (advances from virtual/augmented reality will play a role in it), campuses can extend their footprint to other places over the world where partners are located by contributing to international higher education goals. It is from this point of view where the interaction with the concept of “smart campus” emerges.

Table 15 summarises the main differences between the traditional model of universities and the “platform-based” model described above.

Phase	Traditional model	Platform-based model
Academic offer	Defined by public universities by following governmental rules and hard guidelines (e.g. structure, minimum number of enrolled students, assessment and budget	Defined by universities by following governmental rules and guidelines as usual. New features characterised by: 1. Micro-courses components.

	<p>constraints) to get the approval of degrees.</p> <ol style="list-style-type: none"> 1. Low level of flexibility for customisation to individual needs. 2. Based on full academic years (3+2 or 4+1 models). 3. Other degrees only recognised by universities. 	<ol style="list-style-type: none"> 2. Higher flexibility to create personalised curricula for individual students. 3. Cross-university degrees with flexible curricula. 4. Project-based and blended learning. 5. Company internships during the studies (not necessarily linked to full academic courses but by short and intensive seminars).
Marketing and awareness	<p>Passive approach for quasi-captive local students (strong dependency on territory).</p> <p>Reputation and interest in university rankings to attract foreign students.</p>	<p>Aggressive targeted worldwide marketing.</p> <p>Intensive use of social networks, 2.0 web-based tools.</p> <p>Reputation linked to comprehensive or specialised rankings.</p>
Students' decision	<p>Entry qualifications defined by number of entry students.</p> <p>Open information for pre-selected degrees provided by universities (web-based).</p> <p>Moderate impact of rankings.</p>	<p>It will continue an individual decision but increasingly supported by:</p> <ol style="list-style-type: none"> 1. Use of social networks to receive immediate feedback. 2. AI students' assistants. 3. Specialised platforms for smart comparison (i.e. through specific university recommenders). 4. Customised rankings. 5. Timing knowledge of entry qualifications.
Selection and enrolment	<p>Performed by universities themselves. Based on the marks obtained by students in high school and specific exams to enter to the university.</p>	<p>Use of data analytics and AI assistants to support universities in the selection process.</p> <p>Possible use of external partners to outsource part of these processes.</p>
Teaching and learning	<p>Face to face complemented by some on-line modules and project-based learning.</p> <p>Limited individual tuitions (under request).</p>	<p>Blended models where face-to-face is dramatically reduced.</p> <p>Personalised on-line modules (or micro-modules).</p> <p>Video-calls tuition.</p>
Grading	<p>Based on pre-scheduled individual exams (with increased emphasis on continuous evaluation) and quality of assignments project-based activities.</p>	<p>Increasing use of gamification techniques to assess the students' progress.</p> <p>Knowledge certification at any moment during the academic year (based on ECTS fulfilment).</p>
Campus activity	<p>All activities are conducted in the university premises.</p> <p>If possible, students' dormitories are located in the campus.</p>	<p>Only some activities where face-to-face interaction is essential for the learning process will use the campus facilities.</p> <p>Concentration of physical activities in shared spaces with other partners.</p>
Partnering	<p>Educational public or private partners are not essential components of the university ecosystem.</p> <p>Universities perform all basic activities with its own resources and in their own premises.</p>	<p>Both public and private partners play a role in providing educational services. Some key aspects are:</p> <ol style="list-style-type: none"> 1. Industry internships are common and compulsory to get a degree. 2. Shared facilities and equipment. 3. Use of partners' premises.

	Governance is mainly a university concern based on their own boards and, if needed, advisory committees.	4. Involvement of external instructors and mentors. 5. Deeper engagement with society. 6. Common governance schemes. 7. External quality assurance.
Funding platforms for education³⁷	Funding is provided by governments. Fixed tuition fees set-up by governments (per ECTS). Small percentage from education services offered to firms.	Funding only partly provided by national/regional governments. Crowdfunding platforms (e.g. for ex alumni or industry partners).

Table 15. How the traditional value-chain model for public universities is changing (source: own elaboration)

In parallel, universities should decide if they are ready to provide all these elements by themselves or if it were better to trust on external partner entities (even on other universities' resources), which can provide some of the mentioned educational services.

A key issue behind this transformation process is to decide at what extent one pre-existent public university should move core educational processes to the associated partner ecosystem while preserving its role and visibility. In other terms, what should be the most adequate balance and consequences for the long-term sustainability of the added-value offered by the university to students and society-at-large?

The evolution of the model is to give additional emphasis to the education partner ecosystem instead of relying exclusively on internal resources. Figure 33 presents two options (A and B), which could be also understood as phases to be implemented over time. Phase A reflects near-term changes that can be progressively introduced without implementing deep changes in structure and governance. Phase B assumes the implementation of a disruptive model where the "partner ecosystem" acquires much more relevance in governance and implementation.

³⁷ Resources for research and innovation are not included in the table, which is focused on the education mission of universities.

Figure 33. Relationships between the “university platform” and its partner ecosystem (Source: own elaboration)

Phase A could be understood as an evolutionary transformation of present universities. Only some back-office processes are delegated to partners under service contracts. Then, governance and visibility to students’ context remains under the responsibility of the university. Some of the migrated services could be: 1) use of external premises (e.g. rented buildings or shared equipment), 2) IT services (e.g. cloud-based access, hosting, management of social networks, big data analytics), and 3) limited use of external experts.

Phase B could be understood as a revolutionary transformation of present universities. In this case, many educational activities are migrated although the university keeps the control of “students’ knowledge certification”. In this phase, the governance will evolve towards a “shared governance model” with stronger commitments from partners. Some additional services on top of the phase A services could be: extensive use of external contents and experts, emphasis on course coordination instead of course implementation, permanent use of partners’ facilities, larger visibility of partners to enrolled students, set-up of joint complex governance schemes, stronger economic commitments from partners (joint risk schemes).

Phase B also reaffirms the concept of “university education platform” as an educational model where emphasis is placed on the benefits for students regardless the ownership of contents, payroll or equipment. In this case, the partner ecosystem will be more visible to students (and probably to

administrations) and the responsibility of the quality process is shared amongst partners. Anyway, the university still keeps control of the grading process and assure the quality of the learning process.

Obviously, intermediate situations could be found in practice where specific university partner ecosystem models should be adapted to national/regional regulations and context. Afterwards, both A and B models can coexist for specific degrees in the same university³⁸.

Figure 34 depicts a complementary and restricted view of Figure 33 where a number of potential stakeholders as part of the partner ecosystem have been identified. The figure also represents an intermediate case between phase A and B where some selected processes were migrated to the university partner ecosystem. Notice that data repository can be also migrated.

Figure 34. Putting the university partner ecosystem at work (source: own elaboration)

Data repository is usually an internal component not accessible by non-registered students. This approach could change if the university adopts a “market place” concept of platform where educational components are put at disposal of students, which can retrieve them with some

³⁸ Probably, it will be the common case for comprehensive universities, because the type of partner ecosystem to be built up and the internal mentality of faculties and university leaders involved could be very different from one domain to another and it takes time. Do not forget that the decision to move one educational service to the partners’ area implied the full trust on the quality performance of the service, because the university will remain as the final responsible for quality (and it will suffer external evaluation from governments).

revenues model (e.g. subscription or downloading fee). Here, the university could guide or influence but not impose what should be the most appropriate modules. At the end, the control for grading is based on the assessment process of individual knowledge.

However, the implementation of this model presents some deep consequences. Some of the identified open challenges are as follows:

- Impact on contents creation. If some of the educational material of courses (i.e. learning modules) included in the curriculum are provided by external partners (e.g. from other universities or private firms belonging to the partner ecosystem) or even after buying them in the educational market some questions are open:
 - *What should be the mechanism to select and control the quality and adequacy of that content?*
 - *What is the minimum percentage of proprietary contents necessary to preserve the university identity with respect to the external world?*
 - *What are the consequences with respect to IPRs if some material is modified or extended (e.g. who is the owner)?*
 - *Is it possible to extend the “chair freedom” to this case?*
- Faculties’ composition. Under the university education platform concept, public universities should devote institutional efforts to find the right external experts to complement their internal staff profiles by keeping alive the possibility to develop the professional career for their own faculties’ member.

In fact, this is a common practice for graduate studies³⁹ in many universities but less common in undergraduate studies. We envisage the spreading out of that approach to undergraduate courses and to progressively break internal barriers to accept part-time or invited speakers. Again, open questions are related to the wise balance between permanent faculties and external experts to consolidate university reputation and homogeneity. Are the commitments of teachers at the individual level enough or do they be embedded in the partnership agreements at the institutional level? Furthermore, for public universities it requires a delicate balance with the teaching freedom principle.

³⁹ In Spain, it is common to find university regulations where up to 30% of faculties in master’s degrees could be allocated to external experts (from industry or public administrations); they also increase the attractiveness of those degrees when employability is a must. Apart from that, visitors’ professors are always welcomed even when they are marginal and limited to sabbatical periods.

- Use of physical premises. For some studies (e.g. in science and engineering curricula) the access to advanced facilities and equipment is in the basis of the quality of education. Project-based learning strongly depends on it. Nevertheless, as indicated above budgetary constraints have motivated public universities to find alternative solutions.

If the education ecosystem (partnership model) is fully accepted, why not to rely on equipment located in partners' premises and not in university premises? What are the consequences on the visibility and reputation of university? Do they affect the employability of graduates?

- Continuous grading. The full deployment of the university education platform model and the use of sophisticated IT tools can provide the basis for implementing more innovative "continuous grading" approaches not synchronised to conventional academic years where students can decide to present themselves to the grading exams when they feel ready or when they have passed the minimum set of compulsory activities.

Here, the introduction of IT-based gamification rewarding systems to reduce "students' abandons" (borrowed from experiences in gamification outside the university world) could be automatically provided by a digital platform for a number of subjects included in the academic curriculum. This is also a key issue for graduate students.

- Long-term stable partnerships. The deployment of the university platform model requires to set-up a specific set of partnerships with public and private entities for long periods of time linked to the implementation of some university degrees (usually, five years is the minimum period to ensure that the degree is fully implemented).

These partnerships could assume economic commitments from both sides and also the distribution of profits, if any. This issue introduces a higher complexity degree in the relationships between partners, but experiences can be borrowed from other domains.

- Internationalisation. The platform model as presented in this section has not explicitly addressed the internationalisation issue as a driver. Nevertheless, it is embedded in many of the model's components. Digital platforms try to attract customers from everywhere; it also happens in higher education platforms⁴⁰.

If students and faculties/experts should be attracted to the university it requires effort and experience which could be delegated to "brokers" linked to the university; if the use of blended

⁴⁰ The importance of education as an international or globalized form of trade is apparent in its inclusion in the activities of the World Trade Organization (WTO). Particularly in its inclusion in the General Agreement on Trade and Services as a special type of service (GATS). This approach has been strongly criticized in the past but is penetrating in many universities over the world.

learning models is widening, universities will need also to work with content providers from other places or countries to get agreements to be able to adapt and use them for their own purposes.

- Joint governance. For some committed partners the only way to accept risks is to become part of the governance system and control the use of their contributions. It implies that universities should create common governance spaces not only through specific bilateral agreements but also by working side-to-side with governments to adapt the current legislation to facilitate partners' involvement.

Once the university platform concept is accepted by universities and public administrations the whole transformation process of European universities could be facilitated if specific open "information technology platforms" were designed for that mission. However, technical platforms for higher education in Europe will need to enable great diversity to accommodate very different contexts. Diversity will occur in terms of delivery models and blending with personalised self-services.

Disruptive platforms will also need to enable seamless integration among cooperating providers of the various components of a solution – meaning close partnership among institutions as well as innovative learning tools.

6.3.6 New taxonomies

Biomimetic or biomimicry is the imitation of the models, systems, and elements of nature for the purpose of solving complex human problems⁴¹. Living organisms have evolved well-adapted structures and materials over geological time through natural selection. Humans have looked at nature for answers to problems throughout our existence. Nature has solved engineering problems such as self-healing abilities, environmental exposure tolerance and resistance, hydrophobicity, self-assembly, and harnessing solar energy.

After all, Biomimicry is nothing more than a way of understanding, capturing and transferring that know-how stored by Nature and animals to transform it into its own technological heritage through the technique of the "adjacent possible" (López et al., 2018).

In the literature on socio-economic ecosystems there are many authors who refer, in one way or another, to the actors usually found in these ecosystems, actors such as large, medium and small

⁴¹ <https://en.wikipedia.org/wiki/Biomimetics>

companies, educational institutions, institutes of research, public entities, venture capital, foundations, etc. (Pikinkinie and Maciulis, 2014).

However, and even with the importance attributed to knowledge, in the definitions and theory on systems and ecosystems reviewed in Chapter 3, there is no classification of actors and relationships directly related to the generation, transfer and consumption of knowledge. This is why, due to the importance of knowledge and the effect that organizations and their relationships have on innovation, and therefore on ecosystems, two new taxonomies are described below. The definition of these new taxonomies will start from the example of ecological ecosystems, a concept initially used in socio-economic ecosystems to pay greater attention to the dynamics of these systems.

6.3.6.1 Determinants of innovation ecosystems

As it was presented in Chapter 3, in ecosystems of ecological type the biotope refers to the physical part, where it is possible to identify a series of characteristics that condition organisms to develop in it; characteristics such as relief, climate, soil, water, temperature and luminosity. For its part, in the field of innovation, innovative behavior, as described in the work of Rush et al. (2014), is often associated with entrepreneurship (Drucker, 1985). Although there is much literature in this regard, the majority focuses on small businesses and startups (Burns, 2011). However, it is also important to pay attention to large and medium companies with the figure of the intra-entrepreneur⁴² (Sarasvathy, 2008; Burns, 2008; Schumpeter, 2006; Buckland et al., 2003; Shane, 2003).

Taking into account the relationship between innovative behavior and entrepreneurship, the sources from entrepreneurship ecosystems can help to specify the factors, dimensions and determinants that normally affect or could affect innovation in innovation ecosystems. Thus, based on the analysis of the seven domains identified in Isenberg's work (2011), the eight pillars of entrepreneurship ecosystems defined by the World Economic Forum (2014) and the six determinants of entrepreneurship of the OECD (2015) can be proposed a classification of aspects that could condition the development of organizations in an innovation ecosystem, grouping them according to the following dimensions:

- Political dimension.
 - o Regulatory framework (tax benefits, corporation tax, etc.).
 - o Favorable legislation (bankruptcy, fulfillment of contracts, property rights, and work).
 - o Financial support (R&D, advanced training, scientific infrastructures, etc.).
- Support dimension.

⁴² Intrapreneurship is the act of behaving like an entrepreneur while working within a large organization.

- Access to non-government funding.
- General infrastructure (telecommunications, transport, logistics, energy, spaces, incubation centers, clusters, etc.).
- Support of professional institutions (legal, accounting, investments, technical experts and advisors).
- Support of non-governmental support institutions (promotion of entrepreneurship, conferences, competitions, mentors ...).
- Market dimension.
 - Accessibility to international markets.
 - Networks (networks of entrepreneurs, multinationals, etc.).
 - Early consumers (distribution channels, consumer reference, etc.).
- Dimension of human capital.
 - Labor.
 - Education and training.
- Social dimension.
 - Culture (tolerance to risk, to be wrong, etc.).
 - Others, such as languages in the population, or social services.

These dimensions, and their corresponding aspects, are common elements that have been identified from the source of contents summarized in Table 16.

Source	Domains / Pillars / Determinants
(Isenberg, 2011) 7 domains	<ul style="list-style-type: none"> • Politician (Government) <ul style="list-style-type: none"> • Institutions (investment, support, ...) • Financial support (R&D, ...) • Incentives of the regulatory framework (tax benefits) • Research institutes • Legislation favorable (bankruptcy, fulfillment of contracts, property rights, and work) • Financial • Cultural (tolerance to risk, errors, ...) • Support <ul style="list-style-type: none"> • Non-governmental institutions (promotion of entrepreneurship, conferences, competitions, ...) • Professional supports (legal, accounting, investments, technical experts and advisors) • Infrastructure (Telecommunications, transport and logistics, energy, zones, incubation centers, clusters) • Human capital <ul style="list-style-type: none"> • Labor • Educational institutions • Market <ul style="list-style-type: none"> • Networks (entrepreneurs, multinationals, ...)

	<ul style="list-style-type: none"> • Early consumers (distribution channels, consumer reference, ...)
(World Economic Forum, 2014) 8 pillars	<ul style="list-style-type: none"> • Market accessibility • Human Capital / Labor Force • Financing • Support Systems / Mentors • Government and Regulatory Framework • Education and formation • Main Universities as Catalyst • Cultural Support
(OCDE, 2015) 6 determinants	<ul style="list-style-type: none"> • Regulatory Framework • Market conditions • Access to Financing • Knowledge Creation and Dissemination • Business Capabilities • Entrepreneurial Culture

Table 16. Summary of domains, pillars and determinants of entrepreneurship and innovation
(source: own elaboration)

6.3.6.2 First taxonomy: organizations of innovation ecosystems

In Chapter 3, reference was made to institutions or organizations and their importance in innovation ecosystems. Some of these organizations are focused on regulation (economic, political and the generation of general infrastructures), while others are actors that participate in the ecosystem, that is, startups, small, medium and large companies, universities, etc.

Considering the determinant characteristics of the innovation ecosystems identified above, the institutions involved in the regulation are mainly of a governmental nature (coming from the political, market and social dimensions), responsible for the regulatory framework, legislation, financial support, labor, etc. Here, it is also necessary to point out the existence of typically non-governmental institutions, in charge of the management and application of the rules that normally govern ecosystems (often acting as traction entities), as in the case of large corporations, universities, etc., depending on the type of ecosystem: university-driven, industry-driven, etc.

On the other hand, the actors are those that constitute the "living" part of the ecosystem, which, as in the case of ecological ecosystems, is made up of living organisms⁴³.

In the ecological ecosystems, the biodiversity is the set of the different species that inhabit a certain region, an aspect of vital importance to maintain the equilibrium and the stability of the ecosystem, but also to suppose an important source of new resources (animals, materials, etc.). In innovation ecosystems, the diversity of organizations, according to the function they carry out in the ecosystem, will also affect their development, balance and sustainability, in the sense that an organization, normally, cannot act alone and design products from isolated form: interconnected communities are needed (Iansiti and Levine, 2004). In its process, an organization usually requires suppliers but also intermediary organizations, its clients and even, sometimes, competitors.

Attending to the different organizations identified in the literature, (in business, industrial, entrepreneurship and innovation ecosystems) it is possible to identify organizations from both public and private spheres: Universities, Research Centers, SMEs (whether spin-off and startup), large and medium-sized companies, venture capital funds, intermediary entities, government agencies, innovation support centers, foundations, accelerators, incubators, etc.

Starting from the existing taxonomy in ecosystems of ecological type, the types of organizations based on the function they develop within an innovation ecosystem, be they producers, consumers or simply dedicate themselves to supporting the process, can be classified into three large groups: producer organizations, consumers and support for innovation.

- **Production organizations.** Are those organizations that using the resources offered by the ecosystem (facilities, services, etc.), produce the raw material of this type of ecosystem, that is, knowledge (through research and / or education activities). These organizations are the basis of the chain of knowledge consumption⁴⁴ that occurs in this type of ecosystem, since the rest of organizations, in one way or another, will depend on them. It should be noted that, unlike in the food chains of ecological ecosystems, where the relationship of some organisms with others is limited to those of the chain, in the chains of knowledge external interactions are carried out

⁴³ At this point, it would be possible to carry out a differentiation in two levels, where the first would be the organization and the second an individual. However, this distinction will not be made with the objective of not adding more complexity to the document, and taking into account that, normally, the creation, transfer and consumption of knowledge is carried out between organizations and not between individuals, since even if appropriate initially of an individual, it uses legal entities to conduct this type of interaction.

⁴⁴ As in ecosystems of ecological type, the "trophic" consumption chains formed by organisms are of a food type, in innovation ecosystems they will be chains focused on the production, transformation and consumption of knowledge.

within the chain, in form of imports and exports of ideas, products or economic flows. In other words, these are normally open chains of production⁴⁵, flow and consumption of knowledge.

- **Consumer organizations**⁴⁶. Taking advantage of the taxonomy offered by ecological ecosystems, they could be divided according to their consumption into: primary or first level, and secondary or second level.
 - **Primary or first level consumers.** They are those organizations that consume the knowledge generated by the producer organizations, that is, they are consumers of the knowledge coming from education and research, which they will transform into new knowledge: innovation.
 - **Secondary or second level consumers.** It would be those organizations that consume the knowledge produced by the primary organizations, either by purchasing knowledge or by acquiring the organization that has it (by establishing equivalence with ecological ecosystems, where they would be identified with carnivorous animals whose food is made up of animals of the herbivore type). That is, these organizations would be the consumers of the innovations generated by the primary consumers.
 - **Tertiary consumers.** In the case of ecological ecosystems, they identify with carnivorous animals that feed on other carnivorous animals. In the case of innovation ecosystems, they would also identify with secondary consumer organizations, that is, consumers of innovation. Therefore, in innovation ecosystems, tertiary and secondary organizations will appear under the same group of secondary consumer organizations, since there is no conceptual differentiation between them.
- **Organizations supporting innovation** (equivalent in their function, to some extent, to the decomposers within ecological ecosystems). In the ecological ecosystems, the organisms of decomposers type (bacteria and fungi) are in charge of closing the cycle of the matter, providing by means of their decomposition the necessary inorganic elements for the producing organisms (vegetables). Within an ecosystem of innovation, organizations in order to maintain the knowledge cycle, through management, transformation, and ultimately support, would be support centers for innovation, accelerators, incubators, venture capital funds (or venture capital), government entities, foundations, etc.

