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Genesis of an innovation-based entrepreneurial ecosystem: exploring the role of intellectual capital

Luca Marinelli, Sara Bartoloni, Federica Pascucci and Gian Luca Gregori
Department of Management, Università Politecnica Delle Marche, Ancona, Italy, and
Massimiliano Farina Briamonte
University of Sassari, Sassari, Italy

Abstract

Purpose – The aim of the study is to explore the genesis of entrepreneurial ecosystems (EE) and highlight the role played by intellectual capital (IC) in that process. Specifically, the paper adopts the collective intelligence approach, and the study shows how human capital (HC), structural capital (SC) and relational capital (RC) interact to create an entrepreneurial ecosystem.

Design/methodology/approach – The paper adopts a single case study of an Italian EE. The data analysis is based upon the collection of different sources of data: semi-structured interviews with representatives of each actor of the ecosystem; email correspondence; meetings report; a 24-months period of direct observation. Given the novelty of the topic, the qualitative method seems well suited for studying innovation-based EE since the method offers rich data about a phenomenon in real-life context.

Findings – The case is a top-down, innovation-based EE in which all main components of the IC play a crucial role from the initial stage. Findings show how the constant interchange between IC components occurs at two different levels: the micro and the meso level. HC and RC play major roles at both levels, whilst SC only occurs at a meso level, representing the environment in which the whole ecosystem takes place. Additionally, the use case, a new intangible asset integrating all three components of IC, emerged as one of the main outcomes of this innovation-based EE.

Originality/value – The paper contributes to a rather unexplored topic in the existing literature on EE and IC, namely the formation process of EE and the role played by IC within that process. Additionally, through the application of the collective intelligence approach, the authors shed light on the need to manage IC at both micro and meso level in the creation of an EE.

Keywords Entrepreneurial ecosystems, Intellectual capital, Collective intelligence, Knowledge flows, Innovation roots

Paper type Research paper

1. Introduction

Intellectual capital (IC) has been proven to be one of the main drivers of firms' competitive advantage and a potential source of technological development and economic growth (Hayton, 2005). Nonetheless, prior literature mainly focussed on the impact of IC components (human resources, structural capital and relational capital) on firms' activity and performance (Crupi *et al.*, 2021), thus failing to capture its role at a wider scale.

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Consequently, there is a need to shift from a managerial and single company perspective to an ecosystem perspective, entering the so-called fourth stage of IC research (Borin and Donato, 2015; Pedro *et al.*, 2018).

Amongst the different types of ecosystems addressed by the literature (e.g. innovation, knowledge and organisational), entrepreneurial ecosystems (EE) have recently attracted the attention of many scholars (Cao and Shi, 2021; Cavallo *et al.*, 2019). Defined by Stam (2015) as a set of interdependent actors and factors fostering entrepreneurship, EEs have become pivotal in the creation of economic wealth and prosperity within a certain territory (Prahalad, 2005). Specifically, EEs are considered to be valuable means of creating jobs, attracting qualified human capital and talents, fostering innovation and eventually revitalising local or regional economies (Roundy, 2017). Despite their potential, the emerging domain of EE remain under-theorised and conceptually fragmented (Cao and Shi, 2021). Specifically, there is a lack of scholarship addressing the process that led to the formation of EEs and the roles played by different actors and different elements throughout the EE lifecycle (Cavallo *et al.*, 2019).

Amongst these elements, intangible assets and knowledge dynamics acts as the key resources within the entrepreneurial ecosystem, and the openness to external sources of knowledge fosters innovation to be generated through interdependent interactions (Cao and Shi, 2021; Crupi *et al.*, 2020; Wang *et al.*, 2020). However, despite a growing body of literature on the role of IC in entrepreneurship (Crupi *et al.*, 2021), no studies have yet addressed the relationship between IC components and the formation of EEs.

The paper aims to close these aforementioned gaps, thus contributing to the growing debate on EE by exploring their formation through the lens of IC. Specifically, we want to understand how EEs form over time and the role played by IC in this process.

In order to answer this research question, the paper adopts the collective intelligence approach (Malone *et al.*, 2010). The underlying assumption behind this framework is that EEs are collective intelligence systems in which intellectual assets are coordinated through stakeholder collaboration. Particularly, guided by IC literature, the framework is used to unravel the role of IC in the formation of an EE, thus showing the importance of each component (human, relational and structural) in the process.

Consequently, the paper adopts a qualitative approach based on a single case study of an Italian EE, FermoTech. The case has been chosen for its revelatory potential regarding the genesis of an entrepreneurial ecosystem. Moreover, FermoTech's specialisation in Industry 4.0 technologies dovetails nicely into discussion of innovation-based EE.