⁴⁵ It also occurs in ecological ecosystems when talking about interaction between ecosystems or the appearance of invasive species that displace native species, due to environmental changes, etc.

⁴⁶ Many of them have the double role of producer and consumer of knowledge.

At this point, it should be noted that many organizations could play multiple roles according to their function and interests within the ecosystem, something that will also vary depending on time. Thus, a company at any given time can act as a primary or secondary consumer, and even as an entity supporting innovation (e.g. corporate venture capital), depending on its interest in the consumption of research or innovations. In another example, a startup could play the role of knowledge-producing organization (very common in ICT areas), but also act as an education or research consumer organization, if it were interested in a specific technology needed for development of its products or services.

In short, an organization can play multiple roles depending on the type or types, as well as at different times. Therefore, the role of an organization will be defined by the sum of the different simple roles that it can play at a temporary moment within the ecosystem, something that can be represented according to the following equation:

$$Organization_role_i(t) = \sum (role_{producer} + role_{primary_consumer} + role_{secondary_consumer} + role_{support})$$

Serving the subscript i to identify the organization i , and the subscript t to identify a moment of time.

In turn, at the conceptual level, the different organizations of these ecosystems can be represented on the dimensions defined within the knowledge triangle (European Commission, 2015), since as previously anticipated, knowledge is what connects these organizations, knowledge coming from the dimensions of education, research and innovation. In this way, just as in ecology where food relations between the different organisms of an ecosystem are identified by what are called "trophic levels", knowledge transfer relationships between the different organizations involved in an innovation ecosystem can be represented on the triangle of knowledge, which would be equivalent to the different existing "levels of knowledge", as it is shown in Figure 35, where each level can be differentiated with different colors. Thus, the levels of knowledge in this type of ecosystem would be the following:

- **Level 1** (producer organizations): generation of knowledge from the dimensions of education and research.
- **Level 2** (primary consumer organizations): consumption of knowledge from education and research, and generation of knowledge in the form of innovation.
- **Level 3** (secondary consumer organizations): innovation consumption.

In the scheme of Figure 35, the relationship of the different types of organizations that can be found within an innovation ecosystem, based on the creation, transformation and consumption of knowledge, is represented at a conceptual level.

Figure 35. Taxonomy of organizations of an innovation ecosystem based on knowledge. (source: own elaboration)

Indeed, as can be seen, the knowledge producing organizations tend to be more related to the education and research dimensions represented in the triangle, since they are the main generators of these types of knowledge. On the other hand, primary consumers are in charge of consuming the knowledge generated by the producers (education and research), arriving to produce innovation (hence its location more in the middle on Figure 35). Finally, secondary consumer organizations consume the knowledge generated by primary consumers, in the form of innovations. It is important to highlight the importance of the position occupied by the innovation support organizations in the scheme, responsible for maintaining the knowledge cycle of the three dimensions, helping, therefore, to promote the creation of innovation in this type of ecosystem.

6.3.6.3 Second taxonomy: relationships of ecosystem organizations

As in nature, there are complex networks of relationships between the different organizations that make up an innovation ecosystem. Within this network of relationships, exist in ecology the so-called "trophic chains", referring to simple and linear sequences of organisms that feed on each

other. Equivalently, in an ecosystem of innovation, "knowledge chains" would take place, similar in function to food chains, but formed by the organizations belonging to each of the previously defined levels of knowledge (producers, primary consumers and secondary consumers). The generic sequence of knowledge consumption defined and referred to levels of knowledge would be the one shown in Figure 36 below.

Figure 36. Generic knowledge chain of an innovation ecosystem. (Source: own elaboration)

Within each of these categories of organizations, there are entities of different types, as previously indicated. Figure 37 shows an example of this. This network of knowledge, as can be seen, is an open network that allows for varied interactions and configurations between the different organizations that occupy each level of knowledge, but also with others outside the network, which gives it a high degree of flexibility and potential for the creation of innovations (Chesbrough, 2003).

Figure 37. Example of knowledge chains found in the UPM⁴⁷ innovation ecosystem (Knowledge Network⁴⁸) (Source: own elaboration)

Therefore, following the ecological approach, it is possible to distinguish existing relationships depending on whether they are organizations belonging to the same type (interspecific relationships) or different types (intraspecific relationships).

- **Interspecific relationships.** It will be about relationships that are established between organizations of different types within an ecosystem. The usual relationships from the ecological approach would be the relations of competition, depredation, parasitism, mutualism and commensalism, although in ecosystems of innovation it is also possible to identify relations of consumerism, that is, consumption without reaching predation.
 - o **Competition.** It will be a relationship based on the struggle for a limited resource (geographical area, financing, projects, clients, etc.)⁴⁹. Example: two startups competing

⁴⁷ Universidad Politécnica de Madrid

⁴⁸ The network of knowledge shown would have its equivalence in examples from trophic networks of organisms in Competition. It will be a relationship based on the struggle for a limited resource (geographical area, financing, projects, clients, etc.). Example: two startups competing to obtain a project offered by a public company. This relationship could lead to another one of "coopetition".

⁴⁹ Here we can distinguish two types: of explicit and implicit competence. Of explicit competence, when they are aware of this competence (for example, when they fight for a project in a client). On the other hand, in addition, of implicit competition, when they compete, for example, for funds in a public call. In this second case, they are not usually aware that they compete (in fact, usually they do not even know each other).

to obtain a project offered by a public company. This relationship could lead to another one of "coopetition"⁵⁰.

- **Predation.** It will be a relationship where an organization (of a predatory type) obtains a benefit from another organization of a different type (prey), which seriously harms it to the point of making it disappear. As an example, a large private company (predator) could be interested in the business model or technology of a spin-off (dam), to which it ultimately buys, absorbing all its knowledge and, therefore, making it disappear⁵¹.
- **Parasitism.** It will be a relationship where an organization (parasitic) lives at the expense of another (host) from which it obtains benefits, but which at the same time causes some type of damage, although much less important than that produced in a relationship of predation. An example could be a spin-off from and located in a university, which will affect their activities, whether due to bad publicity, costs, etc.
- **Mutualism.** It will be a relationship where both organizations obtain a mutual benefit for a specific purpose. An example could be a startup allied with a public university for the development of a certain technology, through the signing of a collaboration contract (contract typically collected in Spain within the so-called Article 83 of the L.O.U.⁵²).
- **Commensalism.** It will be a relationship where one species (the guest) gets benefit from another (host), taking advantage of it, but without causing any damage. As an example, a spin-off that uses the resources and the brand of a university to promote itself and make itself known to its clients, but without competing with it in products or services (it is a well-known behavior).
- **Consumerism.** Understood as the relationship between an organization that has a certain knowledge (either in the form of a product or service), and the organization that purchases or acquires it (consumer). In ecology, the relationships of the food chain are only represented by the depredation of some species to others, while in the case of organizations the consumption of knowledge is done, either through predation⁵³ when

⁵⁰ The term coopetition refers to the collaboration, in a period of time or in a sub-scope of its activity, between different economic actors that are competitors.

⁵¹ For many startups this is the best situation and what they really want, even if they disappear from the ecosystem, thus producing a decrease in biodiversity.

⁵² Ley Orgánica 6/2001, de 21 de diciembre, de Universidades <https://www.boe.es/buscar/pdf/2001/BOE-A-2001-24515-consolidado.pdf>

⁵³ This situation could be analyzed with different types derived from purchase, absorption, joint venture, etc.

the producer company is purchased or acquired, or when it is carried out simply the consumption of the knowledge offered through its purchase, acquisition or licensing.

- **Intraspecific relationships.** It will be the relations established between organizations of the same type, where it is possible to distinguish: relations of association and competition.
 - o **Association.** It will be produced by forming groups of organizations with the aim of obtaining certain benefits produced precisely by that union, which individually would be more difficult to achieve:
 - Easier to attract resources.
 - Defense against organizations of other types that attempt or compete against them.
 - Growth, scalability and expansion.
 - Protection.
 - Access to projects, financing, etc.
 - Sharing of resources (legal, etc.).
 - Obtaining the necessary critical mass.
 - Joint acquisition of goods (e.g. scientific infrastructures).
 - o **Competition.** It will occur when two organizations of the same type compete with each other:
 - For the resources of the medium (geographical area, customers, etc.).
 - Growth, scalability and expansion (within a biotope or with expulsion).
 - Dominance (one organization imposes itself on the others).

At this point it should be noted that although in living organisms intraspecific relationships are limited only to these two cases (association or competition), in the case of organizations, even within those of the same type, could also occur predation relationships, consumerism and mutualism. Here are some examples: one SME that absorbs another (predation relationship); an SME that buys its services and / or products from another (consumer relationship); a company that is associated with another, in principle, competitor to reach a larger customer (mutualism).

In summary, Table 17 shows the different relationships previously identified.

Interspecific relationships (between organizations of different types)	Competition, consumerism, depredation, parasitism, mutualism and commensalism.
Intraspecific relationships (between organizations of the same type)	Competition, consumerism, depredation, association and mutualism.

Table 17. Types of relationships between organizations of an innovation ecosystem. (Source: own elaboration)

In addition to the type, each relationship can be classified according to other parameters such as intensity, duration or, even, the benefit obtained from that relationship. The intensity of the relationship could be associated with the amount of resources or dedication put into the relationship, be it economic, human, time, etc. This parameter could be represented by qualitative values (high, medium, low intensity) and based on pre-established maximums and minimums. In addition, the duration of a relationship could easily be defined by qualitative values (long, medium or short duration) and depending on maximum and minimum.

On the other hand, the benefit⁵⁴ could be calculated based on a sub-classification of the relationships, in positive or negative, according to the interest of the organizations involved, that is, according to the intended objective or not with the relationship. With this benefit parameter, it is possible to establish a priori a sub-classification of the different relationships previously identified:

- Positive relationships:
 - *Relations based on the consumption of knowledge* (consumerism and predation, if predation is what the organization is looking for that is absorbed or acquired) (+).
 - *Relationships based on collaboration* (association and mutualism) (+).
- Negative relationships:
 - *Relations based on competition* (competition and predation, if the organization absorbed or purchased did not seek this purpose) (-).
 - *Relations based on abuse* (parasitism and commensalism) (-).

⁵⁴ Distinguishing here between the benefit for the entity and the benefit to the ecosystem. The benefit for an entity would be given by what positively obtains an entity for itself with the relationship (resources, knowledge, etc.), and the benefit to the ecosystem in terms of the gain obtained from the interrelation of the different organizations contained in it. This benefit that could be reflected, for example, with the same increase in total knowledge of the system, whether in the form of education, research or innovation.

Figure 38. Taxonomy of relationships within an innovation ecosystem according to the benefit.
(Source: own elaboration)

Finally, Table 18 summarizes the different parameters for the classification of the different relationships of organizations in an innovation ecosystem.

Parameter	Fist level	Second level	Third level
Type	Interspecific	Competition	-
		Consumerism	-
		Predation	-
		Parasitism	-
		Mutualism	-
		Commensalism	-
	Intraspecific	Competition	-
		Consumerism	-
		Predation	-
		Association	-
		Mutualism	-
Intensity	High	-	-
	Medium	-	-
	Low	-	-
Duration	Long term	-	-
	Medium term	-	-
	Short term	-	-
Benefit	Positives	Consumption	Consumerism
			Predation
		Collaboration	Association
			Mutualism
	Negatives	Competition	Competition
			Predation
		Abuse	Parasitism
			Commensalism

Table 18. Parameters for the classification of relationships in an innovation ecosystem. (Source: own elaboration)

6.3.6.4 Interaction of organizations with the ecosystem

According to Miller (1975), an ecosystem implies that everything is connected to everything. Everything is fed back through the ecosystem and from itself, and this interconnection preserves the system in general. Thus, as has been presented previously, the different types of organizations identified in an innovation ecosystem have been classified according to their relationship with the production and consumption of knowledge, which, as has been argued, constitutes the main element that originates "life" and promotes the movement that occurs in this type of ecosystem. Therefore, each of these organizations interacts with the ecosystem, in general terms, based on knowledge, sometimes acting as producers of the same, sometimes as consumers and often as simple facilitators of their "movement" and transformation. This interaction with the ecosystem can be represented for each of the type organizations in the scheme presented in Figure 39.

Figure 39. Interaction of organizations with the ecosystem (Source: own elaboration)

In this scheme, as it cannot be otherwise, a common line is identified, represented by orange arrows, which constitutes the line of production, transformation and consumption of knowledge in the ecosystem. In addition, as can be seen, each of the organizations must receive from the ecosystem various elements necessary for its operation, such as material and economic resources, talent, services, etc. This is analogous to the different elements that an ecological ecosystem provides to the living beings that inhabit it, basic and necessary elements for its development such as light, water, etc. Knowing the different needs that each type of organization has with respect to the system and knowing what they provide is of vital importance to be able to define a minimum operating structure that allows the development of organizations in the ecosystem and, therefore, the development of its main function: the production, transfer and consumption of knowledge.

6.3.6.5 Phases in the development of innovation ecosystems

James F. Moore (1993) distinguishes the phases of a business ecosystem in birth, expansion, leadership and self-renewal (or death).

- **Birth.** In this phase, it is about designing a business that can serve a potential market, as well as discovering the correct value proposition for customers.
 - o Challenges at the level of cooperation: working with customers and suppliers to define the new value proposition on the seed of innovation.
 - o Competitive challenges: protect the ideas of others who might be working towards the definition of similar offers. Secure critical clients, key suppliers and important channels.
- **Expansion.** In this phase, we mainly compete against other ecosystems to control strategic markets.
 - o Challenges at the level of cooperation: bring the new offer to a large market to work with suppliers and partners to expand the offer and achieve maximum market coverage.
 - o Competitive challenges: try to eliminate alternative implementations of similar ideas. Ensure that it is the market standard in its class through the domination of key market segments.
- **Leadership.** In this phase, it is mainly about maintaining an advantageous position, making sure that the ecosystem has a solid community of suppliers and that the key elements of value are controlled to maintain the bargaining power.

- Challenges at the level of cooperation: provide a convincing vision for the future that encourages suppliers and customers to work together to continue improving the complete offer.
- Competitive challenges: maintain a strong bargaining power in relation to other actors in the ecosystem, including the main customers and the best rated suppliers.
- **Autorenovation.** In this phase, we try to follow the new trends to put the ecosystem at the forefront, know how to "pivot" by changing or totally redefining the ecosystem if necessary. Balance stability and change by incorporating new innovations.
 - Challenges at the level of cooperation: working with innovators to attract new ideas to the ecosystem.
 - Competitive challenges: maintain high entry barriers to avoid innovative alternative ecosystems. Maintain high connection costs with the client in order to gain time to incorporate new ideas in the products and services.

Therefore, according to the phases identified by Moore, different combinations of relationships between ecosystems could be obtained, as shown in Table 19. In addition, to complete these phases, the use of the phases identified in the Product Maturation Cycle is proposed. (Stark, 2015). Its translation to the ecosystem context could be very relevant to improve conceptual detail of the evolution followed by ecosystems, especially when equating these phases with those previously identified by Moore (1993).

Ecosystem phases (Moore, 1993)	Product Maturation Cycle	Description
Birth	Development / Creation	The market does not recognize the ecosystem. Significant amounts of effort and money are used to create the new ecosystem. We work with clients and suppliers to define the new value proposition around the seed of innovation (cooperative challenges).
	Launch / Introduction	The ecosystem is put into operation at the market level and disseminated. Market volume follows the path of ecosystem progress. It must be protected the ideas of others who might

		be working towards similar offers. Critical customers, key suppliers and important channels (competitive challenges) must be protected.
Expansion	Growth	Depending on the speed, appearance of innovations and market needs, the ecosystem will have a better or worse expansion. Bring the new offer to a large market to work with suppliers and partners to expand the offer and achieve maximum market coverage (cooperative challenges). Try to eliminate alternative implementations of similar ideas. Ensure that it is the market standard in its class through the domination of key market segments (competitive challenges).
Leadership	Maturity	The growth rate slows down as the ecosystem approaches the degree of maturity. The volume of the market will reach its maximum (leadership) and from here, it will start to fall (unless there is a reaction). Provide a compelling vision for the future that encourages suppliers and customers to work together to continue improving the complete offer (cooperative challenges). Maintaining a strong bargaining power in relation to other actors in the ecosystem, include the main clients and the best valued suppliers (competitive challenges).
Auto-renovation	Saturation / Substitution	New ecosystems appear with innovations that push back the market share of the ecosystem (moment of reacting for self-renewal). Work with innovators to attract new ideas to the ecosystem (cooperative challenges). Maintain high entry barriers to avoid innovative alternative ecosystems. Maintain high connection costs with the client in order to gain time to incorporate new ideas in products and services (competitive challenges).
	Obsolescence / Decline	The ecosystem already has little or no value and tends to disappear (it has not been renewed or it has not been done in time).

Table 19. Detail and comparison of the phases of an innovation ecosystem. (Source: own elaboration from Moore, 1993 and Product Maturation Cycle)

In Figure 40 summarizes the curve and phases of the evolution of an X ecosystem based on above.

Figure 40. Phases of evolution of innovation ecosystems (Source: own elaboration)

Thanks to this tool, it is possible to represent the state of the level of maturity of an ecosystem, as well as to compare the evolution of any two ecosystems and their interaction, as shown in the example of Figure 41. This is a very valuable information for decision-making: definition of a new strategy to compete, exploration of new ways of collaboration between ecosystems, etc.

Depending on the state of an ecosystem, it will be possible to know if it is "more receptive" to the collaboration, since it is in a phase of creation and, therefore, requires other entities to establish its value proposition; or on the contrary, the ecosystem is in a phase of maturity or leadership, so it wants to maintain its power in a certain sector or technological domain, which hinders relations of collaboration, beyond achieving very specific objectives.

Figure 41. Representation of the interaction between two innovation ecosystems (Source: own elaboration)

6.3.6.6 Relevance of innovation ecosystems

In general terms, relevance can be considered as "one thing" that is connected to a "second thing" in such a way that it makes it useful to consider the first as long as the second thing is not taken into account. Applying this general approach of relevance to the context of innovation ecosystems (regional, national, etc.), to discover how relevant an ecosystem of innovation is to its environment, it will be necessary to pay attention to all those factors that can or can represent this effect in the most faithful way.

In the working paper "Impact assessment of university-driven open innovation ecosystems" (León and Martínez, 2016), the concept of relevance of an innovation ecosystem at a structural level is introduced, through a set of metrics with which it is foreseen provide more information on the temporal evolution of the successes and typical failures found in this type of ecosystem. This information is presumed to be of interest to national and regional authorities, since increasing the relevance of ecosystems could allow improving the socio-economic impact of their region or nation, attracting talent and investments.

In order to show the usefulness of this new concept framework of taxonomies and tools presented so far, the relevance calculation is showed below, based on an example of the innovation ecosystem of an European university.

6.3.6.6.1 Example of calculation of the relevance based on attractiveness, concentration and proximity potential

According to the study by León and Martínez (2016), the three factors identified in the relevance of an innovation ecosystem are the following: attractiveness, concentration and proximity potential.

Attractiveness is defined, informally, as the capacity of an ecosystem to convince public or private entities to belong to the ecosystem. Nevertheless, relevance is not just a question of the attraction of entities. Achieving a critical mass is also essential. In this sense, **concentration** is defined as the number of entities needed in the ecosystem to have a critical mass, depending on the geographical and sectoral dimension.

To complete the relevance equation it is necessary to point out that simply adding entities does not imply any relevance if the proximity or closeness of these entities, as members of the same space, cannot be transformed into opportunities that can be exploited, either to cooperate in activities of research, education and innovation with other entities. Therefore, measuring the **potential of proximity** between the different members of the ecosystem appears as an important and necessary part of the equation for the calculation of relevance.

Therefore, it is understood that in order to measure the proximity potential, it is necessary to pay attention to the relationships and interactions carried out between the entities of the ecosystem, as part of value chains. In addition, to calculate the relevance it is necessary to know the number of entities on which to measure their concentration and the attractiveness produced in others, since, depending on the entities of the ecosystem, and their type, it is understood that it is possible to attract certain entities more than others, according to how their objectives and interests could be aligned in common value chains.

Based on these three factors, it is possible to define the relevance of an ecosystem using the following equation:

$$Ecosystem_{relevance}(0 - T) = K \int_0^T \left(\sum_{i=1}^N att(mi, t) \cdot N(t) + \beta(t) \cdot \prod_{i_1}^N \left(\sum_{j=1}^M prox(mj, t) \right) mi, t \right) dt$$

- **K**, factor between 0-1 related to the orientation (benefits, political impulse) national or regional to innovation. Initially, within the European Union, this factor will be given by the average index of innovation for the period established annually (as an example, in the European Union could

be adopted the Innovation Union Scoreboard⁵⁵). The high values of this variable indicate a propensity of the environment towards the support of innovation activities.

- **att(m_i, t)** is the attraction value of the organization i at an instant t to be part of the ecosystem. To simplify, the global attractiveness will correspond to the sum of the values of individual attractiveness (assuming here independence in the decisions of each organization).
- **N(t)** is the number of organizations belonging to the ecosystem in a time t (this number will evolve over period 0-T). Implicitly, it is assumed that N(t) is always greater than the critical mass⁵⁶.
- **prox(m_j, t)** it is the proximity value of the organization j ($j < i$ since not all organizations cooperate at a given time) that cooperates in research, training and innovation activities with other entities of the ecosystem (cooperation promoted by the proximity of the entities). Here, the product operator is used to take into account the multiple interactions and value of the network.
- **$\beta(t)$** . This is a parameter used to consider the way in which the management of ecosystems facilitates, provokes or enables interconnection. We must bear in mind that proximity is a function that requires a global management support to facilitate interaction between previously unknown entities. B will range from 0 (no support is offered to members of the ecosystem) and 1 (all support).