The remainder of the paper is organised as follows. The next section explores the background literature on EE and IC, thus outlining the research gaps that will be addressed. Section 3 presents the theoretical framework, and Sections 4 and 5 describe the methodology and present the FermoTech case and its main findings. Section 6 discusses the findings, followed by theoretical and managerial implications in Sections 7. Finally, limitations and avenues for further research are presented in the final section.

2. Literature review

2.1 Entrepreneurial ecosystems

In the last thirty years, the 'ecosystem' metaphor has gained considerable attention in a wide range of research streams. The concept was introduced from the field of biology into the business literature by Moore (1993), who used it to symbolise a complex system capable of hosting a number of interdependent identities. Over time, different types of ecosystems emerged in the literature: the innovation ecosystem (Adner, 2006), the knowledge ecosystem (Clarysse *et al.*, 2014), the organisational ecosystem (Mars *et al.*, 2012) and the entrepreneurial ecosystem (Isenberg, 2011). The latter, in particular, has recently gained increased attention from scholars (Cavallo *et al.*, 2019).

Many literature review papers show (e.g. Cao and Shi, 2021; Khatami *et al.*, 2021), several definitions of the term have been introduced, including manifold meanings and purposes (Cavallo *et al.*, 2019; Marinelli, 2020). However, all these conceptualisations shared some aspects. First of all, the fundamental idea that entrepreneurship does not result only from the behaviours of individual entrepreneurs but requires the role of social, cultural and economic forces (Van de Ven, 1993). The ecosystem approach to entrepreneurship focusses on its placement within a network of interdependent actors within a given geographical area, and it implies supporting the creation and development of innovative business projects beyond the mere construction of a network structure between companies (Nicotra *et al.*, 2018). The entrepreneurial phenomenon is situated in a broader context, and that context plays a fundamental role in favouring (or restricting) entrepreneurship without discarding the individual perspective. Regarding the local dimension of EEs some scholars think to be crucial to the study of entrepreneurship (Acs *et al.*, 2017).

Second, most conceptualisations of EEs incorporate their systemness; EEs are systems in which the interaction of their components and actors is critical and determines the evolution of the ecosystem itself (Audreysch and Belitski, 2017). The most remarkable attribute of an ecosystem is its inherent ability to blend the productive potential of stakeholders who are often driven by differing objectives and expectations (Prahalad, 2005). Actors play complementary roles, and together they co-create value and stimulate economic growth.

Even if EEs emerge at different spatial levels – city or region or state – a shared feature is the network formation and flows of knowledge amongst participating actors (Scuotto *et al.*, 2020). Therefore, interdependencies emerge in a spatially delimited community.

Amongst the plethora of available definitions, we chose that by Stam (2015, 5), which has been widely endorsed in the literature because it encompasses all the key features of the EE: '*The EE as a set of interdependent actors and factors coordinated in such a way that they enable productive entrepreneurship within a particular territory*'; productive entrepreneurship is defined as '*any entrepreneurial activity that contributes directly or indirectly to net output of the economy or to the capacity to produce additional output*'. Following this perspective, an EE consists of all the elements that are required to sustain entrepreneurship in a particular territory and to generate economic wealth and prosperity (Prahalad, 2005). In particular, Stam and van de Ven (2021) identified ten components that are mutually interdependent and coevolve in the territory; these are grouped into three categories: 'institutional arrangements' – formal institutions, culture, networks; 'resource endowments' – physical infrastructure, demand, intermediaries, talent, knowledge, leadership, finance; and 'outputs' – productive entrepreneurship. Similarly, Isenberg (2011) grouped the elements of an EE into six domains that interact in highly complex and idiosyncratic ways: a conducive culture; facilitating policies and leadership; availability of dedicated streams of financing; relevant human capital; venture-friendly markets for products and a wide set of institutional and infrastructural supports.

The theme of EE formation appears overlooked; only few papers investigate the genesis of the EE or how they take form (e.g. Thompson *et al.*, 2018), and even fewer papers involve the wide spectrum of actors that may play a role in the EE lifecycle (Cavallo *et al.*, 2019). Thompson *et al.* (2018) identified two different formation models: the first originates from bottom-up, endogenous factors (such as interactions and processes inside the ecosystem), and the second originates from top-down, exogenous factors (such as government projects). Daily, practical interactions and relationships amongst people and groups were what drove Seattle EE formation thus showing the relative importance of endogenous rather than exogenous factors. In any case, authors agree that EEs are path dependent and strongly rooted in their historical and institutional context; therefore, every ecosystem is unique and has distinctive characteristics.

2.2 Intellectual capital

The concept of IC has been extensively studied in recent decades, and today it plays an important role in a new economy in which knowledge and information have become major drivers of competitive advantage and value creation (Cuganesan, 2005; Del Giudice and Della Peruta, 2016; Fiano *et al.*, 2020). Despite the amount of work that addresses the role and importance of IC in creating value for a company, scholars continue to dispute definitions and conceptualisations (Mikic *et al.*, 2020; Pedro *et al.*, 2018). Brooking (1996, p. 12) defined IC as the "*combined intangible assets which enable the company to function*", whilst Stewart (1997) considered it to be a combination of knowledge, information, intellectual property and experience that can be used to create wealth. Similarly, various authors have emphasised the pivotal role of the knowledge dimension in the IC concept, defining IC as any type of resources incorporating knowledge that can create or deliver value (Brennan and Connell, 2000; Edvinsson and Sullivan, 1996; Paoloni *et al.*, 2020; Schiuma and Lerro, 2008).

Additionally, there is no consensus about the components of IC or the method by which they might be evaluated and measured (Pedro *et al.*, 2018). However, the most widely accepted IC taxonomy is certainly the triad formed by human capital, structural (or organisational) capital and relational (or social) capital (Guthrie *et al.*, 2006; Pedro *et al.*, 2018; Roos *et al.*, 1998; Salonius and Käpylä, 2013; Subramaniam and Youndt, 2005), that is also the one adopted in this paper. Human capital (HC) refers to individuals' characteristics, the knowledge, skills, competencies, past experiences and other abilities possessed by a firm's employees, including top management (Hayton, 2005). Structural capital (SC) is what remains inside the organisation without its employees, namely the institutionalised and codified experience stored in databases, culture, routines, patents, manuals and infrastructure, as well as all the other organisational capabilities that facilitate human resources productivity, as well as complementary capabilities (Wang *et al.*, 2022). Relational capital (RC) is the knowledge embedded in the relationships with any stakeholder (internal or external) that influences the life of the organisation and its ability to create value (García-Merino *et al.*, 2014). RC encompasses relations with customers, employees, public and private partners, suppliers and investors.

Notably, these IC components have been found to profoundly impact firms' innovative capabilities and innovation performance (Buenechea-Elberdin, 2017; Crupi *et al.*, 2021; Leitner, 2011; Subramaniam and Youndt, 2005; Wu *et al.*, 2007). However, two important gaps emerge from the literature about IC and innovation. Firstly, a deeper understanding of how different types of capital (such as internal capital, innovation capital, information capital and reputational capital) can be integrated into the dominant triad is needed (Pedro *et al.*, 2018). As a matter of fact, even if HC, SC and RC are the most recognised components in IC literature, social and technological advances have confronted companies with new challenges related to developing and maintaining a sustainable competitive advantage, thus eventually requiring totally new intangible assets (Buenechea-Elberdin, 2017). Even the entrepreneurship literature calls for more studies that address the existence of interactions and synergies amongst the three components and embrace a more holistic view of IC (see Crupi *et al.*, 2021). Secondly, IC has been extensively studied at an organisational level (Borin and Donato, 2015; Pedro *et al.*, 2018). Congruently, the three IC dimensions have mostly been used to explain the creation of wealth in terms of business outcome, thus ignoring the important role of IC, and the knowledge embedded within it, at local, regional and national levels (Edvinssonn and Lin, 2009). Recently, academics have recognised the need to enter a new stage of IC research, namely 'the fourth stage', which extends IC's boundaries into wider ecosystems, like countries, cities and communities, instead of being limited to specific firms. This new approach changes the focus from a managerial and single company perspective to an ecosystem perspective in which IC and knowledge can be created and developed on a wider scale (Borin and Donato, 2015). The concepts of Regional Intellectual Capital (RIC) and

National Intellectual Capital (NIC) are at the core of the fourth stage of IC research, and they encompass all knowledge assets inside the region (or the nation) that can act as potential sources for wealth creation and improved quality of life that goes beyond a single organisation's boundaries (Malhotra, 2001; Schiuma and Lerro, 2008). Following this line of research, the adoption of either a regional or a national view of IC seems appropriate to discuss the creation of EE, as the ecosystem requires integration of both various knowledge assets pertaining to different actors (individuals, firms, institutions, communities, governments) and the knowledge flows within the network to support the creation of innovation dynamics. Furthermore, the prior literature about IC and entrepreneurship has been constrained to an organisational level, thereby highlighting how IC can boost the performance of a new venture (Hayton, 2005) but ignoring how it may facilitate the creation of EE, especially in highly technological environments.

Based on these gaps, the paper aims to answer the following research question:

RQ. How do EEs form over time, and what role does IC play in this process?