As discussed at the beginning of this section, in order to show the usefulness of this new framework of concepts presented previously with the new taxonomies and tools, based on ecological approaches, the following will proceed to the calculation of relevance, starting from an example of a fictitious university-driven innovation ecosystem located in Europe, which consists of the actors represented in Figure 42.

⁵⁵ The Innovation Union Scoreboard provides a comparative evolution of research and innovation performance in Europe. The markers provided help countries and regions identify the areas they need to address.

⁵⁶ Minimum number of organizations necessary for its proper functioning.

Figure 42. Representation of a fictional university-driven European innovation ecosystem for the calculation of its relevance (Source: own elaboration)

Attending to the organizations of the ecosystem of the example represented in Figure 42, at a given moment a series of interviews is conducted to update the available information of the ecosystem with which to be able to know, among others, the role occupied by each organization, relations established between the different organizations, etc. With the information collected, Table 20, of organization classification, is obtained:

Organization	Producer	Primary consumer	Secondary consumer	Innovation support	Roles
University 1	YES	NO	NO	NO	1
Research center 1	YES	NO	NO	NO	1
Research center 2	YES	YES	NO	NO	2
Center for Innovation Support 1	NO	NO	NO	YES	1
Company 1	NO	NO	YES	NO	1
Venture Capital Fund 1	NO	NO	YES	YES	2
Accelerator 1	NO	YES	YES	YES	3
Startup 1	YES	YES	NO	NO	2
Startup 2	NO	YES	YES	NO	2
Startup 3	NO	YES	NO	NO	1

Table 20. Roles of organizations in example ecosystem of Figure 42. (Source: own elaboration)

In addition to the number of roles played by each organization (last column of Table 20, calculated by the role equation of an organization, previously stated in section 6.3.6.2), it is also possible to easily obtain the number of existing total roles in the ecosystem for each type of organization given:

- Number of producer organizations: 4
- Number of primary consumer organizations: 5
- Number of secondary consumer organizations: 4
- Number of supporting innovation organizations: 3

The value of the **concentration** variable, the first factor related to relevance, could in principle be understood as the number of organizations existing at a given moment in the ecosystem, that is, in this case, 10 organizations. However, concentration is defined as the number of entities in the ecosystem needed to have a critical mass. Thus, the critical mass is a concept more related to the minimum number of organizations needed of a certain type, which make an ecosystem can work. That is to say, it will be of little use, for example, to have 50 primary consumer organizations if there is not a minimum number of producer organizations that satisfy this consumption need. Therefore, the number of total roles performed within the ecosystem, which are in this case 16 (total sum of the last column of Table 20), will be the value that will be taken for this example as concentration value.

In terms of **attractiveness**, the second factor identified with relevance, this is defined as the capacity of an ecosystem to convince public or private entities to belong to the ecosystem, a concept whose value will be the sum of the individual attractions of the organizations that are in the ecosystem. Thus, the attraction value of each organization will be given by the capacity that organization has, individually, to attract other organizations. In this sense, the role of the organization in the ecosystem allows calculating the individual attractiveness, since depending on the role or roles played by the entity in the ecosystem, it will attract more to one or other organizations, that is, those with which normally maintains a relationship. In this way, based on the concept of the chain of knowledge, with which it is possible to establish the relationship between the different ecosystem organizations according to their roles and based on knowledge, it is possible to obtain the individual attractiveness of each organization and from here calculate the total attractiveness of the ecosystem. Taking this approach into account, a table with the results of individual attractiveness of each organization for the example ecosystem of Figure 42 is shown below (Table 21).

Organization	Attraction of Producers	Attraction of Primary consumers	Attraction of Secondary consumers	Attraction of Supporting innovation	Attractiveness Organization
University 1	NO	YES	NO	NO	1
Research center 1	NO	YES	NO	NO	1
Research center 2	YES	YES	YES	NO	3
Center for Innovation Support 1	YES	YES	YES	YES	4
Company 1	NO	YES	NO	NO	1
Venture Capital Fund 1	YES	YES	YES	YES	4
Accelerator 1	YES	YES	YES	YES	4
Startup 1	YES	YES	YES	NO	3
Startup 2	YES	YES	YES	NO	3
Startup 3	YES	NO	YES	NO	2

Table 21. Attractiveness of the example ecosystem organizations in Figure 42. (Source: own elaboration)

As noted above, using the individual attractiveness values of the organizations in Table 21, it is possible to calculate the total attractiveness of the example ecosystem of Figure 42, as the sum of the individual attractions: $1 + 1 + 3 + 4 + 1 + 4 + 4 + 3 + 3 + 2 = 26$ (total attractiveness of the ecosystem).

The last factor related to the relevance, the **potential of proximity**, will be given by the possible relationships established within the ecosystem. With this objective, all the possible relationships of the example ecosystem of Figure 42 are shown in Table 9, depending on whether they are of the same or different types, and based on the roles they play in the ecosystem. For this reason, a given organization may maintain only intraspecific relationships (same type) with ecosystem organizations, only interspecific relationships (different types), or intraspecific and interspecific relationships, if playing several roles in the same type coincides with some of the organizations and not others. This last case will be the richest in terms of relationship potential and, therefore, for the increase of proximity potential. In Table 9, the "inter" values will correspond to interspecific type relationships and the "intra" values with intraspecific relationships. In turn, to facilitate the visualization of the table, the organizations are shown with short names, that is, U1 would correspond to the University 1, RC1 to the Research Center 1, etc.

	U1	RC1	RC2	CIS1	C1	VCF1	A1	S1	S2	S3
U1		Intra	Intra	Inter	Inter	Inter	Inter	Intra	Inter	Inter
RC1	Intra		Intra	Inter	Inter	Inter	Inter	Intra	Inter	Inter
RC2	Intra	Intra		Inter	Inter	Inter	Intra / Inter	Intra	Intra / Inter	Intra / Inter
CIS1	Inter	Inter	Inter		Inter	Intra	Intra	Inter	Inter	Inter
C1	Inter	Inter	Inter	Inter		Intra / Inter	Intra	Inter	Intra	Inter
VCF1	Inter	Inter	Inter	Intra	Intra / Inter		Intra / Inter	Inter	Intra / Inter	Inter
A1	Inter	Inter	Intra / Inter	Intra	Intra	Intra / Inter		Intra / Inter	Intra / Inter	Intra / Inter
S1	Intra	Intra	Intra	Inter	Inter	Inter	Intra / Inter		Intra / Inter	Intra / Inter
S2	Inter	Inter	Intra / Inter	Inter	Intra	Intra / Inter	Intra / Inter	Intra / Inter		Intra / Inter
S3	Inter	Inter	Intra / Inter	Inter	Inter	Inter	Intra / Inter	Intra / Inter	Intra / Inter	

Table 22. Possible relationships of the example ecosystem organizations in Figure 42. (Source: own elaboration)

Taking into account that depending on whether the relationship is interspecific (six possible relationships, according to Table 19) or intraspecific (five possible relationships), or both (seven possible relationships, that is, the conjunction of inter and intraspecific relationships), it will be finally a set of possible total relationships for each of the ecosystem organizations. In this sense, Table 23 shows the potential value of proximity of each organization of the example ecosystem of

Figure 42, obtained based on its possible relationships with the rest of the organizations of the system (based on the shown in Table 22).

	U1	RC1	RC2	CIS1	C1	VCF1	A1	S1	S2	S3	Potential of Proximity
U1		5	5	6	6	6	6	5	6	6	51
RC1	5		5	6	6	6	6	5	6	6	51
RC2	5	5		6	6	6	7	5	7	7	54
CIS1	6	6	6		6	5	5	6	6	6	52
C1	6	6	6	6		7	5	6	5	6	53
VCF1	6	6	6	5	7		7	6	7	6	56
A1	6	6	7	5	5	7		7	7	7	57
S1	5	5	5	6	6	6	7		7	7	54
S2	6	6	7	6	5	7	7	7		7	57
S3	6	6	7	6	6	6	7	7	7		58

Table 23. Potentials of proximity of example ecosystem organizations in Figure 42 (Source: own elaboration)

From these individual values of proximity potential, the total proximity potential of the ecosystem will be given by the sum of all the individuals: $51 + 51 + 54 + 52 + 53 + 56 + 57 + 54 + 57 + 58 = 543$ (total proximity potential of the example ecosystem of Figure 42).

In this case, as far as relations are concerned, the "type" relation parameter has simply been used in order to calculate the proximity potential needed to calculate the relevance. However, it is also provided, as seen previously in Table 5, of another series of relationship parameters, such as duration, intensity and benefit. These parameters can be very useful to obtain a more accurate picture of the dynamics of an ecosystem. Therefore, the use of one parameter or another will

depend on the needs of the agents or entities that use this model when measuring the different aspects of which an innovation ecosystem is composed.

The different values obtained as a result of the calculations made for the example ecosystem of Figure 42, can be seen represented in Summary Table 24.

Concentration factor	Attractiveness factor (total) (for individual attractions, see Table 8)	Potential factor of Proximity (total) (for individual proximity potentials, see Table 10)
16	26	543

Table 24. Summary of total factor outcomes for relevance to the example ecosystem of Figure 42.

(Source: own elaboration)

As stated at the beginning of this section, the calculation of the relevance of an ecosystem starts from the individual attractiveness and potential of proximity (León and Martínez, 2016). However, thanks to the new approach presented, a new alternative appears with which the use of the total values of attractiveness and proximity potential of the system is enabled. In the latter case, the equation for the calculation of the relevance at a moment of time t , could be simplified by the following equation:

$$\text{Relevance (t)} = K * ((\text{total attractiveness} * \text{concentration}) + (\beta * \text{total potential of proximity}))$$

K being a value dependent on the average innovation index (Innovation Union Scoreboard), directly related to the region in which the ecosystem is located, and β a parameter that depends on the ease of management offered by the ecosystem (or the ecosystem offers ease, 1 does not offer any).

If for the example ecosystem of Figure 42 a value of β equal to 1 is identified, since there are organizations supporting innovation, and a K value of 0.40, which is the value of innovation performance for Spain in the year 2017 (latest available data) according to the Innovation Union Scoreboard⁵⁷, the relevance of the example ecosystem of Figure 42 would be as follows:

$$\text{Relevance of Figure 42 Ecosystem (t)} = 0.40 * ((26 * 16) + (1 * 543)) = 0.40 * (416 + 543) = \mathbf{383.6}$$

⁵⁷ <https://ec.europa.eu/docsroom/documents/33147/attachments/1/translations/en/renditions/native>

6.3.6.6.2 Example of calculation of the relevance in a real case: CEI Montegancedo (UPM)

In order to show the usefulness of this new concept framework presented in a real case, the following is the calculation of the relevance of the CEI Montegancedo innovation ecosystem (Center of International Excellence of Montegancedo), belonging to the Universidad Politécnica de Madrid (UPM), of the year 2015 (information is available). Figure 43 shows the actors of this ecosystem.

Figure 43. Actors of the ecosystem of the CEI Montegancedo in 2015 (Source: own elaboration)

Referring to Figure 43, where the CEI Montegancedo organizations are shown in 2015, whether they are universities, research centers, companies and public entities, grouped by their main role within the ecosystem in education, research and innovation, below in Table 25 the following information is shown:

Organization	Roles in the ecosystem	Generic type of organization
Madri+d	Education	Public entity
IBM ⁵⁸	Education	Company
INDRA	Education	Company
UCB	Education	University
EIT Digital	Education / Innovation	Public entity
Eleкта	Education	Company
Colorado	Education	University

⁵⁸ This includes both IBM Spain and IBM Research (USA).

CITRIX/CISCO	Education	Company
Telefónica	Research	Company
URJC	Research	University
CSIC	Research	Research Centre
HRyC	Research	Public entity
INIA	Research	Research Centre
UCM	Research	University
Grupo Santander ⁵⁹	Research / Innovation	Company
EPFL	Research	University
LPI	Research	Company
M&B Gates	Research	Company
Zeiss	Research	Company
ESA / BIC-ESA	Research / Innovation	Public entity
Campinas	Research	University
Accenture	Innovation	Company
Plant Response	Innovation	Company
Sharing Matters	Innovation	Company
IMADE	Innovation	Public entity
IMDEA SW	Innovation	Research Centre
T-Systems	Innovation	Company
Tong-Ji	Innovation	University
EIT Health	Innovation	Public entity
Frontiers	Innovation	Company

Table 25. Organizations of the CEI Montegancedo innovation ecosystem of 2015. (Source: own elaboration from UPM data of 2015)

In addition to these organizations, the UPM has a number of organizations belonging to the university in the CEI Montegancedo and which are described below in Table 26.

Organizations	Roles in the ecosystem	Generic type of organization
ETS de Ingenieros Informáticos	Education / Research	University
Centro español de usuarios científicos de la Estación Espacial Internacional (E-USOC)	Research	Research Centre
Instituto Universitario de Microgravedad "Ignacio Da Riva"	Research / Innovation	Research Centre
Centro de Investigación en Biotecnología y Genómica de Plantas (CBGP)	Education / Research	Research Centre
Centro de Investigación en Domótica Integral (CEDINT)	Education / Research	Research Centre

⁵⁹ Including here the companies ISBAN and PRODUBAN, belonging to the Santander Group.

Centro de Supercomputación y Visualización de Madrid (CESVIMA)	Innovation	Research Centre
Centro de Apoyo a la Innovación Tecnológica (CAIT)	Education / Innovation	University
Centro de Tecnología Biomédica (CTB)	Education / Research	Research Centre
Center for Open Middleware (COM)	Research	Research Centre

Table 26. Organizations belonging to the UPM in the CEI Montegancedo innovation ecosystem of 2015. (Source: own elaboration from UPM data of 2015)

As can be seen, the UPM performs within the CEI Montegancedo the roles of education, research and innovation, through the entities it has on Campus, according to Table 26. From the information in Table 25 it is possible know how many are the organizations of type company, university, research center and public entity, as well as the roles played by each of these entities within the ecosystem. The numbers of organizations of each type must be added to those performed by the UPM through its entities in Table 26.

At this point, it is worth noting that the value of each role for a given ecosystem will have a relative associated weight, which will vary according to their particular needs and objectives. That is, each ecosystem usually has some objectives or interests that prioritize some roles within the ecosystem in front of others. In the case of the CEI Montegancedo, the priority is innovation, as can be seen from the text found on its website: "The Campus of Montegancedo wants to make a model of open innovation guided by the user, with the intention of becoming a campus attractive that promotes sustainable technological innovation, seeking a balance between education, innovation and research and emphasizing aggregations with companies". Corroborating this fact with the Management of the CEI Montegancedo, the following table describes the relative weights associated with the different roles for this ecosystem:

Role	Associated weight
Education	25%
Research	25%
Innovation	50%

Table 27. Roles and associated weights of the CEI Montegancedo innovation ecosystem of 2015. (Source: own elaboration from UPM data of 2015)

Using the information contained in Tables 25, 26 and 27 it is possible to create Table 28, which shows the different roles carried out by the CEI Montegancedo organizations based on the new taxonomies previously defined from ecological approaches. Thus, the last column corresponds to the total number of roles played by each organization in the ecosystem with the new taxonomy.

Total number of organizations of the CEI	30 + 1 (UPM) = 31	Total number of roles performed	32 + 3 (UPM) = 35
Number of companies	14	Roles of education	8 + 1 (UPM) = 9
Number of universities	7 + 1 (UPM)	Roles of research	13 + 1 (UPM) = 14
Number of Research Centers	3	Roles of innovation	12 + 1 (UPM) = 13
Number of public entities	6	Organizations with several roles	3 + 1 (UPM) = 4

Table 28. Summary information of the CEI Montegancedo innovation ecosystem of 2015. (Source: own elaboration from UPM data of 2015)

As can be seen, in Table 29, the column "Secondary Consumer" has all its values at zero, due to the fact that this type of information could not be obtained (it is not possible to identify organizations consuming innovations of the CEI Montegancedo ecosystem, only with the available information; it would have been necessary to have a more exhaustive follow-up of this type of activities, something similar to the proposal of the integrated innovation management system of this chapter). The information that it has been possible to extract is related to the organizations of the ecosystem that are producers of both education and research, as well as those that collaborate in the generation of innovation.

Organization	Producer	Primary consumer	Secondary consumer	Supporting innovation	Organization roles⁶⁰
UPM	1	1	0	1	3
Madri+d	1	0	0	0	1
IBM	1	0	0	0	1
INDRA	1	0	0	0	1
UCB	1	0	0	0	1
EIT Digital	1	1	0	0	2
Elekta	1	0	0	0	1
Colorado	1	0	0	0	1
CITRIX/CISCO	1	0	0	0	1
Telefónica	1	0	0	0	1

⁶⁰ $Organization_roles = \sum (role_{producer} + role_{primary_consumer} + role_{secondary_consumer} + role_{supporting_innovation})$

URJC	1	0	0	0	1
CSIC	1	0	0	0	1
HryC	1	0	0	0	1
INIA	1	0	0	0	1
UCM	1	0	0	0	1
Grupo Santander	1	1	0	0	2
EPFL	1	0	0	0	1
LPI	1	0	0	0	1
M&B Gates	1	0	0	0	1
Zeiss	1	0	0	0	1
ESA / BIC-ESA	1	1	0	0	2
Campinas	1	0	0	0	1
Accenture	0	1	0	0	1
Plant Response	0	1	0	0	1
Sharing Matters	0	1	0	0	1
IMADE	0	1	0	0	1
IMDEA SW	0	1	0	0	1
T-Systems	0	1	0	0	1
Tong-Ji	0	1	0	0	1
EIT Health	0	1	0	0	1
Frontiers	0	1	0	0	1
TOTALES	22	13	0	1	36

Table 29. Actual roles performed by the organizations of the CEI Montegancedo in 2015 according to the new taxonomies (Source: own elaboration from UPM data of 2015)

Therefore, to complete the ecosystem role table, it would be necessary to have a list of organizations usually connected and associated with the Montegancedo CEI, which consume the innovations produced by this ecosystem. One way would be through access to billing organizations that generate innovations in the ecosystem in the form of products or services, from which the list of consumer companies could be obtained⁶¹.

On the other hand, at a general level, the organizations usually identified as consumer innovation organizations that normally acquire and license innovations are those that correspond to the organizations identified in Figure 43 of the company and public entity type. Therefore, all these organizations are potential consumer organizations of innovation in the CEI Montegancedo ecosystem. In the same way, the organizations identified in Figure 43 as universities are usually associated with the generation of knowledge in the form of education and research, that is,

⁶¹ The compilation of this type of information, in a centralized way, can be a very complex task to carry out at present, with the current systems and resources used.

producer organizations, and research centers with the generation of research (producers) and innovation (primary consumers).

Taking into account all of the above, with the available information it is possible to generate Table 30 using the real and potential roles (marked in red⁶²) of all the organizations of the CEI Montegancedo ecosystem, and based on the new taxonomy presented:

- Where organizations initially identified as companies and public entities can play the role of secondary consumer organizations (consumers of innovation).
- Organizations identified as universities can play the role of producer organizations (education and research).
- Organizations identified as research centers can play the roles of producers (of research) and primary consumers (consumers of research and producers of innovation).

Organization	Producer	Primary consumer	Secondary consumer	Supporting innovation	Organization roles ⁶³
(1) UPM	1	1	0	1	3
(2) Madri+d	1	0	1	0	1+1 = 2
(3) IBM	1	0	1	0	1+1 = 2
(4) INDRA	1	0	1	0	1+1 = 2
(5) UCB	1	0	0	0	1
(6) EIT Digital	1	1	1	0	2+1 = 3
(7) Elekta	1	0	1	0	1+1 = 2
(8) Colorado	1	0	0	0	1
(9) CITRIX/CISCO	1	0	1	0	1+1 = 2
(10) Telefónica	1	0	1	0	1+1 = 2
(11) URJC	1	0	0	0	1
(12) CSIC	1	1	0	0	1+1 = 2
(13) HRyC	1	0	1	0	1+1 = 2
(14) INIA	1	1	0	0	1+1 = 2
(15) UCM	1	0	0	0	1
(16) Grupo Santander	1	1	1	0	2+1 = 3
(17) EPFL	1	0	0	0	1
(18) LPI	1	0	1	0	1+1 = 2
(19) M&B Gates	1	0	1	0	1+1 = 2
(20) Zeiss	1	0	1	0	1+1 = 2
(21) ESA / BIC-ESA	1	1	1	0	2+1 = 3
(22) Campinas	1	0	0	0	1
(23) Accenture	0	1	1	0	1+1 = 2

⁶² The roles marked in red in Table 17 correspond to the potential roles that can be played by ecosystem organizations.

⁶³ $Organization_roles = \sum (role_{producer} + role_{primary_consumer} + role_{secondary_consumer} + role_{supporting_innovation})$

(24) Plant Response	0	1	1	0	1+1 = 2
(25) Sharing Matters	0	1	1	0	1+1 = 2
(26) IMADE	0	1	1	0	1+1 = 2
(27) IMDEA SW	1	1	0	0	1+1 = 2
(28) T-Systems	0	1	1	0	1+1 = 2
(29) Tong-Ji	1	1	0	0	1+1 = 2
(30) EIT Health	0	1	1	0	1+1 = 2
(31) Frontiers	0	1	1	0	1+1 = 2
TOTALS	24	15	20	1	60

Table 30. Actual and potential roles of organizations of the CEI Montegancedo in 2015 according to the new taxonomies (Source: own elaboration from UPM data of 2015)

Next, Table 31 shows the comparison of the results of Table 29 (real roles) and Table 30 (real and potential roles).