In order to investigate the role of IC in EE formation, we adopt the collective intelligence approach (Malone *et al.*, 2010). Previous studies have investigated EE through the lens of collective intelligence (Elia *et al.*, 2020; Elia and Margherita, 2016), but they did not focus on the role of IC in EE formation. Also, this approach has already been employed to investigate IC in its fourth stage of research (e.g. Iacuzzi *et al.*, 2020); however, most of these studies were conducted in the public sphere (e.g. universities and healthcare systems). Therefore, it could be interesting to explore if and how the collective intelligence approach might be applied in a business-oriented context, such as an entrepreneurial ecosystem, to study how IC practises are distributed amongst the genes of collective intelligence and contributed to the genesis of EEs. This approach allows us to reveal how collaboration amongst the different stakeholders create more favourable conditions for managing IC, thus also showing the role played by HM, RC and SC in the creation of an entrepreneurial ecosystem.

3. Theoretical background

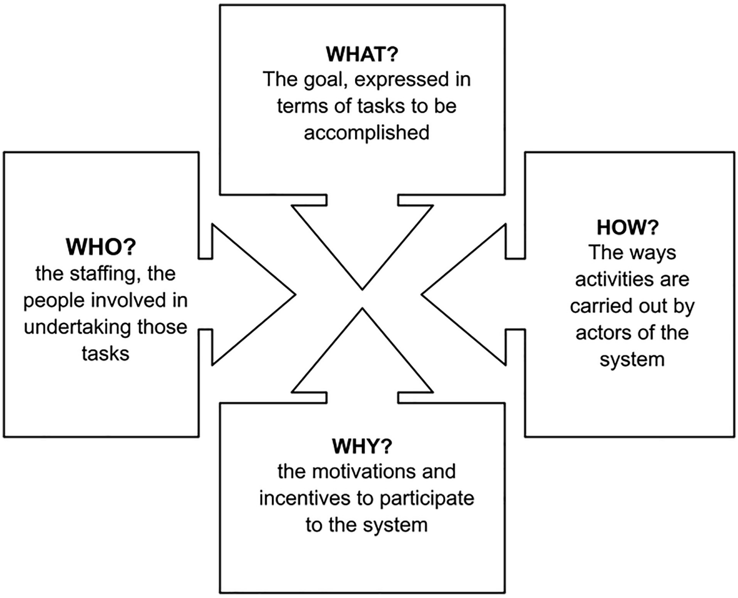
The concept of collective intelligence was introduced in Levy's book "*L'intelligence collective: Pour une anthropologie du cyberspace*" (1994), and thereafter, it was systematised by a research group from MIT in the early 2000s. The idea behind this approach is that multiple independent actors who work together may perform better (that is, more intelligently) than any individual actor working alone. For this reason, it is particularly suitable for generating solutions to global challenges, such as climate change and poverty. As the complexity and scope of technical and social challenges increase, solutions to those challenges can be addressed by collaborative research and IC-sharing efforts involving multiple actors (Carayannis *et al.*, 2014). Consequently, corporations have recently started to use the collective intelligence approach to foster participative forms of collaboration and to boost innovation. There are three conditions to successful implementation of this approach: *diversity* – the presence of actors with different competencies and forms of expertise – *independence* and *aggregation* – the use of mechanisms to combine individual contributions. All these conditions are present in the entrepreneurial ecosystem. In this sense, we can consider an ecosystem to be a collective intelligence system composed of the following four building blocks, i.e. the 'genes' of the system (see Figure 1):

(1) The goal, expressed in terms of tasks to be accomplished ("*What is being done?*");

(2) The staffing, the people involved in undertaking those tasks ("*Who is doing it?*");

(3) The motivations and incentives for participating in the system ("*Why are they doing it?*");

(4) The ways activities are carried out by actors in the system ("*How is it being done?*").



Source(s): Our adaptation from Malone *et al.*, 2010

Figure 1. The collective intelligence framework

Therefore, since EEs can be considered collective intelligence systems in which intellectual assets are coordinated through stakeholder collaboration, we decided to use this framework (see Figure 1, above) to investigate the role of IC in the genesis of such an ecosystem, thus showing the importance of each component (human, relational, and structural) in the process. As a matter of fact, by integrating the two streams of research we can reveal which IC components lie in the "genes" of collective intelligence systems. Specifically, the "who" gene describes all the actors involved in the system and how they contribute to achieving the set goal (the "what" gene), thus shedding light on the role HC plays in the genesis of an EE. Additionally, RC, defined as the knowledge and value embedded in relationships with any stakeholder, pertains in particular to the "how" gene that explains how decisions and activities are jointly implemented by all the actors involved in collective intelligence systems (Elia *et al.*, 2020). Finally, since SC concerns routines, practices, systems, and structures that facilitate human resource productivity and refers to the overall organisation, it can be difficult to trace it back to a single gene. More likely, this component represents the enabling environment for the development of the entire EE.

In addition, we should consider that collective intelligence systems operate through the collaboration that takes place between and amongst different actors who, especially in the initial development stage of the EE, bring into play different types of IC at the individual level. However, in line with the literature on the fourth stage of IC (Pedro *et al.*, 2018), we should investigate the role of IC from both a single and a collective perspective in order to go beyond the simple creation of wealth in terms of business outcomes (Borin and Donato, 2015; Edvinsson and Lin, 2009). Consequently, we need to adopt a wider view by also considering how the components of IC act at the ecosystem level. Based on these reflections, we posit that to better understand the genesis of an EE, we need to integrate two different perspectives of IC into the collective intelligence approach: the "micro" level, meaning the IC provided by individual actors taking part in the EE, and the “meso” level, which considers the EE as a whole.

4. Methodology

4.1 Research method

The research employed a single case study – the FermoTech ecosystem – to perform an exploratory analysis of the role of IC in EE generation. Considering the novelty and the complexity of the topic the case study approach is particularly suited because it emphasises the richness of the context in which the phenomenon of interest occurs, and the findings are deeply grounded in the varied empirical evidence that is collected (Eisenhardt, 1989). Case studies are particularly useful because they provide in-depth information regarding “how” and “why” research questions, thus enabling a holistic, comprehensive and realistic understanding of the phenomenon. Additionally, as stated by Roundy *et al.* (2017), qualitative methods are well suited for the study of EEs as complex systems, thanks to their flexibility and richness of data. As a matter of fact, previous studies (e.g. Elia *et al.*, 2020) employing the collective intelligence approach have proven case study to be an appropriate methodology for the accurate depiction of such complex systems. Consequently, to get a clearer understanding of an EE’s complexity in its real-life context (Eisenhardt, 1989; Yin, 2009), a single case study of an Italian EE – FermoTech – has been purposefully chosen for its revelatory potential (Patton, 1990).

Firstly, it offers a distinctive setting in which to explore the phenomenon under investigation and significant insights that other cases would not be able to provide (Coviello and Joseph, 2012; Siggelkow, 2007). Secondly, FermoTech involves the development and use of Industry 4.0 technology, allowing us to further explore an innovation-based ecosystem. Thirdly, the case is particularly representative of the national entrepreneurial landscape, as it is located in a small city and involves small and medium size enterprises (SMEs) as actors. As is well known, SMEs are the backbone of the Italian and European economy, representing 99% of all businesses in the European Union (https://ec.europa.eu/growth/smes_en, accessed 23 September 2021). Moreover, approximately 60% of the EU’s population lives in small- (from 10,000 to 50,000 inhabitants) or medium-sized (between 50,000 and 250,000 inhabitants) urban centres; in Italy, the municipalities with more than 50,000 inhabitants make up only 7% of the population (https://www.tuttitalia.it/comuni-per-fasce-demografiche/, accessed 23 September 2021). Finally, one of the authors was directly involved in the entirety of the EE creation process, and his active involvement enhances knowledge acquisition through direct participation, allowing us to gather richer and more relevant information (Siggelkow, 2007; Yin, 2009).

4.2 Case description: FermoTech ecosystem

FermoTech is an ecosystem emerging in the local area of Fermo, a small city in the Le Marche region of central Italy that is characterised by a high density of entrepreneurial activities, mostly SMEs. Specifically, its industrial footwear and mechatronic production manufacturing districts are globally recognised. In addition, the city of Fermo stands out for its technical education footprint, as it hosts a master’s degree course in Management Engineering (at a branch of the largest regional university, Università Politecnica delle Marche) as well as several high schools with technical curricula.

FermoTech as an entrepreneurial ecosystem originated in a project called *FERMO TECHnology lab for innovation and research of “Made in Italy” products* (FermoTech). The project was developed as a response to the increasingly decisive role that research, and innovation plays in the competitiveness of manufacturing firms, even the most traditional ones. In fact, the project aimed to design and develop innovative IT (Information Technology) methodologies and technological solutions that could support the participating companies in the development processes of new products.

With this aim, the project took the form of an integrated and collaborative research hub equipped with a physical laboratory. Within this laboratory manufacturing companies collaborate with dedicated R&D teams to develop ad hoc technological solutions based on specific needs.

Indeed, the main pillars of FermoTech are based on the Industry 4.0 domain, especially regarding enabling technologies for the design, prototyping and marketing of "Made in Italy" products. In particular, the solutions developed within FermoTech are based on the following three technological fields:

(1) Extended reality;

(2) Additive manufacturing and

(3) Data science.

The partners who joined the FermoTech project are summarised in Table 1.