	Producer	Primary consumer	Secondary consumer	Supporting innovation	Roles
Actual roles	22	13	0	1	36
Actual and potential roles	24	15	20	1	60
Difference	+2	+2	+20	0	+24

Table 31. Comparison of results from Tables 29 and 30. (Source: own elaboration from UPM data of 2015)

The value of the concentration variable, the first factor related to relevance, could be understood as the number of organizations existing at a given moment in an ecosystem, that is, in the case of the CEI Montegancedo, which according to the ones provided by the ecosystem in 2015 it would be 31 organizations (see Table 25). However, concentration is defined as the number of ecosystem entities needed to have a critical mass. Thus, the critical mass is a concept more related to the minimum number of organizations needed of a certain type, which make an ecosystem can work. That is to say, it will be of little use, for example, to have 50 primary consumer organizations if there is not a minimum number of producer organizations that satisfy this consumption need. Therefore, the number of total roles performed within the ecosystem will be the value to be taken as concentration value, which for the case of the CEI Montegancedo would be 60 (total of the last column of Table 30).

In terms of **attractiveness**, the second factor identified with relevance, it is defined as the capacity of an ecosystem to convince public or private entities to belong to the ecosystem, a concept whose value will be equal to the sum of the individual attractiveness of the organizations that belong to the ecosystem.

The attraction value of each organization will be given by the capacity that organization has, individually, to attract other organizations. Thus, as presented above in the point 6.3.6.6.1, the attractiveness of organizations will be governed by the relationship established in the chains of knowledge, from which it is possible to deduce that:

- A producer organization (producers of education and research) will attract primary consumer organizations (consumers of education and research).
- A primary consumer organization (consumer of education and research, and producer of innovations) will attract producer organizations (producers of education and research) and secondary consumer organizations (consumers of innovations).
- A secondary consumer organization (consumer of innovations) will attract primary consumer organizations (which are producers of innovations).
- Finally, the existence of producer organizations (producers of education and research) and primary consumers (producers of innovation) will attract entities that support innovation.

Taking this approach into account, a table with the results of individual attractiveness of each organization for the CEI Montegancedo ecosystem (Table 32), defined from the real and potential roles identified in Table 30, is shown below.

Organization	Attraction of Producers	Attraction of Primary consumers	Attraction of Secondary consumers	Attraction of Supporting innovation	Organization's Attractiveness Index
UPM	YES	YES	YES	YES	4
Madri+d	NO	YES	NO	YES	2
IBM	NO	YES	NO	YES	2
INDRA	NO	YES	NO	YES	2
UCB	NO	YES	NO	YES	2
EIT Digital	YES	YES	YES	YES	4
Elekta	NO	YES	NO	YES	2
Colorado	NO	YES	NO	YES	2
CITRIX/CISCO	NO	YES	NO	YES	2
Telefónica	NO	YES	NO	YES	2
URJC	NO	YES	NO	YES	2
CSIC	YES	YES	YES	YES	4
HRyC	NO	YES	NO	YES	2

INIA	YES	YES	YES	YES	4
UCM	NO	YES	NO	YES	2
Grupo Santander	YES	YES	YES	YES	4
EPFL	NO	YES	NO	YES	2
LPI	NO	YES	NO	YES	2
M&B Gates	NO	YES	NO	YES	2
Zeiss	NO	YES	NO	YES	2
ESA / BIC-ESA	YES	YES	YES	YES	4
Campinas	NO	YES	NO	YES	2
Accenture	YES	YES	YES	YES	4
Plant Response	YES	YES	YES	YES	4
Sharing Matters	YES	YES	YES	YES	4
IMADE	YES	YES	YES	YES	4
IMDEA SW	YES	YES	YES	YES	4
T-Systems	YES	YES	YES	YES	4
Tong-Ji	YES	YES	YES	YES	4
EIT Health	YES	YES	YES	YES	4
Frontiers	YES	YES	YES	YES	4
TOTALS	15	31	15	31	92

Table 32. Attractiveness of the organizations of the CE Montegancedo ecosystem in 2015. (Source: own elaboration from UPM data of 2015)

As it can be seen from the results obtained in Table 32, it seems reasonable that the CEI Montegancedo, of university origin and therefore mainly generator of knowledge (education and research), attract more primary consumer organizations of knowledge, that is, organizations that consume education and research, and in turn to entities supporting innovation, interested in supporting the generation of innovation carried out by the primary consumers of the ecosystem. Therefore, the attractiveness of the Montegancedo CEI will be given by the sum total of the individual attractions and divided by the total number of ecosystem organizations:

$$\text{Total attractiveness} = 92 \text{ (sum of individual attractions)} / 31 \text{ (organizations)} = 2.97$$

The last factor related to the relevance, the **potential of proximity**, will be given by the possible relationships established within the ecosystem. With this objective, all the possible relationships of the CEI Montegancedo ecosystem are shown in Table 33, depending on whether they are of the same or different types, and based on the roles played by these organizations in the ecosystem (roles identified in Table 30).

Thus, a given organization may maintain only intraspecific relationships with another organization (if both perform only one role and share that same role in the ecosystem), only interspecific relationships (if both perform a single role and do not share it), or intraspecific relationships and interspecific (if they carry out more than one role, since by playing several roles it is possible to establish different types of relationships between organizations, be they the same or of different types). This last case will be the richest in terms of relationship potential and, therefore, the most interesting for increasing the potential of proximity. In Table 33, the "inter" values will correspond to interspecific type relationships and the "intra" values with intraspecific relationships.

To facilitate the visualization of the complete matrix (Table 33), organizations will be shown based on the associated number according to their corresponding order in Table 30: (1) UPM, (2) Madri+d, and so on). In addition, for simplicity, relationships will be identified in this matrix with the following symbols:

- Intraspecific (same type) = "X"
- Interspecific (different type) = "Y"
- Intraspecific and interspecific (both) = "B"

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1																															
2																															
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Organization	Number of relationships	Organization	Number of relationships	Organization	Number of relationships
(1) UPM	210	(12) CSIC	210	(23) Accenture	210
(2) Madri+d	210	(13) HRyC	210	(24) Plant Response	210
(3) IBM	210	(14) INIA	210	(25) Sharing Matters	210
(4) INDRA	210	(15) UCM	207	(26) IMADE	210
(5) UCB	207	(16) Grupo Santander	210	(27) IMDEA SW	210
(6) EIT Digital	210	(17) EPFL	207	(28) T-Systems	210
(7) Elekta	210	(18) LPI	210	(29) Tong-Ji	210
(8) Colorado	207	(19) M&B Gates	210	(30) EIT Health	210
(9) CITRIX/CISCO	210	(20) Zeiss	210	(31) Frontiers	210
(10) Telefónica	210	(21) ESA / BIC-ESA	210		
(11) URJC	207	(22) Campinas	207		

Table 34. Potential of proximity of the organizations of the CEI Montegancedo ecosystem in 2015.

(Source: own elaboration from UPM data of 2015)

From these individual values of proximity potential, the potential of total proximity of the ecosystem will be given by the sum of all the individuals, divided by the total of organizations of the ecosystem:

Total potential of proximity (according to Table 34) = $(210 \times 25) + (207 \times 6) / 31$ (number of ecosystem organizations) = $(5250 + 1242) / 31 = 209.41$

The different values obtained for the CEI Montegancedo ecosystem, necessary for the calculation of relevance, can be represented in Table 35.

Concentration index	Total attractiveness index	Total proximity potential index
60	2.97	209.41

Table 35. Summary of total factor results for relevance of the CEI Montegancedo ecosystem in 2015. (Source: own elaboration from UPM data of 2015)

The calculation of the relevance of an ecosystem starts from the attractiveness and potential of individual proximity. However, thanks to the new approach presented, a new alternative appears with which the use of the total values of attractiveness and proximity potential of the system is enabled. Therefore, the equation for the calculation of the relevance at a moment of time t , could be simplified by the following equation:

$$\text{Relevance ecosystem } (t) = K * ((\text{total attractiveness} * \text{concentration}) + (\beta * \text{potential total proximity}))$$

K being a value dependent on the average innovation index (Innovation Union Scoreboard), directly related to the region in which the ecosystem is located, and β a parameter that depends on the ease of management offered by the ecosystem (or the ecosystem offers ease 1, does not offer any 0). For the CEI Montegancedo ecosystem:

- $\beta = 1$, since there are organizations supporting innovation in the ecosystem. Specifically, the UPM carries out this work in the ecosystem through the entity CAIT (see Table 26).
- $K = 0.38$, value corresponding to innovation performance for Spain in 2015 according to the Innovation Union Scoreboard⁶⁴.
- Being t equal to the corresponding moment of representation of the information (2015).

Therefore, the relevance value for the CEI Montegancedo ecosystem in 2015 would be:

$$\text{Relevance CEI Montegancedo (2015)} = 0.38 * ((2.97 * 60) + (1 * 209.41)) = 0.38 * (387.61) = \mathbf{147.29}$$

6.3.7 Social Network Analysis (SNA)

As presented in the Chapter 3 (point 3.5.2.2 of Social Network Analysis (SNA)), SNA allows the representation of the ecosystem in graph format, which enables the analysis of the behavior carried out by the different actors of the ecosystem, both individual level as a collective.

Apart from general metrics of SNA, it is possible to identify additional ones through the application, combination and adaptation of these general metrics with concepts related to the innovation process. In this section, there are presented several metrics and tools related to the behavior of innovation ecosystems, such as sustainability or dynamism, among others.

⁶⁴ Innovation Union Scoreboard 2015 https://ec.europa.eu/growth/content/innovation-union-scoreboard-2015-0_en

6.3.7.1 Sustainability through equilibrium measures and under the optics of the Game Theory

An innovation ecosystem can be analyzed from two complementary perspectives: external and internal. Furthermore, in whatever system is important to pay attention to two main goals, efficiency and efficacy, which can be analyzed through their actors: organizations in the innovation ecosystem case. Referring to belonging relations, we can say that an organization belongs to an innovation ecosystem, which belongs to a region and, in turn, it could belong to a larger “entity” (e.g. Spain as region belonging to the European Union).

On the other hand, one of the main aims of a large organization or entity composed by regions is the “regional cohesion”⁶⁵. For instance, the Regional policy of the European Union (EU), also referred as Cohesion Policy, is a policy with the stated aim of improving the economic well-being of regions in the EU and also to avoid regional disparities. More than one third of the EU's budget is devoted to this policy, which aims to remove economic, social and territorial disparities across the EU, restructure declining industrial areas and diversify rural areas which have declining agriculture. In doing so, EU regional policy is geared towards making regions more competitive, fostering economic growth and creating new jobs. This reflects its importance for a region development.

European Union, as a large entity composed by regions, is focused on keeping cohesion and improving the economic well-being of regions. Therefore, EU should obtain results from its regions in order to can compare them and act for solving regional disparities. Thus, “the game” of a region will be based on the production of outcomes for EU in a specific time and under certain rules; this matches with the definition of “final game”⁶⁶ in the Game Theory (Myerson, 2013). However, the game of a region will be also focused on the sustainability of the own region; which in turn matches with the “infinite game” approach⁶⁷ in the Evolutionary Game Theory (Tanimoto, 2015).

⁶⁵ See for further details “Regional policy of the European Union”

https://en.wikipedia.org/wiki/Regional_policy_of_the_European_Union

⁶⁶ Games that have rules and pre-established possibilities and have an end. They are played with the purpose of winning, of obtaining an objective, and when this is achieved the game ends.

⁶⁷ The goal is the game itself and the act of playing.

Figure 44. Schema of belonging relations and aims of organizations in innovation ecosystems
(Source: own elaboration)

As shown in Figure 44, ecosystems belonging to a region should search for their sustainability and profit, in order to be efficacious, but also efficient. Accordingly, innovation ecosystem's game will be based on the sustainability of itself (an infinite game), but also to produce outcomes (a final game) for improving region economy and competitiveness. In addition, in order to keep sustainability of the innovation ecosystem, it is important that organizations belonging to this ecosystem will be efficacious and efficient too. Accordingly, organization's game should be based on the sustainability of itself (infinite game) and also produce outcomes (final games) for improving economy and competitiveness of the innovation ecosystem.

Therefore, ecosystems should search for their sustainability and profit to be efficacious and efficient. So, innovation ecosystem's game, on the one hand, is based on the sustainability of itself as in an infinite game. In short, innovation ecosystem should provide all needed by organizations belonging to this one, in order to preserve ecosystem. However, on the other hand, innovation ecosystem's game is focused on the production of outcomes as in a final game, for improving region economy and competitiveness. Definitely:

- Outcomes came from organizations belonging to the innovation ecosystem.

- Region establishes game's rules (legal, politic, social...) and defines time for presenting results (e.g. yearly).

With respect to a given organization, to keep the sustainability of an innovation ecosystem it is important that organizations belonging to this one will be efficacious and efficient too. So, organization's game, on the one hand, it is based on the sustainability of itself as in an infinite game. In short, organization main aim is focused on keeping alive. However, on the other hand, organization's game is focused on the production of outcomes as in a final game, for improving economy and competitiveness of the innovation ecosystem, but also for itself. Thus, organization will provide/sell products and services in order to earn money and continue improving, to be more competitive and growth up.

Coming back to the Game Theory concept, *"it attempts to model strategic situations where several individuals are interacting, and tries to predict what decisions individuals will take in a given situation, assuming rationality. This theory views components as players, their behavior as strategies and specifications as winning conditions"*⁶⁸, which is very relevant for aiming the present work.

Game logic can be defined through the relationships obtained from the new taxonomies (Tejero and León, 2016): competition, predation, parasitism, mutualism, commensalism and consumerism. Table 36 describes this logic between two whatever nodes A and B of the ecosystem. Each node could obtain values between 0 and 1. Note that the relationships of competition, parasitism and commensalism could be together, because they share the same values. Mutualism and consumerism could be also for the same reason (in fact, consumerism is itself a subtype of mutualism, so this is reasonable).

Nodes	Competition		Predation		Parasitism		Mutualism		Comensalism		Consumerism	
	A	B	A	B	A	B	A	B	A	B	A	B
Values	1	0	1	0	1	0	1	1	1	0	1	1
	0	1	0	1	0	1	-	-	0	1	-	-
	-	-	1	1	-	-	-	-	-	-	-	-

⁶⁸ CASSTING project https://cordis.europa.eu/news/rcn/125159_en.html

Table 36. Game logic using relationships of new taxonomy obtained from ecological sciences.

(Source: own elaboration from Tejero and León, 2016)

Such as it can be seen in Table 36, when nodes A and B hold a relation of competition, values can be (1 / 0) if A wins and (0 / 1) if B wins. With respect to the relationship of predation, values (1 / 1) are given when A or B nodes wanted to be “eaten”⁶⁹ and values (1 / 0) or (0 / 1) when no. Through this approach, the value of one node will be given from the sum of the total value based on all its relationships within the ecosystem. In this sense, node must maintain a double equilibrium, keeping moving⁷⁰ for its own sustainability (infinite game), and, at the same time, overcoming a predefined threshold (end game) for the ecosystem sustainability which it belong. Ecosystem sustainability will be given when ecosystem is in equilibrium, based on a predefined threshold too. Axioms that describe the sustainability related to overcome these predefined thresholds, for both nodes (actors) and ecosystem, can be defined as follows:

- **[Node equilibrium]** = [Node value] / [Number of node relationships within ecosystem]
 - o Where *[Node value]* is the sum of total value based on all its relationships within ecosystem.
 - o **A** node will not be in equilibrium if its *[Node equilibrium]* variable is between 0 and 0.4 (taking it as well-known assumption, since 0 is the lowest value and 1 the highest).
 - o Hence, **A** node will be in equilibrium if its variable of *[Node equilibrium]* is between 0.5 and 1.
- **[Ecosystem equilibrium]** = [Sum of values of all nodes] / [Number of nodes * (Number of nodes – 1)]
 - o An ecosystem will not be in equilibrium if the *[Ecosystem equilibrium]* variable is between 0 and 0.4.
 - o An ecosystem will be in equilibrium if the variable of *[Ecosystem equilibrium]* is between 0.5 and 1.

Example of an ecosystem with three nodes A, B and C (see Figure 45):

⁶⁹ The goal of some companies use to be eaten by others, this is, grow to be sold.

⁷⁰ Having paths to go to, within the ecosystem.

Figure 45. Example of ecosystem based on Game Theory logic and using relationships from new taxonomies (Source: own elaboration)

- **A** node holds 2 relationships and its value is 2. Therefore, [Node A equilibrium] = $2/2 = 1 > 0.5$. It means that **A** node is in equilibrium.
- **B** node holds 2 relationships and its value is 1. Therefore, [Node B equilibrium] = $1/2 = 0.5 = 0.5$. It means that **B** node is in equilibrium.
- **C** node holds 2 relationships and its value is 0. Therefore, [Node C equilibrium] = $0/2 = 0 < 0.5$. It means that **C** node is not in equilibrium. So, it is necessary to act in order to solve this situation. This can be solved by the own node or, if necessary and relevant for the ecosystem, by the own innovation ecosystem (applying new rules, ...).
- [Ecosystem equilibrium] = $(2+1+0) / (3*2) = 3 / 6 = 0.5 = 0.5$. It means that the ecosystem is in equilibrium.

Ecosystem efforts will focus on maintaining certain conditions for actors can develop their relationships within the ecosystem and, therefore, “keeping moving”⁷¹ for their sustainability (infinite game).

With respect to the type of actors defined, using the new taxonomy of organizations (producers, primary consumers, secondary consumers and support organizations), it will also necessary to keep a certain equilibrium, due that an ecosystem will cannot works if there are not enough producers to generate and guarantee that the knowledge flows (with the support of the support organizations), but also consumers that transform and consume that knowledge.

Taking advantage of the variable of the node value, it can be defined the equilibrium of each group of actors according to the following:

⁷¹ It is related to the "Dynamism" of the actor.

- **[Group equilibrium]** = [Sum of values of all group nodes] / [Number of group nodes * (Number of group nodes – 1)]
 - A group will not be in equilibrium if the *[Group equilibrium]* variable is between 0 and 0.4.
 - A group will be in equilibrium if the variable of *[Group equilibrium]* is between 0.5 and 1.

Recapitulating, actors of innovation ecosystem (producers, primary consumers, secondary consumers and support organizations) will play to get their own sustainability, but also the sustainability of the system. Thus, their behavior and game strategies are crucial for these purposes.

6.3.7.2 Dynamism

Nowadays, knowledge cannot be considered as a static element. In open innovation environments, the exchange of knowledge is essential and a common practice, so understanding its dynamics, through its management and analysis, can bring great benefits not only operational but also strategic. In fact, innovation ecosystems are systems that, in essence, create, move and transform knowledge. So, in particular, the dynamism may let us know what the capacity of the ecosystem at any given time is to move knowledge, but also monitoring its evolution over time and make decisions based on this metric for operational and strategic purposes (Tejero et al., 2019).

According to Oxford dictionaries, dynamism can be defined as follows:

- (Quality) The quality of being characterized by vigorous activity and progress. For example, “the dynamism and strength of the economy”.
- (Philosophy) (historical) The theory that phenomena of matter or mind are due to the action of forces rather than to motion or matter.

The movement due to the forces, second definition of dynamism, is a concept more associated to the one explored previously in the section dedicated to the calculation of sustainability. That is, different forces come into action, in a combination of finite and infinite "games", to generate the movement of a certain entity or "thing". Here lies precisely the main connection between sustainability and dynamism. From its analysis and joint understanding, it is expected to obtain highly relevant information for decision-making.

On the other hand, the dynamism concept, according to the first meaning of the above definition related to an attribute or quality can be associated to the movement or vigorous activity. Specifically, in the case of innovation ecosystems, movement will be associated with the essential element of these

ecosystems, that is, knowledge. Knowledge moves in the ecosystem network (graph) among the different actors (nodes) through their relationships (edges). Therefore, the "mobile" element is a type of knowledge (whether scientific, technological, business-oriented, etc.) and the causes of its movement, i.e. "what forces act" to cause that movement, are very important aspects to take into account for decision-making. A clear example in a university-driven ecosystem is the creation of a spin-off from the common knowledge shared by people from various departments, university centers, etc. Thereby, in innovation ecosystems, dynamism can be associated with the actors and their relationships, taking into account the following principles:

- The more relationships there will in the ecosystem, higher will be its potential dynamism because actors will have more options for moving knowledge through these relationships.
- The more actors there are in the ecosystem, higher will be its potential dynamism because it will have more actors for moving the knowledge (this will only be true when the number of relations provided by the new actor to the ecosystem is enough to maintain or increase the pre-existing dynamism).

With respect to the dynamism calculation, the simplest measure that can be imagined to establish the relationships between points and lines is the density of the graph. Density represents the number of links that are established between the nodes in relation to a maximum number that could be established if all the actors were directly connected by a line with all the others; in such a way, the maximum density is 1 (for a complete graph) and the minimum density is 0 (Coleman and Moré, 1983). Therefore, on the graph created from (Tejero and León, 2016), starting from the density formula ($Den = \frac{2Ln}{n(n-1)}$) and using the degree measure ($CD(n_i) = \sum_j (x_{ij})$), which represents the number of actors to which an actor is directly connected, is possible to calculate the dynamicity as described below (Tejero et al., 2019):

$$Dynamism = \frac{\sum_{i=1}^A \sum_{j=1}^{M_i} R_{ij}}{(A \times (A - 1) \times N)}$$

(From a minimum of 0 or low dynamism to a maximum value of 1 or high dynamism)

Where:

- A, number of actors
- R, number of relationships between two nodes (edges of the graph)

- N, types of relationships (competition, predation, parasitism, mutualism, commensalism, and consumerism)
- M_i , degree of actor i

Figure 46. Example of actors and relationships of an innovation ecosystem for calculating the dynamism (Source: (Tejero et al., 2019))

As simple example of use, using the dynamism formula in the ecosystem X, showed in Figure 46, the result should be the following:

Dynamism (X) = $((R_{ij}+R_{ik}+R_{il}) + R_{ji} + (R_{ki}+R_{kl}+R_{kv}) + (R_{li}+R_{lk}+R_{lz}) + (R_{vk}+R_{vz}) + (R_{zl}+R_{zv})) / (6*(6-1)*6) = ((2+2+1) + 2 + (2+1+3) + (1+1+6) + (3+4) + (6+4)) / (6*5*6) = (5+2+6+8+7+10) / (30 * 6) = 38 / 180 = 0,21$ (at first instance and in absence of more information, it should mean low dynamism, because it is closer to the 0 value than the 1 value)

- Where: $A = 6$, $R = 7$, $N = 6$, $M = \{i=3, j=1, k=3, l=3, v=2, z=2\}$

The dynamism could be a powerful and very useful tool, which in combination with others can yield results of great interest in the context of open innovation ecosystems. Below it will see an example of its application for the calculation of relevance, as an alternative to the one presented in the previous section 6.3.6.6.

6.3.7.3 The relevance based on the dynamism and performance

According to Cambridge Dictionary, relevance can be defined as follows: “the degree to which something is related or useful to what is happening or being talked about⁷²”. Therefore, the relevance of an ecosystem with its environment, whether regional, national, etc., will be given by the relationship or utility of the innovation ecosystem to its environment, that is, how it affects it.

On the other hand, trying to simplify as much as possible the innovation ecosystems function, innovation ecosystems can be seen like systems that, in essence, are dedicated to move knowledge and transform knowledge. Taking into account, as shown in Chapter 3, that the importance of knowledge at the economic level is well recognized (OECD, 1997), the movement and transformation of knowledge in the ecosystem would be relevant, therefore, to its environment at economical level, that is, it will be effect in its economic development.

Moving knowledge might be represented by the “dynamism”⁷³ of the ecosystem and transforming knowledge with its “efficiency” or performance. Thus, an innovation ecosystem will be more “relevant” if its dynamism is higher as well as its efficiency. In other words, the more dynamic an ecosystem is and the higher is its efficiency, the higher will its relevance be, because more knowledge will have been moved, allowing for more new options, and more knowledge will have been created successfully. This affirmation can be presented as follows (Tejero and León, 2016):

$$\text{Relevance} = \text{Dynamism} \times \text{Efficiency}$$

Dynamism was defined in the above point. On the other hand, efficiency can defined through the rate of inputs and outputs of the ecosystem. It is something that could be calculated using metrics generated through the approach of Howard T. Odum.

Odum was an American ecologist. He is known for his pioneering work on ecosystem ecology⁷⁴, and for his provocative proposals for additional laws of thermodynamics, informed by his work on general systems theory. Among others, Odum received the French Prix de Vie, and the Crafoord Prize of the Royal Swedish Academy of Science, considered the Nobel equivalent for bioscience.

⁷² Definition of relevance: <https://dictionary.cambridge.org/dictionary/english/relevance>

⁷³ Dynamism is related to the path dependence concept (David, 1994).

⁷⁴ Howard T. Odum https://en.wikipedia.org/wiki/Howard_T._Odum#Ecological_modeling

Figure 47. Ecosystem represented using Odum's approach (Source: Brown, 2004)

In 1960, Odum developed an analogy of Ohm's law⁷⁵ to represent ecosystem flows. Resistances represented the producing and consuming populations, batteries represented solar energy and energy imports, and the flows were currents in the electric wiring (Golley, 1993).

Using the approach and diagrams created by Odum, it would be also possible to generate an own symbology for innovation ecosystems (see Figure 48).

Figure 48. New symbology for innovation ecosystems created from Howard T. Odum approach
(Source: own elaboration)

⁷⁵ Ohm's law https://en.wikipedia.org/wiki/Ohm%27s_law

Using this new symbology, Figure 49 depicts a simple example of knowledge flow in a fictitious innovation ecosystem.

Figure 49. Example of knowledge flow representation using the new symbology created from the approach of Howard T. Odum (Source: own elaboration)

In Figure 50 is depicts the flows of producers and consumers internally, from the consumption of inputs until the production of their respective outcomes. As can be seen, in all cases, part of the knowledge generated it is reversed to be used in the process of creating of the own knowledge (shown in red).

Figure 50. Internal processes of organizations carry out for consuming and production in innovation ecosystems (Source: own elaboration)

In ecological ecosystems, some organisms are able to make their own food from chemicals, using solar energy (this process is called photosynthesis). Plants that make food products are called

producers. This food is used by living cells to make more cells and form organic matter, such as wool and fat. Organic products of living organism are sometimes called biomass. Thus, ecological ecosystems generate matter (included biomass) and use energy to produce this matter. Therefore, the units used to represent and measure these flows are energy and matter.

In innovation ecosystems, the units are not the same. Firstly, innovation ecosystems generate knowledge and not matter. On the other hand, in innovation ecosystems it is not always easy to measure production of knowledge through the energy (e.g. financial funds are difficult to translate in energy metrics). In this case, it will be better to use time as unit of measure and, more specifically, person-hour. Person-hour is a conventional unit to quantify the hours of presence or intervention of people in a process or activity, and, precisely, all process in innovation ecosystems are conducted by people, in order to transform inputs to outputs in the form of knowledge. Some examples:

- Person-hour for training a student (hours dedicated by professor per student).
- Person-hour for researching (hours of a researcher dedicated to a research project).
- Person-hour to innovate (hours of a professional dedicated to an innovation project).
- Person-hour for commercialising (hours of a professional dedicated to commercialize a new product or service).

It is presumed that the new symbology could allow to measure the time expended not only in each of the processes, but also measure time dedicated to generate an innovation, the average to produce outcomes per each dimension (education, research and innovation) and, even, to get economic totals transforming the time obtained to monetary units (e.g. one person-hour is equal to twenty Euros in the education dimension).

6.3.7.4 Actuation tools: connectors and events

Each actor of an ecosystem has its own goals and interests, although many times they are pre-configured based on their roles or functions (institutional missions) (Scott, 2008). In general terms, organizations with the role of “producer” access to innovation ecosystems to participate in the “production” of education and research activities, such as educational programs and research projects (mainly), but also to connect with primary consumer organizations to transfer them new knowledge (within education and research dimensions).

On the other hand, primary consumer organizations access to innovation ecosystems to conduct innovation using knowledge from education and research dimensions (Tejero and León, 2016), getting

innovation whether in the form of new patents, spin-off, etc; knowledge produced by primary consumer organizations, within the innovation dimension, is transfer to secondary consumer organizations.

Therefore, secondary consumer organizations access to innovation ecosystems to commercialize or consume innovation products and/or services. Finally, support organizations will access to innovation ecosystems in order to support the maintenance of the cycle of knowledge, through its management, processing and supporting (to support the whole process).

As seen, not all organizations seek the same when they access to innovation ecosystems, depending on their needs and interests). This is an important point and one that should be considered since from its understanding it is possible to conclude very relevant decisions that can be taken to benefit the satisfaction of actors, but also to improve the sustainability of the whole ecosystem (Iansiti and Levien, 2004). Here, it is the main connection of the actuation tools with the sustainability concept, presented above.

Since an innovation ecosystem needs actors to work properly (remember equilibrium equations shown in point 6.3.7.1), one key aspect is to know how to attract relevant actors and how to retain them into the ecosystem (Rabelo and Bernus, 2015). From that perspective, any given ecosystem will have a series of “connectors and events” that will help improve its dynamism and sustainability over time (Tejero et al., 2019).

“Connectors” are timeless elements⁷⁶, used by the actors of the ecosystem in a recurrent way to interrelate them in a voluntary basis without being forced to do so⁷⁷. On the other hand, “events” are elements associated to specific moments in time, which provoke the interaction of actors of the ecosystem around a specific connector or set of connectors; then, actors are retained into the ecosystem because of these events. Both connectors and events, complement each other, making the ecosystem more dynamic, more “alive”, attracting and keeping actors into the ecosystem. Therefore, connectors and events are also related to the dynamism of the ecosystem: actuation tools can be used to improve the ecosystem dynamism.

Connectors and events are not restricted elements to innovation ecosystems. In fact, examples of connectors and events can be found in different types of ecosystems:

⁷⁶ Although all things are related to time in one way or other, according with their function and comparing with the “events”, connectors are less dependent to the time variable.

⁷⁷ Actors feel themselves attracted by one specific connector of the ecosystem due their own interests and motivations.

- In people ecosystems (non-digital), for instance a beach ecosystem, a volley-ball net installed on the beach or a soccer/rugby ball are typical examples of connectors, while a concert of a group of musicians in a beach bar or a Zumba class into the water are usual examples of these events⁷⁸.
- In ecological ecosystems, we can find examples of events such as migrations of birds, and a puddle of water or lake as a connector where the animals of a certain region meet regularly to drink water, cool off, etc.
- In a social network, as a typical case of a digital ecosystem, the publication of a photo or even a post is the typical case of an event, while the influencers are clear cases of connectors.
- In innovation ecosystems, the usual connectors are the so-called support organizations. It could also exist connectors with the role of producer or consumer. However, the support organizations are the most common, since one of their main functions is to help maintain the ecosystem. In the case of the innovation ecosystem of the UPM, an example of connector is the “Center for Technology Innovation” (CAIT), which carries out this role, connecting entrepreneurs of the university with investors and business experts, among many other complementary roles; as example of events, the annual business models competition organized within a university community (actúaupm). The “Office for International Projects” (OPE) of the UPM plays a similar role for researchers preparing proposals for calls for participation in projects for programs such as the H2020 of the European Union; one event is the information day for a specific call issued by the European Commission.

The application of these concepts and metrics to the context of innovation ecosystems implies a set of steps:

- First, identify the interests, objectives and needs of the different groups of the ecosystem.
- Identify, or design and implement (if they do not exist yet), connectors and events tailored specifically to each group, according to the strategy and resources of the innovation ecosystem, to attract and energize the organizations of greatest interest for the ecosystem that allow its dynamism and sustainability over time.

Finally, on other issues, in open innovation (Chesbrough, et al., 2006; Chesbrough, 2003) the concepts of connectors and events can also be applied. For example, in an open innovation ecosystem associated with a company (industry-driven innovation ecosystem), a usual connector would be its IT

⁷⁸ Beaches of innovation [https://www.linkedin.com/pulse/beaches-innovation-alberto-tejero-lopez/\(8-01-2019\)](https://www.linkedin.com/pulse/beaches-innovation-alberto-tejero-lopez/(8-01-2019))

department and the associated event would be a call launched by that department to solve a specific challenge of interest to the organization. A business incubator could also be represented as an example of a connector in an innovation ecosystem and the different phases of its incubation program such as associated events.

6.3.7.5 Example of application of new taxonomies and SNA to a real case: UPM case

UPM is a Spanish technological university strongly focused on transforming the knowledge generated into advances applied to the production sector. The UPM reacted to the pressure from public administrations to develop specific internal mechanisms in order to exploit the results of R&D with the creation of the Centre for Technology Innovation (CAIT) in 2012 as a part of the activities funded by the Campus of Montegancedo (CEI Montegancedo, 2015). Through the institutional entrepreneurship⁷⁹ and commercialization of technologies⁸⁰ programs, open to the community of the university, the UPM was able to build up and consolidate a solid reputation in Spain as the leading university in technology transfer outcomes. In particular, the success of the *actúaupm* entrepreneurship program in the UPM (managed by the CAIT) with around 20 new companies created annually (248 since 2007) was able to attract more than €60M since 2007 from venture capital firms. From the previous historical period and reinforced in the last decade at the international level, there is a strong connection of the UPM with the interests of industrial sectors, which has derived in a very large number of contract research agreements and joint participation in collaborative research at the national and international level. Consequently, schools, departments and individual faculty members of the UPM keep a continuous and solid relationship with the industrial sector through a number of funding instruments and personnel interactions in research, education and knowledge transfer activities (León, 2013). Thus, the university-driven innovation ecosystem of the UPM is composed of organizations belonging to the structure of the UPM (schools, foundations, research centres, CAIT, Business Centre, etc.) and other organizations, such as industrial partners (e.g. Accenture), public entities (e.g. EIT Digital), start-ups, spin-offs, etc.

In this point, it will show a way to conduct the framework to systematically implement and analyze the structure and fluxes of a university-driven innovation ecosystem for decision-making, using the

⁷⁹ *Actúaupm*

http://www.upm.es/Investigacion/innovacion/CreacionEmpresas/Servicios/Competicion_Creacion_Empresa

⁸⁰ *Innovatech_UPM* <http://www.upm.es/Investigacion/innovacion/InnovacionComercializacionTecnologias>

new taxonomies from ecological sciences and SNA. The case used to test the new framework is the UPM innovation ecosystem.

Since the first objective is to establish the framework for the analysis and monitoring of the UPM ecosystem, in order to do this, the graph of the UPM ecosystem will first be created using the new taxonomies of point 6.3.6. Once the ecosystem has been modelled through the graph, SNA and dynamism metrics can be applied to the graph. The final purpose of this example is to assess the impact of entrepreneurship in the dynamism of the UPM ecosystem, for a double reason: 1) Test the usefulness of the tools (SNA and dynamism) and their reaction to typical events produced in this type of ecosystem, as occurs with entrepreneurship, which is used as a resource (one of them) for the exploitation of R&D results ; 2) Check the operation and utility of the actuators, seen in section 6.3.7.4 (in the case of UPM, actuators will be the CAIT as connector and actúaupm program as event).

It will be followed several steps, which will facilitate the systematic application of the framework and obtaining the necessary information (Tejero et al., 2019):

1. Identify the organizations that conform the skeleton of the UPM innovation ecosystem; i.e. from where the knowledge begins to flow within the ecosystem (producer organizations core or core producer system).
2. Identify the organizations that support the innovation ecosystem; i.e. the organizations that originally support that knowledge continues to flow in the ecosystem (supporting innovation organizations).
3. Describe how core organizations are connected (both, producers and support). Core organizations are the organizations that are essential part of the structure of the ecosystem, from knowledge starts and flows.
4. Use available sources of information to represent the universe of connections around the organizations that conform the core of the ecosystem analysed; i.e. identify the rest of producer, support and consumer organizations that are connected to the core organizations (if possible, it is recommendable to use several years to analyse the evolution over time and be able to extract more conclusions).
5. Use tools and metrics to analyse the UPM innovation ecosystem; i.e. explain how organizations are connected, how the knowledge flows, the most influencer

organizations, detect malfunctions, calculate the dynamism of the ecosystem and draw conclusions for supporting decision making about the ecosystem. In short, the purpose in the UPM case is to do:

- An analysis of the dynamism of the ecosystem, in order to verify that the ecosystem is prepared to house the flow of knowledge and know how the entrepreneurship affects the dynamism.
- An analysis of the actors and ecosystem behaviour using SNA metrics on the ecosystem modelled (graph).
- Extraction of conclusions, suggestions and recommended actions, based on all information collected.

6.3.7.5.1 Identification of producer organizations core

An organization can be defined as “a collection of people organized together into a community or other social, commercial or political structure, who share common goals”⁸¹. In the case of UPM, its technical schools, departments, research groups, and research centres can be defined as the organizations (actors) that compose the core structure of the UPM innovation ecosystem (at the time of this work, UPM disposes of 17 faculties and engineering schools, 60 departments, 204 research groups, and 19 research centres).

6.3.7.5.2 Identification of support organizations core

In the UPM, support organizations related to innovation are found, mainly, in the Rectorate of UPM and they belong to the Vice-rectorate of Research, Innovation, and Doctorate⁸². There are different sub-organizations that depend on the Rectorate to support the innovation ecosystem, but those most related to innovation are the Centre for Technology Innovation (CAIT), the Business Centre, the Office of Transfer of Research Results (OTRI) and the Office of European Projects (OPE). In this case, since the

⁸¹ The Organization Ontology. <https://www.w3.org/TR/vocab-org/>

⁸² There are more organizations in the UPM ecosystem in relation to innovation and they depend on other vice-rectors: the realization of projects with the private sector goes through the USRE and the OTT that depend on another vice-rector's office; the educational innovation agreements belong to a different vice-rectorate; the university-business chairs depend on another vice-rectorate too, as well as the foundations.

analysis pretends to assess the impact of the entrepreneurship in the dynamism of the ecosystem, the support organization used for the analysis in this example will be the CAIT.

6.3.7.5.3 How core organizations are connected

The producer organizations of UPM are connected as follows:

- One department belongs to one centre and usually maintains with it a relationship of commensalism.
- One centre has one or more departments.
- One research group belongs to one or more centres and maintains with them a mutualism relationship.
- One centre has one or more research groups.
- One research group belongs to one department and maintains with it a mutualism relationship.
- One department usually has one or more research groups.
- One research group can belong to one, many or no research centre and maintains with it a mutualism relationship.
- One research centre has one or more research groups.

Furthermore, as seen above, the support organizations of UPM belong to the Rectorate (with the exception of foundations), which is connected in turn to all the producer organizations of UPM. Therefore, since Rectorate is connected to all organizations, in Figure 51 it is only represented the innovation ecosystem core with the producer organizations, in order to distinguish better their connections. In addition, the support organizations role can be seen much better through the representation of the organizations that they attract and help to connect, as ecosystem's connectors.

Figure 51. Structure of the producer organization's core of the UPM innovation ecosystem
(Source: Tejero et al., 2019)

As Figure 51 depicts, almost all the organizations of the ecosystem are connected although there are three groups of organizations that are not connected to the rest of the ecosystem (three centres with their respective associated departments and research groups). This is typically found in whatever ecosystem, due to the specialization of its organizations, recent events happened into the ecosystem, arising from very new organizations, etc. The most important thing here, when these kinds of things are detected, is to identify if there is a problem and how these organizations can be connected with the rest of the ecosystem to act as a "whole"⁸³.

⁸³ One way to act is to use connectors and events for these purposes.

6.3.7.5.4 Use of information sources

There are different sources where it is possible to find relevant information for describing the activities that are typically involved within an innovation ecosystem, such as patents, projects, new start-ups and so on. In this sense, considering the stages of the whole innovation process, from the discovery stage to the commercialization of the technology, their main actors (according to the classification of Deborah J. Jackson, 2011) and roles played in relation to the knowledge process (based on Tejero and León, 2016), it is possible to identify in Figure 52 these sources of information.

Figure 52. Sources of information of an innovation ecosystem in relation with actors and actors' roles (Source: own elaboration from Jackson (2011))

It is important to highlight that in all the sources of information depicted in Figure 52 can be identified, at least, one main connector (it is normally an organization of support belonging to the ecosystem), that helps to the generation and development of such actions and, hence, to the existence of this source of information. In fact, at the UPM, CAIT acts as main “connector” in the creation of start-ups and spin-offs through the actúaupm “event”, which takes place every year and it is composed by different activities or sub-events too.

The main source of information used in the case study is the S2I database, owned by the UPM. This database stores the information related to the different administrative research entities of the university. In addition, S2I also stores the spin-off created within the university, and their relationship with existing university entities. This information is updated instantaneously with each change of state of a company (creation, disconnection with the entities of the university or closure). Figure 53 shows a simplified view of the S2I relational model:

Figure 53. Simplified view of the S2I relational model (Source: Tejero et al., 2019)

All this information will serve to create the innovation ecosystem model of the UPM. In the model, there is a more stable part, formed by the administrative entities whose changes are unusual (core organizations), and a more dynamic part that represents the spin-off (and startups).

6.3.7.5.5 Measurement, analysis and extracting conclusions

As mentioned in Chapter 3, start-ups and spin-offs are typical examples of R&D&I outcomes in university-driven innovation ecosystems. For that reason, the information depicted in Figure 52 as “Start-ups/Spin-offs” is analyzed below to assess the impact of entrepreneurship in the dynamism of the UPM ecosystem (on the UPM producer organizations’ core). It will be compiled in an evolution analysis in the last five years, from 2013 to 2017.

The UPM ecosystem⁸⁴ is creating an average of 20 companies per year⁸⁵. However, the information of Table 37 shows that the dynamism decreases every year with the adding of the new organizations coming from the current UPM event.

⁸⁴ Specifically, the CAIT organization with the actúaupm event, which is its entrepreneurship institutional program.

⁸⁵ Other well-known examples, such as the MIT, are creating 25 companies per year.

	Organizations number		Relationships number		Dynamism (0 minimum, 1 maximum)	
UPM Core	300		581		0,00108	
2013	318	↑	595	↑	0,00098	↓
2014	338	↑	605	↑	0,00089	↓
2015	364	↑	624	↑	0,00079	↓
2016	384	↑	639	↑	0,00072	↓
2017	401	↑	649	↑	0,00067	↓

Table 37. Dynamism of the UPM innovation ecosystem. (Source: own elaboration from the information extracted from the UPM S2I database and the network analysis and visualization tool Gephi⁸⁶)

According to Table 37, from the UPM ecosystem point of view, the adding of new companies (spin-off and start-ups) in relation to the creation of new relationships into the ecosystem is not enough to preserve or even increase its dynamism. Of course, the new companies added are potential opportunities for the ecosystem. However, the opportunities are such when are taken advantage through actions, reflected in relationships such as (see Figure 52): projects, patents, etc.