The participating firms belong to two of the main industrial districts of the region: fashion (footwear and jewellery) and mechatronics (lifts, elevators, stairs), and they are quite representative of the industrial structure of the territory, which is characterised by the presence of a variety of manufacturing SMEs that mainly operate in traditional sectors.

4.3 Data collection and analysis

The primary source of empirical data consisted of seven semi-structured interviews with individuals who played key roles in FermoTech's formation. Specifically, the key informants' profiles are presented in Table 2.

Semi-structured interviews suited the study's explorative aim because they allow researchers to follow a structured approach whilst also leaving space for interviewees to freely talk about their experiences and opinions (Yin, 2009). Each interview lasted approximately one hour, was conducted in Italian, was audio-recorded and transcribed verbatim and was based on open-ended questions within a semi-standardised protocol to ensure both guidance and consistency in the interviewing style and an adequate level of freedom in answering. The protocol was carefully designed based on the previously analysed literature about collective intelligence, IC and EEs in order to unravel the role IC plays in the formation of the EEs. Specifically, interviews covered the following topics: actors' motivations to participate in the project and expected benefits; the role played by their organisation in the entire process; the activities they helped develop so far and the resources provided; and future steps and developments. Each interviewee was also asked to talk about their backgrounds, both educational and professional, their role within the organisation, and their future tasks inside the FermoTech ecosystem.

The interview data were then enriched by additional documents, email correspondence, meeting reports and field notes from the direct observations of the author who participated in FermoTech (all the data sources are summarised in Table 3). Particularly, the researcher directly involved in the process selected only the official correspondence between all the actors involved in the project.

The entire period of observation lasted 24 months: from October 2019 to September 2021. The first meetings between potential members date back to October 2019, whilst the kick-off meeting was organised in January 2020. In September 2020, the FermoTech project was presented to a call for proposals in order to obtain the necessary financial resources.

All the collected data were entered into NVivo12 software for deductive coding (Miles *et al.*, 2013), using the collective intelligence approach (Malone *et al.*, 2010) and IC literature.

Actors	Description
Technology provider #1 (Project leader)	Startup founded in 2020 as a joint investment between two leading companies in the research and digital sectors and with the aim of establishing itself as a reference player in the eXtended Reality (XR) sector
Technology provider #2	Innovative start-up that offers solutions such as design, reverse engineering, modelling and printing in the field of 3D printing. The main sectors of reference are aerospace, industrial, automotive, medical and dental and artisanal
University #1	Three university departments are involved: DIISM (Department of Industrial Engineering and Mathematical Sciences), focussed on research projects for the development of mechanical and mechatronic products; DII (Department of Information Engineering), dedicated to projects relating to the fields of the internet of things, artificial intelligence, data science and sensor networks; and DIMA (Department of Management), which supports companies in advanced digital marketing projects
University #2	Researchers representing the School of Science and Technology – Computer Science and the School of Science and Technology – Chemistry are involved
End user company #1	The company has 55 employees and recorded a turnover of over 10 million euros in 2019; operates in the footwear sector producing high-end footwear
End user company #2	The company has over 100 employees and generated a 2019 turnover of over 17 million euros. Its core business is the design and manufacture of all types of lifts and lifting platforms. In 2009 it set up a medical division for the development of software for viewing and managing data from remote monitoring and diagnostics equipment
End user company #3	The company has about 60 employees and a 2019 of over 20 million euros, and it operates in the footwear sector. It currently owns 4 brands and produces under licensing for 3 other national and international brands
End user company #4	The company has 70 employees and generated a turnover of over 7 million euros. It is one of the leading national companies in the design, production, installation and maintenance of lift systems for people and things (elevators, hoists and escalators)
End user company #5	The company has over 200 employees. It sells in 30 countries and generates a turnover of over 38 million euros. The company specialises in the design and production of fashion jewels for its 5 brands
End user company #6	The company has 112 employees and generated a 2019 turnover of 25 million euros; it is specialised in the production of high-quality boxes, packaging and paper products for sectors such as publishing, jewellery, footwear, fashion accessories, leather goods, eyewear, perfumery, food, displays, multimedia and objects

Table 1.
The actors involved in the FermoTech Project

The results are presented following the four building blocks (genoma) of collective intelligence (what, who, why and how) and are summarised in Table 4.

5. Results

5.1 What?

The interviewee heading the lead company defined FermoTech as *"an ecosystem represented by a set of relationships, entities and assets that are shared within the laboratory, but which remain under the ownership of the individual players"*. Being deeply rooted in the territory, FermoTech can be defined as a regional collaborative platform whose mission is to provide technological support for manufacturing SMEs, thus enhancing the digital transformation of the local manufacturing system. Notably, the technology transfer process occurs by developing ad hoc, tailored R&D projects called "use case", which are based on companies' specific needs.

N	Role	Actor	Interview span
1	Project Manager	Technology provider	60 min
2	Full Professor Department of Industrial Engineering and Mathematical Sciences	University	60 min
3	Full Professor Department of Information Engineering	University	70 min
4	CEO	End user company	45 min
5	Product Design Manager	End user company	50 min
6	Researcher Department of Management	University	70 min
7	Researcher Department of Information Engineering	University	60 min

Table 2.
The interviewees' profiles

Data sources	Volume
Project documents	*n*.4 documents
Meeting reports	*n*.13 documents
Email correspondence	*n*.51 emails with 19 different people
Meeting participation	*n*.13 meetings
Face-to-face interviews	*n*.7 interviews

Table 3.
Data sources for the case study

Therefore, FermoTech is evolving not only as an individual business reality but also as a "hub" in which students, start-ups, established companies, and freelancers can collaborate and interact, thus exploiting the technological assets shared in the laboratory. This helps accelerate the entrepreneurial development of the local communities as well as improve its employment rate.

Indeed, all the interviewees spoke of a strong link with the local area where the project is located, defining it as a *"fertile territory"* characterised by steady entrepreneurial activity operating in strategic sectors of Made in Italy manufacturing.

5.2 Who?

FermoTech is the result of the joint action(s) of several partners, which can be grouped in four categories.

(1) The first group is represented by the two companies defined as "*technology providers*", which both develop and sell technological solutions. For them, being part of FermoTech is positively impacting their business since the sharing of technological assets and expertise with other companies allows them to develop new dedicated solutions. Both actors have already gained experience in previous collaborative research and platform development. Representatives of both companies are currently working in the operational headquarters of FermoTech.

(2) The second group is formed by "*academic organisations*": specifically, two universities located in the Marche Region; six university researchers are employed as technical staff at the FermoTech headquarters. The presence of this highly qualified team working full time at the laboratory emerged as a critical asset for the

Table 4. Summary of the FermoTech entrepreneurial ecosystem

Gene	Description
What?	As a regional collaborative platform, FermoTech's goal is to provide technological support to manufacturing SMEs in the Made in Italy sector
Who?	Four categories of partners are involved in FermoTech · Technology providers · Academic organisations · End user companies · Local stakeholders
Why?	· To enable technology transfer (from providers and universities to SMEs) · To provide SMEs with new, possible competitive advantages deriving from technological progress · To promote new entrepreneurial initiatives based on the solutions designed within the ecosystem
How?	· Frequent meetings amongst partners and joint investments in technology · Use case development: ad hoc R&D projects based on end user companies' specific needs · Constant interchange of know-how and experience amongst partners

ecosystem's formation. According to one of the university representatives, the constant personal support acts as a main driver of the success of the entire project in the long term, as it guarantees that *"the various activities are followed day-by-day"*.

(3) A third group of actors includes the six "*end user companies*" that are the target of the innovative solutions developed within FermoTech. The companies are SMEs operating in the Made in Italy sector with a number of employees ranging from a minimum of 55 to a maximum of 200. In their markets, all these firms are competing with larger organisations and multinationals that have more resources and knowledge to drive the innovation process. Hence, SMEs struggle to sustain the complex and uncertain innovation development process by relying only on their own limited resources. Consequently, joining FermoTech has helped SMEs and entrepreneurs to develop innovative and customised solutions by providing them with a series of resources, such as tools, technologies, and expertise that is shared within the project.

At the same time, the interviewees revealed how at the beginning, some entrepreneurs were sceptical of this partnership because they did not perceive the benefits of being part of the project. Therefore, bringing all firms on board, in spite of uncertain innovative solutions output, was the main initial challenge. These companies have no past experience in collaborative platforms, but they already had contact with the universities.

(4) The fourth group includes other relevant "*local stakeholders*". In particular, the interviewees refer to the Fermo *"municipality"*, which provided the laboratory with a physical location. Given its institutional position as well as its ongoing relationships with several actors in the ecosystem, the municipality has played a very important role in developing the project from its earliest stages. Specifically, according to the interviewees, these stakeholders provide both financial and organisational support.

As local stakeholders, *"trade associations"* have also been invested in the project since the very beginning; specifically, they helped identify the end user companies and acted as intermediaries between them and the other actors in the ecosystem. Finally, another important local stakeholder that contributes to the ecosystem is what the interviewers defined as *"the local education system"*, meaning the whole set of higher education institutions, in particular the technical institutes that interface with FermoTech and involve their students in innovative training programs focussed on the learning-by-doing method.