The data of Table 37 confirms that only the creation of companies in entrepreneurship does not improve to the dynamism of the ecosystem. It is necessary something more: an increase of relationships and, for example, to generate more connectors and events. Table 38 depicts the relationships that would be needed to have with respect to the new companies added, in order to keep, at least, the dynamism of the ecosystem.

	Organizations number	Relationships number	Number of relationships really necessary (inflection points)	Dynamism
UPM Core	300	581	-	0,00108
2013	318	595	653	0,00108
2014	338	605	738	0,00108
2015	364	624	856	0,00108
2016	384	639	953	0,00108
2017	401	649	1039	0,00108

Table 38. Number of relationships required per companies added to the ecosystem to keep the same dynamism. (Source: own elaboration from the information extracted from the UPM S2I database and the network analysis and visualization tool Gephi)

⁸⁶ Gephi <https://gephi.org/>

At this point, it is noteworthy that in the UPM case only has been used the information from the creation of the start-ups and spin-off through the CAIT as connector and the event of actúaupm. That is, it is a simplified version that will have limitations if external responses are sought to the scope of action of the decision-making regarding the management of the actúaupm event. However, with this example, it is possible to show how the entrepreneurship affects the ecosystem, which is the purpose and what was intended to demonstrate with this example.

From previous analysis, it would be required the activation of other connectors (CAIT) and events (actúaupm) to preserve and even increase the dynamism during the creation process. For instance, promoting the connection between the UPM core organizations and the new start-ups and spin-off in one or several of the stages of the process: adding co-working sessions, sharing of research results to their commercialization, etc.

In addition to the dynamism metric, SNA can provide another evidence of the low dynamism of the ecosystem using general metrics. In Table 39, some SNA metrics can help for this purpose.

	Graph Density	Average Clustering Coefficient	Average Degree	Connected components	Modularity	Eigenvector Centrality	Average Path length
UPM Core	0,013	0,550	3,807	4	0,832	0,0345	6,130
2013	0,012	0,545	3,673	12	0,828	0,0355	6,167
2014	0,010	0,543	3,503	24	0,828	0,0359	6,137
2015	0,009	0,540	3,357	31	0,828	0,0365	6,162
2016	0,009	0,539	3,260	36	0,828	0,0364	6,193
2017	0,008	0,539	3,167	44	0,828	0,0368	6,195

Table 39. Comparison of SNA Metrics from 2013 to 2017 of the UPM innovation ecosystem.

(Source: own elaboration from the information extracted from the UPM S2I database and the network analysis and visualization tool Gephi)

The first metric that indicates low dynamism of the ecosystem is the Density⁸⁷. In this case, Table 39 shows a decreasing from the UPM core to the year 2017. Another metric that confirms the decreasing of the dynamism is the referred to the “Connected components” in Table 39. As can be

⁸⁷ “Graph density” represents the number of links that are established between the nodes in relation to a maximum number that could be established if all the actors were connected directly by one line with all the others.

seen, this metric starts with 4 components unconnected (see Figure 51 to identify these components) and finish with 44, which indicates that were added new organizations to the ecosystem that were not connected with the rest of the ecosystems, that is, they did not add new relationships. As seen above, this contributes to the decreasing of the ecosystem dynamism.

Apart from what has been shown so far, there are other benefits of using SNA on the innovation ecosystem graph. For example, it is possible to know what are the most influencer organizations of the ecosystem, what are the entities that intermedia between two different sectors, etc. Below, in Table 40, can be seen some examples.

Questions	Metric used	Influences	Answers
What is the organization more important or influent of the ecosystem in 2017?	"Degree" (influencer) defines the importance of an individual node in the network	Having more opportunities and alternatives	ETS DE INGENIEROS DE TELECOMUNICACIÓN (Degree = 48)
What is the organization that connects the sectors of "ICT" and "Transport, security, and space" in the of the UPM ecosystem in 2017?	"Betweenness" (intermediaries or gatekeepers) represents the control of others' communication and their ability to restrict it	Brokering contacts among organizations to isolate them or prevent connections	CENTRO DE INVESTIGACIÓN EN SIMULACIÓN COMPUTACIONAL (Betweenness = 0,26)

Table 40. Questions about the UPM ecosystem answered thanks to the new framework. (Source: own elaboration from the information extracted from the UPM S2I database and the network analysis and visualization tool Gephi)

Figure 54 depicts one of the examples. Specifically, the intermediary organization between the "ICT" and "Transport, security, and space" sectors in 2017 for the UPM case (the colours represent the different industrial sectors identified in the ecosystem). Organizations in blue belong to the "Transport, security and space" sector and the red ones to the "ICT" sector.

Figure 54. Intermediary organization between the sectors of “ICT” and “Transport, security and space” of the UPM innovation ecosystem in 2017. (Source: own elaboration from the information extracted from the UPM S2I database and the network analysis and visualization tool Gephi)

The information obtained in the two examples in Table 40 can be very useful for decision-making. For example, taking advantage of the influence of the “ETS DE INGENIEROS DE TELECOMUNICACIÓN”, in the year 2017, the UPM could extend the use of certain software or the promotion of any activity throughout the UPM, putting all the resources in convincing only this organization (avoiding making a broadcast type communication to the whole ecosystem). In another example, if an ICT organization of the UPM ecosystem, asked whom it would have to contact to explore possibilities for carrying out an investigation project in the aerospace sector, the direct answer would be to contact the “CENTRO DE INVESTIGACIÓN EN SIMULACIÓN COMPUTACIONAL”.

6.4 Disruptive approach

6.4.1 Conceptual schema of the chapter

Figure 55. Conceptual schema of the Theory Background Chapter (source: own elaboration)

Blue color is used to show the main topics of the chapter. The main concepts of the topics are shown in **black color**. Finally, the case studies and results are shown by the **green color**.

6.4.2 Disruptive approach description

In the previous section, an incremental approach to the evolution of university-driven innovation ecosystems has been presented. In this section, a more radical / disruptive approach is presented, which is presumed would allow universities not only to face the challenges presented in Chapter 4, but also greater integration with their ecosystems. In Figure 56, this fact is shown by the analogy with the trees, trying to show graphically what the difference lies in (tree planted in the soil of the field vs. tree in a pot).

Figure 56. Analogy between trees and universities in relationship with their ecosystems. Image on the left would be more related to the disruptive approach (Source: own elaboration)

Indeed, the main reason that could lead a university to face a more disruptive approach, would be the promise of a greater benefit, be much more prepared to face all the challenges presented in Chapter 4, also taking advantage of the potential of the competitive advantages that could be offered, for example, by the new technologies available for an adaptive development to the new times, users, suppliers and competitors. However, the real potential, and perhaps a major disruption characteristic of the approach presented below, lies in the possibility it offers to universities for integration with their ecosystems.

The universities now have their own sources of information and resources, with the well-known problems of information storage and management presented in Chapter 4. These sources of information, in the vast majority of cases, are only accessible by the university, not being connected to the outside. Broadly speaking, this situation could be associated with the case of the tree in a pot shown in the right image of Figure 56. The connection with "the outside", that is, the enrichment of internal information sources with other external sources (its connection, in short), would allow not only a greater benefit for the universities, but also for the rest of the actors of their ecosystems; these actors could also take advantage of the fact of having the enrichment of the data obtained from the ecosystem, by the contribution of the sources of information coming from the universities. Figure 57 shows an integrated innovation management system with this disruptive approach.

Figure 57. Representation of an integrated innovation management system for universities using a disruptive approach (Source: own elaboration)

As can be seen in Figure 57, it is shown a system that is composed of the following parts:

- **Innovation ecosystem ontology.** This part is the basis on which the system is built and supports for its operation. In this sense, it replaces the structure of internal information sources that were shown in the system of Figure 21, expanding its possibilities with the connection and enrichment with other sources of information, whether these are economic, political, social, technological, legal, etc.
- **Knowledge graph.** A knowledge graph is a model of a knowledge domain generated with the help of intelligent machine learning algorithms⁸⁸. It provides a structure and a common interface for all data and allows the creation of intelligent multilateral relationships through its databases. Structured as an additional virtual data layer, knowledge graph is based on existing information sources to link all data to scale, whether structured or unstructured.
- **Digital platform.** As seen in the previous section, within the incremental approach, digital platforms are an essential element for the transformation of the value chain of universities. In the proposed system of Figure 57, the digital platform would also be in charge of

⁸⁸ Enterprise Knowledge Graphs – Transforming Data into Knowledge <https://www.poolparty.biz/white-paper-knowledge-graphs/>

managing and acting as an interface to the information generated from the ontology and knowledge graph. Likewise, through the digital platform, different services could be offered, those already mentioned and related to IMT, as well as new ones, either through APIs or technological intelligence services for the benefit of the different actors and ecosystem users.

- **IMTs.** As in the incremental approach, a series of services could be offered on the digital platform through different IMTs. Of course, thanks to the new possibilities offered by the information obtained through the use of the innovation ecosystem ontology and knowledge graph, new IMT services could be implemented.
- **APIs.** As mentioned in point 6.3, APIs are formal specifications on how a module of a software communicates or interacts with another. The solutions developed on the APIs offered by the technical platforms can fulfill the role of final applications (directly instantiated by the users) or, on the contrary, also offer "high level APIs" on which the developers can generate very specific applications for a specific domain (León et al., 2017).
- **Technology Intelligence services.** The appearance of new technologies and cognitive intelligence systems enable an improvement based on the implementation of disruptive services of technological intelligence through the use of cognitive intelligence adapted to the needs of decision-making (Tejero and León, 2017). These cognitive services promise to combine a reduced cost of access and processing of externally available technological information with the ability of interactive adjustment to specific needs through question and answer systems in natural language (Hurwitz et al., 2015). The actors of the ecosystem could benefit from this type of services, through the digital platform, extracting information of great relevance from the ontology and knowledge graph generated for the ecosystem.
- **Ecosystem.** Thanks to technological intelligence services and other possible services through the IMT layer and the design of new APIs, ecosystem actors can benefit from new information services for decision-making. On the other hand, the universities, and therefore the whole ecosystem, also obtain new information, coming from the data sent by the different actors in the forms and query tables used during their interactions with these new services and platform. This information, without a doubt, can help to improve the understanding of the behavior, needs and motivations of the different actors, allowing a decision-making based not on simulated data but on real behavior data: creation of policies that involve or affect certain groups or specific sectors, the strengthening of weaknesses or

solution of system malfunctions, creation of new connectors and events to attract new actors, etc.

6.4.3 Recommended steps for the implementation of the disruptive approach

As mentioned above in the case of the incremental approach (section 6.3), although each university has its own idiosyncrasy, this section shows a series of recommended, basic and rational steps to be able to conduct the successful implementation of an integrated system of Innovation management of disruptive type.

Figure 58. Recommended steps for the implementation of the disruptive approach (Source: own elaboration)

As discussed in the previous point, this incremental approach will be based on the resources and databases currently available to universities, for their adaptation and integration with the proposed new system. In particular, the steps necessary for its correct achievement are described below:

1. **Innovation ecosystem ontology.** As will be shown in more detail below, from the sources of information related to the different phases of the innovation process, a structure is generated that will house and feed on various data, to form the knowledge base of the system.
2. **Knowledge graph.** From the ontology and the data, it is possible to generate the knowledge graph of the ecosystem. The knowledge graph is a model of the knowledge base, which allows a unified access to information and expands the options, connection and knowledge

exchange. Thanks to the knowledge graph, knowledge is obtained enriched with information connected from very diverse sources, not only the ecosystem.

3. **Digital platform.** The digital platform serves as a superior knowledge interface, expanding access to knowledge through different possibilities, such as IMTs, Technology Intelligence Services, or simply APIs for the development of new services or giving the option to connect with other applications.
4. **IMTs.** As in the incremental approach in section 6.3, the availability of a well-powered digital platform will allow the implementation and use of different IMTs. In particular, depending on the degree and quality of the digital platform implemented and recorded information, it will be possible to use different techniques such as those shown in Table 7. Again, the use of one or other IMTs will ultimately depend on the university and its opportunity. IMTs for the creation of open innovation profiles or selection of partners, presented in point 6.3.4, are very useful in environments such as the one proposed.
5. **APIs.** The use of APIs allows endless possibilities of creating new services or connection with other existing applications that can get the most out of the knowledge of the system.
6. **Technology Intelligence services.** Thanks to the structure and configuration of the knowledge of the ecosystem, through ontology and knowledge graph, the creation of intelligence services for the benefit of the actors of the ecosystem is a fact to be highlighted because of its enormous importance and transcendence. The actors can take advantage of these services for their own benefit, expanding their degree of action and knowledge of the ecosystem, while offering "real" information about their behavior, customs, interests, etc. (this is information of enormous interest).

In the identified parts of the integrated innovation management system depicted in Figure 57, ecosystems and IMT have already been discussed (Chapters 3 and 4). In addition, digital platform was cover in point 6.3.5 (university as a platform) of this Chapter. The APIs, on the other hand, have been briefly described when listing the parts of the integrated innovation management system; being "software pieces" customized according to specific needs, it is not deepened in its description within this work. Therefore, the parts dedicated to technology intelligence services, innovation ecosystem ontology and knowledge graph will be detailed in next points.

6.4.4 Technology intelligence services

The fast emergence of big data analytics⁸⁹ solutions provides another source of relevant information for decision-making when combined with smart processes into the organizations. They complement methodological tools to support complex decisions. After using and stocking experience on these processes in specific domains, institutions are able to collect a set of structured decision rules to reuse later on in similar situations. They constitute the “corpus of knowledge” in one specific area.

Since the eighties, tools have been appearing and perfected that encode in one way or another "decision rules" used intuitively by (human) experts; once explicitly codified with the ultimate goal of replacing the interpretation of the human expert with an automated system, what was known in the literature as expert systems was generated (Power, 2007). Despite the hopes placed on this approach, with the beginning of the 21st century there has been a clear stagnation of its capabilities and usefulness. In short, expert systems have been unable to learn and react to unstructured information or rules, following the reasoning patterns used by the human brain. Unfortunately, this is the usual context of decision-making in organizations and the source of their complexity.

In recent years, a new set of tools to support reasoning within the cognitive computing stream has arrived. Cognitive computing refers to the development of computer systems modeled on the human brain's way of reasoning (Feldman and Reynolds, 2014). After two decades of academic work, commercial systems based on cognitive computing begin to proliferate and begin to be used in business and scientific-technical environments in which decision-making benefits from access and analysis of large volumes of data, interaction in natural language and the capacity for inference (Chen et al., 2016).

One of the most relevant areas for the most part of high-tech organizations concerns the evaluation, acquisition and use of technology. Today, in medium or high-tech sectors, industrial competitiveness is strongly dominated by the wise of technology exploitation inside the firm. The analysis of technology consequences in the short, medium or long term (globally known as “technology intelligence”) constitutes a key element to ensure future competitiveness (Tejero and León, 2017). Some of the most interesting technological domains correspond to the so-called “enabling technologies” (as information and communications technologies is being used in all

⁸⁹ Big data analytics is the use of advanced analytic techniques against very large, diverse data sets that include structured, semi-structured and unstructured data, from different sources, and in different sizes from terabytes to zettabytes. (<https://www.ibm.com/analytics/hadoop/big-data-analytics>)

industrial sectors), while others are specific of the product or services created and used by organizations in one specific industrial sector.

From an operational point of view, the company's decisions on the selection, acquisition and absorption of a given technology imply to access a number of multidimensional information on the pre-selected technology obtained from multiple sources. Then, firms should be able to analyze their relevance by filtering out non-useful information, and finally, to elaborate specific technology intelligence reports and recommendations for feeding-up decision making in the top management layers of the firm and, if adequate, to launch a technology-change process.

The emergence of new technologies and systems of competitive intelligence allows applying innovative approaches, which offer an effective improvement through the implementation of disruptive cognitive-based services of technology intelligence. In fact, the Universidad Politécnica de Madrid (UPM) and IBM (NYSE: IBM) launched an innovative joint research project⁹⁰ in 2015 to help technology-based SMEs and start-ups to define their technology strategy and support decision-making on the use of technologies that could help them to achieve it successfully. The objective of the project was to train the IBM Watson system⁹¹ to develop a cognitive application that functioned as a strategic and technological adviser or "guide".

The value proposition of the use of cognitive services in relation to the function of "technology intelligence" in organizations starts from its consideration as a domain of unstructured data and a decision-making process based on the existence of expert knowledge. Its degree of utility increases with use, incorporating aspects linked to new experiences of the users themselves when reasoning about technologies within their organizations. The power of a system such as the one indicated to support the desired technological intelligence functions depends to a large extent on the predictability on stored information and the ability to interact with the user, which are precisely the key elements of cognitive systems.

Within the project conducted by UPM and IBM, a first pilot service for the provision of patent information is carried out, framed in the service module "structuring knowledge of the domain of a technology and its evolution". This new service, deployed in the IBM cloud platform "Bluemix"⁹², combines its own components belonging to the IBM architecture, as well as others generated "ad hoc" by the research team of the UPM to provide new search, management and patent analysis, in

⁹⁰ UPM-IBM project <https://www-03.ibm.com/press/es/es/pressrelease/48208.wss>

⁹¹ IBM Watson <https://www.ibm.com/watson>

⁹² Bluemix <https://en.wikipedia.org/wiki/Bluemix>

a differentiated way to the services traditionally developed in these areas by the organizations of the sector. Specifically, the use of cognitive services, such as those offered by IBM Watson, allows access and classification of unstructured patent data. Figure 59 shows the capture of one of the pilot's interaction windows developed.

Figure 59. Capture of the UPM-IBM patent information pilot cognitive service (Source: Tejero and León, 2017)

To arrive at the final achievement of a "complete" service of technological intelligence, the idea starts from the "dynamic" and continuous generation of the different micro-services that are being demanded, according to the needs of the actors. These micro-services, cumulatively, will join others until they form the complete structure of technological intelligence services, as shown in Figure 60. This idea of cognitive technological intelligence services, fits very well with the approach and structure presented in this section for the integrated innovation management system (Figure 57).

Figure 60. Micro-services progressively added towards an ideal toolset (Source: Tejero and León, 2017)

6.4.5 Innovation ecosystem ontology (INNEO)

"An ontology is a model of reality of the world and the concepts in the ontology must reflect this reality", Natasha Noy (2001).

There are different sources where it is possible to find relevant information for describing the activities that are typically involve within an innovation ecosystem, such as patents, projects and so on. In this sense, taking into account the stages of the whole innovation process, from the discovery stage to the commercialization of the technology, and their main actors, according to the classification of Deborah J. Jackson (2011), it is possible to identify the sources of information (see above Figure 52).

Although all the information belonging to the innovation process is useful in one way or another, really, the information needed for modelling an innovation ecosystem is related to its actors and relationships. However, it is also important to know how all concepts connect and shape these complex systems, which could be very useful for a better understanding of their operation. Thus, in order to define a common and scalable approach, it is possible to use ontologies for this purpose. An ontology is a formal, explicit specification of a shared conceptualization (Studer et al., 1998). In fact, computational ontologies are a means to formally model the structure of a system, that is, the relevant entities and relations that emerge from its observation, and which are useful to the purposes of this research (Guarino et al., 2009).

According to Natasha Noy (2001), an ontology defines a common vocabulary for researchers who need to share information in a domain. It includes machine-interpretable definitions of basic concepts in the domain and relations among them. Sharing common understanding of the structure of information among people or software agents is one of the more common goals in developing ontologies. An ontology together with a set of individual instances of classes constitutes a knowledge base; there is a fine line where the ontology ends and the knowledge base begins. However, often an ontology of the domain is not a goal in itself. Developing an ontology is akin to defining a set of data and their structure for other programs to use. In fact, this is the purpose for the innovation ecosystem ontology of this research: to be used for the integration innovation management system.

On the other hand, if we need to build a large ontology, we can integrate several existing ontologies describing portions of the large domain. Therefore, taking into account integrated innovation management system for universities of the Figure 57, the approach of this research, the definition of the ontology of an innovation ecosystem can be described. In fact, for the development of the ontology of innovation ecosystems it is intended to carry out a process that can be developed gradually and progressively, as shown in Figure 61, until reaching the possibility of having an ecosystem model in graph format.

Figure 61. Procedure for creating the innovation ecosystem knowledge graph. (Source: own elaboration)

In practical terms, developing an ontology includes the definition of classes (definition of the concepts of a specific domain) in the ontology, arranging the classes in a taxonomic (subclass–superclass) hierarchy, defining slots (the futures and attributes of this concept) and describing allowed values for these slots, filling in the values for slots for instances⁹³. Thus, according to the work of Natasha Noy (2001), “we can then create a knowledge base by defining individual instances of these classes filling in specific slot value information and additional slot restrictions... An ontology is a model of reality of the world and the concepts in the ontology must reflect this reality”.

Using the method described in the paper of Noy et al. (2001) to develop the ontology through an iterative process, which is defined by progressive approximations, coming up next it is described an initial version of the ontology, that will can be evolve in next iterations, such as it is presented in the method, “After we define an initial version of the ontology, we can evaluate and debug it by using it in applications or problem-solving methods or by discussing it with experts in the field, or both... This process of iterative design will likely continue through the entire lifecycle of the ontology”.

6.4.5.1 Domain and scope of the ontology

In order to determine the domain and scope of the model, which correspond with the first step of the method to build ontologies, it is recommended to begin answering a few of basic questions:

- ***What is the domain that the ontology will cover?*** It pretended to develop an ontology that represents “university-driven innovation ecosystems”.
- ***For what we are going to use the ontology?*** We plan to use the ontology for a system that could provide tools and metrics of innovation ecosystems for decision-making⁹⁴. In particular, the ontology will be used by the integrated innovation management system depicts in Figure 57.
- ***For what types of questions the information in the ontology should provide answers?*** Mainly, ontology should provide answers to questions related to the actors of the ecosystem and their relationships, based on the information sources from the innovation process (see Figure 52). Departing on that, ontology should also provide detailed contextual information of actors and the relationships.

⁹³ Classes are the focus of most ontologies. Classes describe concepts in the domain. For example, a class of wines represents all wines. Specific wines are instances of this class. The Bordeaux wine in the glass in front of you while you read this document is an instance of the class of Bordeaux wines (Noy et al., 2001).

⁹⁴ The goal is to support the decision-making of managers, actors and policy makers of the innovation ecosystem.

- **Who will use and maintain the ontology?** Actors of the ecosystem, but also policy-makers and decision makers, both public and private, related to the ecosystem that will use and maintain the ecosystem and ontology.

6.4.5.2 Competency questions

From the information collected of the interaction of actors with the system (ontology), one of the main final objectives behind of the ontology is also to offer more specific details about the steps followed in an innovation process until the achievement of the final product. An interesting example to follow, as a guide, would be that produced in a chemical reaction until the final product appears. As can be seen in the Figure 62, "of the reality" shown in the upper part in different images, a "translation" or representation is made that allows adding information of the process, for its better understanding.

Figure 62. This series of images shows the intermediaries that are formed in an organic chemical reaction at the molecular level, before it appears in the final product (Source: cerebrodigital.com)

Chemists know very well that when two or more substances are mixed, they will react in a series of events that will culminate in the formation of a final product. However, during chemical reactions other compounds that precede the formation of the final compound called “reaction intermediates” are produced (Riss et al., 2016). In Figure 62, the images show the moment in which the reaction intermediates of a single organic molecule are produced, being able to appreciate the formation and rupture of bonds at the molecular level.

Reaction intermediates are very unstable substances that are formed in the different stages of a reaction, before obtaining the products, and are extremely difficult to identify and characterize, due to their short life. Knowing the structure of these intermediate species can be of great help to

understand the reaction mechanisms, and that, in addition, can generate a great impact in the chemical industry, in the pharmaceutical industry and in medicine.

Saving the distances, the implication of knowing “the intermediaries”, how the formation of the different structures is in the innovation process, could generate a great impact on many levels. Thus, using the above chemical reaction example as inspiration, we will put all the attention to the innovation process depicts in Figure 52, in order to define the questions that the ontology should answer (competency questions⁹⁵). Of course, these questions are just a sketch and do not are exhaustive (this is the first set of questions to be completed in future iterations, after its debug by using it in applications or problem-solving methods). Competency questions will be used to test if the ontology contain enough information to answer these types of questions:

- Using the source of **Scientific publications**
 - From the point of view of the actors:
 1. *What are the organizations working in the area of knowledge X at scientific level?*
 2. *Is the organization X working in the area of knowledge X?*
 3. *In which technologies is working the organization X?*⁹⁶
 4. *What are the organizations working in the sector X at scientific level?*
 5. *What are the organizations that collaborated in the scientific publication X?*
 6. *In what areas of knowledge are organizations similar to organization X working? (In order to explore new lines of work for a scientific organization)*
 - From the point of view of the relationships:
 7. *With what (type) organizations does organization X collaborate scientifically?*
 8. *Is working the organization X with the organization Y at scientific level?*
 9. *In which technologies/areas?*
 10. *How can collaborate the organization X with other organizations in the area of knowledge X?*⁹⁷

⁹⁵ Competency questions help first to determine the ontology scope and second these will serve to test the ontology (Gruninger and Fox, 1995). Using these questions, it is possible to determine if the ontology contain enough information to answer these types of questions or if answers require a particular level of detail or representation of a specific area.

⁹⁶ In order to know the portfolio of technologies.

⁹⁷ The system must not only be able to show information "about what is being done", but it must also offer information "about what can be done" to make decisions.

11. *What are my competitors in the area of knowledge X?*
 12. *With organizations from which countries does organization X collaborate scientifically?*
 13. *How can collaborate the organization X with the country X?*
- Using the source of **Projects** (all types, R&D&I)
 - From the point of view of the actors:
 14. *What are the organizations that participate in R&D&I projects in the area of knowledge X?*
 15. *What are the organizations that participate in R&D&I projects in the sector X?*
 16. *What are the organizations that collaborate in the project X?*
 17. *From which countries are the organizations that participate in projects in area of knowledge X?*
 18. *From which countries are the organizations that participate in projects in the sector X?*
 19. *In what projects (sectors / areas of knowledge /...) are organizations similar to organization X working?⁹⁸*
 20. *What are the organizations that finance the project belonging to the sector X?*
 - From the point of view of the relationships:
 21. *Which countries collaborate in R&D&I projects in the area of knowledge X?*
 22. *Which countries collaborate in R&D&I projects in the sector X?*
 23. *What are the countries working in the area of knowledge X?*
 24. *What are the countries working in the sector X?*
 25. *With which countries does X organization collaborate in R&D&I projects?*
 26. *With what organization/s should contact the organization X to get funds for projects related to the area of knowledge X?*
 - Using the source of **Talent attraction**
 - From the point of view of the actors:
 27. *In what areas of knowledge (countries / gender /...) does the organization X hire staff?*

⁹⁸ Exploring new lines of work for an organization at a scientific level.

- 28. *What are the organizations that hire staff of the area of knowledge X?*
- From the point of view of the relationships:
 - 29. *In what research groups does the employees of the X center work?*
 - 30. *In what research groups does the employees of the X department work?*
 - 31. *In what research groups could work people of the X center?*
- Using the source of **Patents**
 - From the point of view of the actors:
 - 32. *What organizations are patenting X technology?*
 - 33. *Which organizations are patenting in area X of the patent classification (IPC)?*
 - 34. *Is the organization X patenting in the area X of the patent classification (IPVC)?*
 - 35. *In which technologies is patenting the organization X?⁹⁹*
 - 36. *In what countries does organization X patent?*
 - From the point of view of the relationships:
 - 37. *With what (type) organizations is the organization X patenting?*
 - 38. *With what (type) organizations is the organization X patenting in the country X?*
 - 39. *Does the organization share patents with the organization Y?*
 - 40. *What are my competitors in the technology X?*
 - 41. *With organizations from which countries does organization X patenting?*
- Using the source of **Spin-off and Startups**
 - From the point of view of the actors:
 - 42. *How many spin-offs were created in year X in the ecosystem?*
 - 43. *How many startups in sector X were created in year Y?*
 - 44. *What spin-offs created in year X are still active today?*
 - From the point of view of the relationships:
 - 45. *How many startups from the X Center of the university have been created since the year Y?*
 - 46. *Which Center of the university have participated more in the creation of spin-off of sector X?*

⁹⁹ In order to know the portfolio of technologies.

47. *In which sectors does the X Center of the university participate for the generation of startups?*
- ¿Using the source of **Funding**
 - From the point of view of the actors:
 - 48. *Which organizations have received funding in year X?*
 - 49. *What organizations give funding in sector X?*
 - From the point of view of the relationships:
 - 50. *What organizations are financing organizations of type X?*
 - 51. *To which organizations is financing organization X?*
 - Using the source of **Licenses**
 - From the point of view of the actors:
 - 52. *Which Centers are licensing the most in the ecosystem?*
 - From the point of view of the relationships:
 - 53. *With what type of organizations does the X Center of the university have licenses?*
 - Using the source of **Mergers and acquisitions**
 - From the point of view of the actors:
 - 54. *What type of organizations have the most mergers in the ecosystem?*
 - 55. *What type of organizations are the most acquired in the ecosystem?*
 - 56. *In which sector are more mergers carried out?*
 - 57. *In which sector were more acquisitions carried out in year X?*
 - From the point of view of the relationships:
 - 58. *With which organizations are organizations of type X commonly merged?*
 - 59. *In which sector are the organizations most commonly purchased by type X organizations?*
 - Examples of questions, using a **combination of different sources of information**
 - From the point of view of the actors:
 - 60. *What is the organization of the X project that employs the most talent in area X?*
 - From the point of view of the relationships:
 - 61. *What type of employees should I hire/attract to be able to carry out projects in area of knowledge X?*

62. *What type of employees should I hire/attract to be able to publish in area of knowledge X?*
63. *Among the organizations that publish the most in area of knowledge X, which is the one that collaborates with organizations in the sector X and works in projects of the sector Y (or with European countries)?*

6.4.5.3 Reusing existing ontologies

Step 2 of the method proposed by Noy (2001) consider reusing existing ontologies. In this sense, it seems that there are not ontologies for innovation ecosystems such as. However, paying attention to the Figure 52, we can identify the sources of information of an innovation ecosystem and check if we can refine and extent these existing ontologies for our particular domain, if exist. Below are some examples founded that could be of interest in this or other subsequent iterations to improve the innovation ecosystem ontology:

- **Scientific publications**
 - There are coming up several initiatives to create frameworks and connections with the articles datasets and other sources such as grants, researchers, etc. A Research Graph dataset for connecting research data repositories using RD-Switchboard is proposed in the paper of Aryani et al. (2018).
 - Another example is FABIO¹⁰⁰. The FRBR-aligned Bibliographic Ontology (FaBiO) is an ontology for describing entities that are published or potentially publishable (e.g., journal articles, conference papers, books), and that contain or are referred to by bibliographic references.
- **Patents**
 - A patent system ontology for facilitating retrieval of patent related information is proposed by Taduri et al. (2012)
- **Talent attraction.**
 - This information is usually find it in recruitment databases as e.g. Infojobs. Since the information is about people, it is very difficult to access to this type of information because the privacy (an example is the S2i database of UPM where it is possible to find out information about researchers, pre-doctoral personnel and so on).

¹⁰⁰ FABIO ontology <https://sparontologies.github.io/fabio/current/fabio.html>

- Licenses

- Copyright Licenses Reasoning using an OWL-DL Ontology (García and Gil, 2009) constitutes an ontology that conceptualizes the copyright domain. The ontology provides the building blocks for flexible machine understandable licenses and facilitates implementation because DL reasoners can be directly used for license checking.

- Funding and projects

- The Funding, Research Administration and Projects Ontology (FRAPO)¹⁰¹ is an ontology for describing the administrative information of research projects, e.g., grant applications, funding bodies, project partners, etc. Figure 63

Figure 63. Diagram of the FRAPO ontology (Source: SPAR ontologies¹⁰²)

In this research, will not be taken into account ontologies for reuse, since it does not see a more or less direct fit with the intended. Of course, in other iterations of the ontology, above findings may be considered, in order to improve and complete the ontology.

¹⁰¹ FRAPO ontology <https://sparontologies.github.io/frapo/current/frapo.html>

¹⁰² SPAR ontologies <http://www.sparontologies.net/ontologies/frapo>

6.4.5.4 Important terms in the ontology

At this point, it is very useful to define terms and concepts relevant to ontology. These terms will help to better understand the complete ontology. In the case of the ontology of university-driven innovation ecosystems, the following terms are important and deserve a definition for their clarification and use within the domain of knowledge generated:

- **Innovation ecosystem:** Innovation ecosystems are dynamic systems made up by organizations and connected by knowledge flows based on the relationships of these organizations.
- **Organization:** Organization represents a collection of people organized together into a community or other social, commercial or political structure, who share common goals.
- **Relationship:** A relationship represents a type of interaction between two organizations.
- **Knowledge:** It is the "element" created, transferred and consumed by the organizations of the innovation ecosystem.
- **Explicit knowledge:** Explicit knowledge refers to that type of knowledge that has been or can be articulated, codified and stored in some kind of medium.
- **Tacit knowledge:** Tacit knowledge is highly personal (held within the holder), subjective, difficult to formalize, articulate and communicate fully, experience based, contextualized, job specific, transferred through conversation or narrative, not captured by formal education or training and may even be subconscious but capable of becoming explicit knowledge.
- **Patent:** A patent is a form of intellectual property. A patent gives its owner (organization or person) the right to exclude others from making, using, selling, and importing an invention for a limited period of time, usually twenty years¹⁰³.
- **Article:** An article is a written work published in a print or electronic medium, for the purpose of propagating news, research results, academic analysis, or debate¹⁰⁴.
- **Project:** Contemporary business and science treat as a project any undertaking, conducted individually or collaboratively and possibly involving research or design, that is carefully planned to achieve a particular aim¹⁰⁵.

¹⁰³ <https://en.wikipedia.org/wiki/Patent>

¹⁰⁴ [https://en.wikipedia.org/wiki/Article_\(publishing\)](https://en.wikipedia.org/wiki/Article_(publishing))

¹⁰⁵ <https://en.wikipedia.org/wiki/Project>

- **Talent:** A talent is a group of aptitudes useful for some activities, which is normally represented or accumulated in one or more persons.
- **Funding:** Funding is the act of providing financial resources, usually in the form of money, or other values such as effort or time, to finance a need, program, and project, usually by an organization or company¹⁰⁶.
- **Connector:** Connectors are timeless elements, used by the organizations of the ecosystem in a recurrent way to interrelate them in a voluntary basis, without being forced to do so.
- **Event:** Events are elements associated to specific moments in time, which provoke the interaction of organizations of the ecosystem around a specific connector or set of connectors.

6.4.5.5 Classes, class hierarchy and properties of the classes

There are several possible approaches to be used when defining classes: top-down, bottom-up or a combination of both. In this work, a top-down approach will be used, since as it was anticipated at the beginning of the section, the definition of the ontology will be based on the sources of information that are identified in the process of innovation management (starting with the definition of the main concepts), seen in Figure 52 (projects, articles, etc.).

According to Noy (2001), the classes alone will not provide enough information to answer the competency questions. The definition of the classes will start from the concepts described in the section “6.4.5.4 Important terms in the ontology”. Once we have defined the classes, we must describe the internal structure of concepts. Most of the remaining terms of the list of point 6.4.5.4 are likely to be properties of these classes; for example, tangible knowledge and intangible knowledge. For each property in the list, we must determine which class it describes. These properties become slots attached to classes.

In general, there are several types of object properties that can become slots in an ontology (Noy, 2001):

- “Intrinsic” properties, such as the flavor of a wine in the Noy’s example (definition of the wine ontology).
- “Extrinsic” properties, such as a wine’s name, and area it comes from.

¹⁰⁶ <https://en.wikipedia.org/wiki/Funding>

- Parts, if the object is structured. These can be both physical and abstract “parts” (e.g., the courses of a meal).
- Relationships to other individuals. These are the relationships between individual members of the class and other items (e.g., the maker of a wine, representing a relationship between a wine and a winery, and the grape the wine is made from).

Therefore, based on the list of terms defined in point 6.4.5.4, the classes of the ontology will be the following: innovation ecosystem, organization, knowledge, patent, article, project, talent, funding, connector and event. Figure 64 depicts the schema of classes, subclasses, class hierarchy of the ontology.

Figure 64. Classes, subclasses and class hierarchy of the innovation ecosystem ontology (Source: own elaboration)

Below is an example of the code used for the description of classes, relationships and attributes.

```
#####
#   Object Properties
#####

### http://inneo.linkeddata.es#attractsOrganization
:attractsOrganization rdf:type owl:ObjectProperty .

### http://inneo.linkeddata.es#belongsToInnovationEcosystem
:belongsToInnovationEcosystem rdf:type owl:ObjectProperty .

### http://inneo.linkeddata.es#consumesKnowledge
:consumesKnowledge rdf:type owl:ObjectProperty .

### http://inneo.linkeddata.es#contractsTalent
:contractsTalent rdf:type owl:ObjectProperty .

### http://inneo.linkeddata.es#createsConnector
:createsConnector rdf:type owl:ObjectProperty .
```

Figure 65. Code used to create the ontology (Source: own elaboration¹⁰⁷)

In the URL https://atejerolopez.github.io/innovation_knowledge_graph/ it is described and published the innovation ecosystem ontology (INNEO).

6.4.6 Innovation ecosystem knowledge graph

According to Ehrlinger and Wöß (2016), a knowledge graph is a higher entity or level, being something more complex than a knowledge base (as an ontology). This is because knowledge graph applies a reasoning engine to generate new knowledge and integrates one or more sources of information. Consequently, a manually created knowledge graph that does not admit aspects of integration is a simple knowledge base; if it provides reasoning capabilities then it can be considered a knowledge-based system. This last case is the one that is sought for the integrated innovation management system proposed.

¹⁰⁷ https://github.com/atejerolopez/innovation_knowledge_graph/blob/master/inneo.owl

Figure 66. Architecture of a knowledge graph (Source: Ehrlinger and Wöß (2016))

In the present work, taking into account the scheme represented previously in Figure 57, the innovation ecosystem university-driven knowledge graph would be as the one described in Figure 67.

Figure 67. Innovation ecosystem university-driven knowledge graph (Source: own elaboration)

As shown in Figure 66, the reasoning engine function would be performed by the digital platform, something that could be carried out using APIs that would allow its configuration and management. In the following point is shown an example of the application of the ontology and knowledge graph in a real case: the innovation ecosystem of the UPM.

6.4.6.1 Examples of application of ontology and knowledge graph

The potential of the Innovation Knowledge Graph is very large; it can already be applied at different levels. At a particular level, in the case of an innovation ecosystem of university type, it allows to enrich the information that is usually available with the incorporation of external sources to those of the university itself. This fact enables the obtaining of context knowledge, which helps in an important way in the usual process of decision-making. In the case of the UPM shown above, the connection of information obtained from S2i, for example the patents generated from the university, with contextual information such as scientific articles, projects and information from organizations, allows obtaining knowledge maps such as the one shown in Figure 68.

Figure 68. Application case of the Innovation Knowledge Graph in the UPM context (Source: own elaboration)

The knowledge graph shown as an example in Figure 68, allows to link the management of patents with activities of publication of scientific articles and projects. Therefore, the connection of several phases of the innovation process is enabled. This fact allows to advance and forecast of the planning of actions as well as the establishment of alerts.

At another scale, the use of the Innovation Knowledge Graph in other collaboration contexts is also possible. For example, the Digital Innovation Hub (DIH), an initiative launched by the European Commission on April 19, 2016 and currently has over 200 fully operational hubs across the EU. A DIH is a regional multi-partner cooperation around specific technical competences (e.g. artificial intelligence and cognitive systems, Internet of Things, etc.), which include organizations like universities, industry, regional development agencies, etc.).

The sources of information typically associated with a DIH are those shown in the example in Figure 69. In this case, as can be seen, they coincide almost entirely with the information sources represented by classes in the INNEO ontology (see Figure 64).

Figure 69. Information sources associated to a Digital Innovation Hub of Internet of Things
(Source: own elaboration)

It is important to highlight in this point, that the application of the Innovation Knowledge Graph does not have to be restricted to a single DIH, but to an entire DIH network in relation to the same technical competences or even encompassing the total DIH network. Again, the benefits of combining the information of several DIH or of all, are the multiple possibilities that are open for decision-making with the enrichment and connection of the knowledge of these units of collaboration.

7 CONCLUSIONS AND FUTURE WORK

This work has been proposed to develop an evolutionary action framework for universities. This section shows the conclusions obtained regarding the identified challenges and objectives, the contributions presented by the study, inputs to motivate the (necessary) discussion for evolution, limitations for the realization of the study itself, as well as, lines of future work that have been identified in the different sections of this document.

7.1 Conclusions

From the present research work, the following general conclusions are obtained:

- Universities currently face a series of challenges that can be transformed into new opportunities that allow them to evolve to remain as strategic suppliers of knowledge and

innovation, through the adoption of any of the two proposed, incremental and disruptive approaches, which facilitate the creation of an integrated innovation management system.

- The implementation of both the incremental approach and the disruptive approach will bring about a certain complexity. However, the benefits outweigh the inherent complexity of implementing an integrated innovation management system.

At particular level, a series of conclusions are also extracted:

- With respect to the **demographic changes challenge**, the use of digital platforms in combination with IMTs for human resource management and innovation project management, and the use of knowledge graphs in the most disruptive approach, make it possible to have a system that allows a service management adequate to the demand: planning and management of human and material resources, coordination with the market, etc. Therefore, thanks to the use of these tools it is possible to conduct an efficient management of human and material resources. In particular, using knowledge graphs it is possible to show cross-information and enriched with other sources, which allows to establish alerts for the early identification and demand planning; in the same way as in the example shown on the S2i database of the UPM, in Figure 68 of section 6, showed a knowledge graph that linked patent management with activities of publication of scientific articles and projects, thus connecting the different phases of the innovation process for the planning of new actions.
- **New students needs and pace** make necessary the adaptation of the services offered by the universities to the new times. The use of digital platforms, integrated with e-learning tools, make possible to have a system that allows students to learn aligned with their pace and needs, being able to access when and where they want. This achieves the goal of having services adapted to the new needs of students, as a platform university. E-learning platforms are common tools that can be found in universities today. However, its integration with other services offered by the university for their students is not yet carried out; services such as the awareness and marketing of the academic offer, management of the student's decision to choose one university degree, or the enrolment (see Figure 31).
- With respect to **technology**, an innovation system is "*the network of public and private sector institutions whose activities and interactions initiate, import, modify and disseminate new technologies*". For a university, the ability to incorporate technologies into its products

and services is essential, as well as being able to become a competitive advantage when this incorporation takes place at the most appropriate time. In this sense, digital platforms allow to adopt new technologies to take advantage of the huge possibilities that they can offer. On the other hand, the tools of technology watch (incremental approach) and advanced technology intelligence services (disruptive approach) allow the analysis, management and decision-making for the adoption of technology, as could be seen in the research project between UPM and IBM in 2015 shown in section 6.4.4 of this paper, which can be applied to the context of universities.

- As it has been identified in section 4, it is necessary to apply a transformation in the universities, in order to have **knowledge digitalized and store properly**. Much of the relevant and necessary information for the development and evolution of universities for their positioning as strategic suppliers of knowledge and innovation, is not yet properly stored or not as accessible as it should be. For this reason, from a more incremental evolution, at least a digital transformation that would allow storage, access, management and analysis of knowledge for decision-making should be applied. Going a step further, towards a solution more adapted to the new times, proposes in point 6 the creation of an advanced digital platform (using ontology and knowledge graphs), within a more disruptive approach, that can be prepared not only to make the most of the data, but also for the integration of the new knowledge base generated, with other sources of information; creating a richer, more homogeneous knowledge base for its sharing and comparison with others and, definitely, scalable.
- The intelligent use of digital platforms in combination with IMTs (Open Innovation, Market intelligence, Cooperation and networks) and other tools for analyzing the behavior and representation of ecosystem actors and the knowledge exchanged between them (e.g. SNA) allow to **change the university model where emphasis shifts from ensuring "competitiveness" (as an isolated goal) to create the most adequate "higher education ecosystem" (as a shared goal)**. Section 6.3.7.5 shows an example of the potential in the case of UPM, using these tools (SNA, dynamism, connectors, events, sustainability, ...) that allow to know how the different actors of the ecosystem interact, as well as the creation of new indicators and metrics for the monitoring, analysis and management of the evolution of the ecosystem. This, without a doubt, shows the possible increase in the ability to make

decisions not only to compete, but also to collaborate in new open contexts of generation and consumption of innovation.

- The gradual decrease of funding for public education makes it necessary for universities to seek to establish **new models for financing**, but also for service. As well-known strategic knowledge providers, universities now have the opportunity to position themselves as strategic innovation suppliers, or at least as relevant entities in the process of generating innovation. Using the available knowledge, mainly within the research dimension, universities can generate new services and products that allow their maintenance and sustainability at the financial level, as in the examples shown of the **commercialization of R&D results or in the creation of new companies** (spin-off and startups). For these purposes, having digital platforms that allow not only the connection with suppliers, but also with customers of these new services and products, seems basic. In addition, tools such as those shown during this work, both for the identification and selection of new partners in open innovation contexts, as well as for the monitoring and management of new technologies and areas of work, through technological intelligence services, do more possible the achievement of these objectives and, therefore, their independent sustainability of public financing.
- The role of universities in innovation systems is crucial. So much so that, at present, one of the most important objectives marked in the transformation and evolution of universities is precisely that of positioning themselves as coordinators and facilitators of innovation, with direct interaction with other actors in their ecosystems (the Third mission). The creation of the university as a digital platform allows the combination of traditional activities and services of education and research, with new ones of generation, transformation, commercialization and launch to the market of new products and services in collaboration or as support of other organizations. These new digital platforms, together with the tools shown in the different case studies, within sections 6.3 and 6.4, make possible the creation of **new integrated systems for innovation management**, to maximize opportunities not only in the innovation dimension , but also of research and, of course, education.

7.2 Inputs for discussion

One of the main objectives of this document is to serve as a document for the debate on university policies and strategies towards the future, focusing on technology as a dynamic element for change. In concrete, this work has presented a feasible scenario of evolution of European public universities within the digital economy, which is seen as a necessary step to address current challenges and to keep the value and prominent role of public universities in a digitised society.

If IT technology for educational processes will continue its maturation process in the near-future, if experts and educational contents we need to satisfy the demands of our students will be accessed regardless the location, if economic pressures to break facilities' obsolescence with restricted budgets is growing up,... and money could be found outside, it is time to conceive innovative approaches to university evolution.

The concept of “university platform ecosystem” presented and developed in this document is a potential answer to these challenges as seen. We are well-aware that internal barriers still exist, and they will be even stronger the near future if the evolution forces universities to move towards the deployment of the platform concept in short periods of time. One question that arises at this point is, at what extent university staff will become deeply committed to a “loose institution”?¹⁰⁸ In fact, as Kennedy recently wrote (Kennedy et al., 2016): *“There are also internal forces at work that limit reform and innovation. The principal one is that, unlike most for-profit corporations, where the workforce is controlled by management, in higher education the workers (i.e., professors) largely control the means of production. In this case, management (e.g., chancellors, presidents, provosts) has limited ability to change work organization, restructure departments, change pedagogy, and make other changes”*.

It seems necessary to conduct deep “structural reforms” (OECD, 2017; ULAB, 2014; OECD, 2012) with consequences for the whole university. Some authors recently spoke about the “time of disruption” for universities (Abel, 2017; Davis, 2017; Driessen, 2017) thinking in the creative destruction of universities as the only way to survive on the future.

The following sentence extracted from Christensen and Eyring (2011) is an example of this movement: *“In time, the new institutions will cultivate demand for their products, improve quality and displace the older institutions—which did not change fast enough. This happens in Silicon Valley,*

¹⁰⁸ Academia is strongly driven by the construction of individual academic identities and reputations within groups of academic peers. Those reputations are associated with that of their institution (Marshall, 2018).

and it will soon happen to campuses across America". The reasoning behind means that universities will disappear as we understand them today in the same way that other service-based sectors are doing (see the evolution of banking or retail sector); however, six years later the work of Christensen and Eyring was published, the pace of universities' changes seems slower than assumed, and universities are still there, more or less in the same way.

Other scholars have a more critical view on the (over-used) application of the concept of "disruption to education". Johan Need (2017), from the University of Virginia's Institute for Advanced Studies in Culture said: *"What makes such reforms so hard to resist is the presumption that the world is moving too fast to take stock. But is this true? Is the world changing so fast that all the things colleges and universities are supposed to do and have done have been rendered irrelevant? Are the forces of disruption really that powerful?"* Nevertheless, disruptive structural models are gaining momentum in new universities (where legacy structures and internal reactions are less relevant) to consider the university as a "container" or "platform" to provide the context (adequate space, equipment, administrative support & interaction) where professors (or groups of) proactively perform its activity looking for resources and with full responsibility on their activity; in fact, they act as "institutional-start-ups" and the whole university is behaving as "incubator").

The effort made by the EU to mobilise universities in new shared governance structures (even by accelerating their evolution through specific calls for funding¹⁰⁹) is becoming deeper with the launching of Erasmus+ – Key Action 2 – European Universities. This action "aims to encourage the emergence by 2024 of some twenty 'European Universities', consisting of bottom-up networks of universities across the EU which will enable students to obtain a degree by combining studies in several EU countries and contribute to the international competitiveness of European universities". It is too early to assess the impact, but the way is open.

True challenges are there out, and this is time for universities to launch wide institution-based debates to identify new challenges, opportunities, and analysis of solutions or approaches pursued by others. Based on that public universities need to explore the feasibility of the prioritised ones, to perform "controlled experiments", to analyse results, to take stock of them and to debate on the experience, and then, to implement the most adequate ones, and to set-up some indicators to track progress. And we (European public universities) should start very soon (many others are in the way)

¹⁰⁹ See https://eacea.ec.europa.eu/erasmus-plus/news/call-for-proposals-the-european-universities_en

by recognizing that we will need to select and convince committed partners for this journey because it is not an easy trip to the future to walk alone.

7.3 Limitations of the study

In order to demonstrate the validity, usefulness and benefits of the framework of action defined in the present research work, the ideal option would have been to present the before and after the complete evolution of a university towards an integrated system of innovation management, through any of the proposed approaches. However, this option is not viable, as was advanced at the beginning of this document, due to multiple reasons, such as: acceptance of the change, allocation of necessary resources, time required for complete transformation, etc. For this reason, in this research work various application cases are used, specific and limited, but that allow demonstrating both the ability and the feasibility of application of the different tools and approaches shown.

The set of application cases used also allow knowing the details necessary for its implementation, as well as the specific requirements for each case. In each and every one of the cases presented, the university, in this case the UPM, is the receiver, executor, or actively participates, which also demonstrates its possibility of use and execution by other universities.

Some of the tools shown are also presented as high potential tools for the benefit of an integrated innovation management system, but without an associated case study. However, and even showing in fictitious cases and not of real application tested in a specific university, they do have an inspiring role for the generation of new and exciting lines of research. In any case, these tools have been conceived and presented in real harmony with the idiosyncrasy of the public university, so their interest for this study is also of vital importance, helping to complete and better understand the vision of the intended integrated innovation management system proposed, for the evolution of the university towards the adaptation of the new needs and confrontation of the identified challenges.

7.4 Contributions

- The present research reflects the need for a change in the current model used by public universities, through the analysis and identification of the current challenges they face, which also contributes very positively to the necessary debate that must take place at present to raise awareness of the need for this change. An Ishikawa diagram is generated for the representation of these major challenges in their different dimensions (social,

economic, technological and political), which facilitates their connection and analysis as factors or causes of the problem, which in turn allows the subsequent definition of specific objectives for face each challenge in a particular way and thus evolve.

- To understand the concepts treated throughout this document, an exhaustive review of the literature is conducted, where the following main concepts are treated:
 - Innovation ecosystems. A journey is made from the ecological ecosystems, from which it is possible to learn, as it is demonstrated in the present research work in its different sections (relationships, levels and chains, types of actors, etc.), until its concretion in the university-driven innovation ecosystems, which are the focus of research application.
 - Knowledge management. Concepts of special importance are dealt with in detail in the analysis of knowledge management. The main contribution of the work is conducted in this section being the relationship and demonstration of the importance of knowledge both in decision-making and in the innovation.
 - Innovation management. Within the review conducted on this point, the path followed in the management of innovation is shown, from the initial use of linear and closed models, to the current adoption of the paradigm of open models: Open Innovation. It should be noted here that not only a simple tour of the different models is conducted to the present, but also an analysis and critique of each of them is made, showing their strengths and weaknesses, which makes it possible to understand why the current recommendation and assumption of Open Innovation models. In addition, a point dedicated to IMTs (Innovation Management Techniques), their usefulness, different options and classification is shown.
 - Network analysis. Open models are characterized by the interaction of different actors, which make up innovation ecosystems. Therefore, the analysis of both the actors and their behavior, as well as the network, or the ecosystem in general, is an aspect of special relevance when it comes to configuring management systems. That is why in this section a review of the literature is done, which helps to show from the models and tools of a more analytical type, such as the SNA (Social Network Analysis), to the models that focus on the value provided, that is, based on shared knowledge, such as value networks. This point serves to show the different possibilities and metrics that can be used in these contexts.

- For the evolution of the universities, two paths or approaches that a given university could use to adapt to the new times are shown, confronting the great challenges that have been identified. Each of the approaches presents the necessary steps for its implementation, the tools and techniques that can be used in each of the steps, also showing examples of application for better understanding of its usefulness, and where the university is the protagonist. A comparative analysis of the benefits that can be obtained against the complexity of its implementation is added. The tools and techniques shown in both proposed approaches are the following:
 - Incremental approach. This approach contributes to the evolution of universities, allowing them to evolve from the resources available for them, but combining them with other tools and application techniques to achieve the different objectives set. Specifically, the following deserve special mention for their contribution:
 - New Open Innovation IMTs. Understanding the lack and necessity of using new techniques and tools for the identification and selection of partners in Open Innovation contexts, two new tools are created to carry out these two functions: identification and selection of partners in international Open Innovation contexts. The contribution made in this field is extremely important for the strengthening of international collaboration networks in Open Innovation schemes, something that is demonstrated in detail, with the description of the complete process of design and implementation of each of the tools, applying them, in addition, in a real case, within the framework of collaboration of the research project carried out between the UPM and Facebook Connectivity Lab in three international projects within Latin America (Chile, Mexico and Peru).
 - University as a platform. This contribution is presented with the central objective to provoke the debate on the need for a change in the current European public university model towards one based on platforms. In addition, this point also contributes to the definition of the new platform model, showing the activities in detail and necessary steps. The concept of value chain is used as an analysis tool in this section, which also allows to show different change scenarios from the current university value chain,

from an extension of the current model (more incremental approach), to one of a more disruptive type and integrated with the ecosystem.

- New taxonomies. Starting from the need for a network analysis to know the behavior of actors and the ecosystem, in an integrated system of innovation management, it is necessary to represent the ecosystem in such a way as to allow this type of management and analysis. For this reason, it contributes with the creation of two new taxonomies from ecological ecosystems that allow to represent both the actors of a given ecosystem and their relationships. In addition, this section creates a new relevance metric for an innovation ecosystem, which is tested in the university context, within the case study of the UPM.
- Social Network Analysis (SNA). Thanks to the representation of the actors and relationships with the new taxonomies created, it is possible to apply tools such as SNA. The combination of taxonomies with SNA allows a new contribution with the creation of new metrics and indicators, such as Dynamism, Connectors and Events, and Sustainability. The dynamism metric is also used as an example to show its applicability, but also potential, for the case of UPM application. In addition, as an added contribution at this point, another way to calculate the relevance of the ecosystem is shown through the use of the new dynamism created metric in combination with the ecosystem performance. This contribution shows a very encouraging new path to obtain information about the importance and performance of a given ecosystem to its environment.
- Disruptive approach. This approach contributes to the evolution of universities, allowing to evolve from a new knowledge infrastructure, with greater integration, homogeneity with other sources and ability to scale. In addition, this approach makes it easier to incorporate other tools and application techniques to achieve the different objectives set. In particular, the following elements of this approach deserve special mention for their contribution:
 - Innovation ecosystem ontology (INNEO). For the generation of the new structure of necessary knowledge, the concept of ontologies is used. That is why, it contributes to the generation of knowledge in this field, with the

creation of a new ontology of innovation ecosystems. Thanks to this new ontology, it is possible to connect to other data sources, and therefore to scale up, for a wider connection of knowledge within the ecosystem. The new ontology is published on a public access website, which shows the definition of its classes, relationships and attributes, for the benefit and use of the scientific community.

- Knowledge graph. Based on the new innovation ecosystem ontology created, a new type of knowledge representation models within the ecosystem is defined, through the Innovation knowledge graph. Thanks to this new representation of knowledge, it is possible, as shown in the section, to obtain models of enriched information, planning and establishment of alerts, etc. The case is shown on an example of a combination of internal data of the UPM, S2I database, and external sources, to illustrate the different combinations and possible opportunities.
 - Technology intelligence services. Thanks to the provision of a new knowledge structure with the new ontology and knowledge graph, it is possible to integrate new technology intelligence services based on cognitive technologies. The potential for use and application is shown through the application case of the project carried out between UPM and IBM, being fully applicable in the case of universities.
- Finally, from the present research work contributes with the generation of new future lines of research, which are shown below in detail.

7.5 Future work

From the work developed in this research work, new lines of work and research are opened. Specifically, the new lines detected for future progress are summarized below:

- Nature is undoubtedly a source of inexhaustible inspiration, from which it is always possible to learn. The study of ecological ecosystems has opened in this research a new line of development, from which it is possible to extract some interesting ideas and often applicable to the context of innovation ecosystems. In fact, in addition to the taxonomies, metrics and identifiers generated, there are several studies on the control of natural ecosystems for the preservation of flora and fauna (the balance of species) that point to a

promising future for its possible application in innovation ecosystems. For example, from the calculation made for the control of fishing and hunting in certain geographical areas, it would be possible to create new formulas for monitoring and management in business ecosystems that would allow knowing the need to attract new actors to the ecosystem to maintain their balance or for the survival of the new startups and spin-offs generated within it.

- With the concept of Open Innovation and IMTs, a new work area is opened for the creation of new tools and techniques. This work shows two new IMTs for the identification and selection of partners in international Open Innovation contexts. However, on the one hand, the new tools identify new areas for improvement, such as the evaluation process conducted by peers, which can be improved by applying other criteria (more evaluators, evaluators specialized in the subject, etc.), as well as the application of other decision-making tools based on different alternatives and criteria, which allow improving the degree of subjectivity of said evaluation, such as Analytic Hierarchy Process (Saaty, 2014) or even the well-known Delphi method (Dalkey, 2018). On the other hand, in view of the results and lessons learned from the application of both IMTs in the project developed between UPM and Facebook Connectivity Lab, new and interesting aspects to be investigated are identified, such as the concept of scalability.
- Network analysis is an area of great interest where, as has been shown in the Chapter of "Theory background", there are multiple studies dedicated to the quantitative analysis of networks. However, the application of this type of analysis for the case of universities is a step that has taken place within the present work. That is why I still see a lot of work ahead of research and application in this area, especially and especially with the focus on value networks.
- In relation to the two new taxonomies created from ecological approaches, which focus on the biotic part (actors and their relationships) of the innovation ecosystem, another area of study dedicated to the abiotic or environmental part, known in the ecological ecosystems as a biotope (sometimes referred to as habitat, although both terms are not exactly the same). Within the present work, point 6.3.6.1, some of the determinants of innovation ecosystems have been described initially. However, the need to analyze in a more exhaustive way what these determinants are and how they affect or condition ecosystem

organizations is identified. Having more knowledge of these determinants could help to influence them, through various instruments and policies generated by decision-making bodies, for the proper development and sustainability of ecosystems.

- A topic of interest that has also been pointed out in the present work, within section 6.3.6.4, and in connection with the analysis area of the determinants of an innovation ecosystem (mentioned in the previous point), is that dedicated to the interaction of organizations with the ecosystem. Knowing how each type of organization interacts with a given ecosystem would be very relevant to understand their particular needs and establish actions within the ecosystem based on them. On the other hand, a given ecosystem could attract certain types of organizations, in preference to others, if they knew more details about their needs and interests. This issue also has a direct relationship with the two new concepts created in the present work: Connectors and Events. It is presumed of great interest the realization of a research work that initially carried out an analysis of the interests and needs of the organizations, creating a classification, and then being able to prove at a practical level the attraction, improvement and development of these organizations based on the configuration of certain connectors and specific events, generated for these purposes.
- Like other types of systems, innovation ecosystems go through different phases or stages from their creation to their disappearance. Knowing these phases, as pointed out in point 6.3.6.5, could allow, among others, identify needs for action for their evolution and / or maintenance, as well as being able to compare a given ecosystem with other ecosystems, understand the influence of some ecosystems in others, etc. In high-tech sectors, it would be of paramount importance to have this type of information to understand their evolution and, even, to venture or try to forecast future movements, either from the point of view of the governments for their promotion or abandonment, or from the point of view of the organizations interested in its adoption. This issue, in relation to the technological intelligence services, also described in this paper (also presented in conjunction with cognitive technologies), could lead to the generation of new knowledge and services in these subjects.
- The relevance of innovation ecosystems is a concept that has been developed and its potential has been proven in the present work, with the possibility of calculation in several different ways. Perhaps the most hopeful is that presented as a product of the concepts of

dynamism and efficiency. While the dynamism has been developed and its calculation and analysis have been shown in a specific application case, the efficiency has only been enunciated at the theoretical level, using the approach of Howard T. Odum. In section 6.3.7.3, a new symbology has been created that allows the representation of an innovation ecosystem for the calculation of its efficiency by this method. Subsequent research studies in this line would allow to complete its definition, by applying it to case studies, with the consequent benefit also of being able to resolve the relevance formula that has been presented in terms of efficiency and dynamism.

- Being able to know at all times how it is possible to maintain the sustainability of an innovation ecosystem is very important, not only for its evolution but also for its survival. In section 6.3.7.1, a new way of calculating sustainability through measures of equilibrium and under the perspective of the Game Theory has been presented at the theoretical level. The equilibrium measures described, both for individual nodes, as for groups of nodes or the entire ecosystem, present a new area of study that is presumed to be of great interest. This new line of work, in conjunction with the aforementioned determinants of the ecosystem of innovation, interaction of organizations with the ecosystem, and connectors and events, could be configured as a large area of new advances in this type of knowledge.
- In section 6.4.5 the definition of a new ontology has been presented: Innovation ecosystem ontology (INNEO). Also, along with the new ontology, the consequent "innovation ecosystem knowledge graph" has been presented (section 6.4.6). This new ontology is described based on a series of initially defined classes, relationships and attributes. Although its use for the creation of new knowledge bases has been pointed out and examples of application have been shown, it is still in the testing and development phase. There are several organizations, one of them a large entity in the banking sector, which have shown interest in its application. Although at the date of presentation of this document there is no firm agreement and no further details can be provided, the implementation of both the ontology and the corresponding knowledge graph is envisaged, within a project configured to generate new structures that allow not only the connection of the current sources of information and ease of incorporation of new ones for its enrichment, but also create as standards and the last, but not the least, have the scalability capacity of the system.

- Finally, in addition to the intrinsic interest in the application of ontologies and knowledge graph for the generation of new knowledge structures on which to build new integrated innovation management systems, there is an underlying area of very special interest, focused on the study and knowledge of the innovation process. Point 6.4.5.2 showed the analogy with the organic chemical reaction process, which has opened a large field of research focused on knowing the intermediate reactions, for the improvement of products within the pharmaceutical sector. In the case of innovation, being able to know a little more detail of how the different steps occur within "the black box" where the very diverse innovation processes that occur habitually in the ecosystems take place (from the creation of knowledge and until its launch to the market in the form of products and services), it would undoubtedly be a step of enormous importance for the field of innovation.

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