5.3 Why?

According to the interviewees, FermoTech has created a favourable business and cultural environment where research and innovation profitably coexist, allowing participating firms, thanks to technological advancement, to increase their competitiveness in the national and international landscape. As two interviewees stated, the obtained funds helped create this favourable environment for uprise technology, since they allowed end user companies to undertake innovation projects without depleting their own financial resources. Moreover, according to the promoters, the presence in the territory of a player like FermoTech has acted as a catalyst for the genesis and development of new entrepreneurial activities, characterised by "*high knowledge intensity*". Notably, the interviewees listed a range of opportunities, including the production of vertical knowledge focussed on specific technological fields, which is used by the participating companies to train qualified human capital; the multidisciplinary nature of the university researchers allows for an integrated vision of the technological and managerial fields.

Findings show that motivations to join FermoTech differed amongst actors. Technology providers were moved to participate mainly to have the chance to enter the manufacturing sector, which required them to develop new knowledge and skills, and consequently, to expand their solutions portfolio thanks to use case implementation. Regarding universities, FermoTech represented an ideal environment in which to conduct applied research. According to one university representative, *"with the FermoTech project it was possible to apply the results of academic research into practice"*. Notably, all of the interviewees acknowledged that some of the main drivers for participation were the possibility of networking and the establishment of lasting relationships amongst actors – although some of them were already partners – as well as the creation of knowledge interchange. As one interviewee said, *"FermoTech favours the creation of a collaborative environment between companies and researchers that have innovation as a common factor"*. In addition, end-user entrepreneurs mostly decided to participate in order to *"increase companies" competitive advantages'* and gain access to a set of resources, knowledge, and technologies that they would not have been able to acquire on their own. Finally, local stakeholders' motivation to strongly support the project lay in the strategic role and long-time benefits FermoTech would bring to the entire local community. The municipality, trade associations, and the local education system have embraced the idea of supporting an environment that serves as the engine for a virtuous circle of applied research, innovation, and new entrepreneurial initiatives aimed at increasing the attractiveness and competitiveness of the territory.

5.4 How?

Over time, the FermoTech ecosystem has provided a lively and continuous exchange of both tangible (such as tools and machinery) and intangible (such as know-how) resources. These exchanges are carried out on equal terms between the various actors and affect all phases of the research and development of technological solutions. Usually, actors communicate through regular meetings, designed as a work routine, in which they discuss FermoTech's overall strategy as well as the operational activities agenda. According to one of the promoters, there are two types of meetings: "dedicated meetings" that focus on the individual use cases developed within the laboratory and are attended only by staff directly involved in the process; and "general meetings" in which all the actors involved in FermoTech participate and during which updates and milestones are shared and governance decisions are discussed and taken. In addition, general meetings appear to play a crucial role for end user companies since they allow them to acknowledge the existence of all the available technological solutions within the ecosystem. As one of the interviewees stated, *"By sharing with other firms and partners the experience of implementing a given technology into a specific sector, we got the idea for a similar application in our industry, equally innovative, but transformed and adapted to our reality"*. For example, from these general meetings it emerged that two different companies, one in the elevator sector and the other in the footwear sector, use the same technology, i.e. extended reality, for different purposes: remote presence by the former, showrooming by the latter. Hence, despite operating in different markets, these companies were able to share their experiences and potential issues surrounding the implementation of the same technology that is available in the laboratory. Similarly, two companies in the same sector collaborate to *"converge on a common path in the field of predictive maintenance"*. In this case, insights and knowledge about the core functionalities of certain technologies could be merged in order to create a shared platform able to act as a starting point for building customised features.

How to design and arrange physical space is another important decision usually taken in general meetings and shared amongst all the actors involved. The operational headquarters is divided into three different spaces, each one dedicated to a single FermoTech technological solution, namely extended reality, additive manufacturing, and data science. Each space has been equipped with technologies and machinery that allow the teams to adequately support the end-user companies, such as virtual showrooming technologies for extended reality, 3D printers for additive manufacturing, and servers for data science projects and algorithm development to be applied in predictive maintenance. Although technological providers endowed FermoTech with some of these tools, the majority of them were purchased thanks to the financial resources won with the call for proposals.

In this regard, also the planning for purchasing the equipment, both hardware and software, is jointly taken by considering the expertise of the actors who, depending on the subject area, assured the higher level of confidence in evaluating the investment. Specifically, it emerged that the end-user firms are mostly involved in the initial stages where they are asked to share some information about their business problem or opportunity; in doing so, they bring to the ecosystem their business expertise and knowledge, both of which are beneficial to the technological providers and universities. This was made possible thanks to the assessment activity that the technology providers carry out through interviews with company representatives in the early phases of the innovation development process. In some cases, such as in the field of data science, companies bring their databases, such as the CRM or the database containing sales data. Additionally, the intermediate meetings that are usually scheduled to check the ongoing development process enhance the exchange of information between different actors (mostly universities, end user companies, and technological providers). Moreover, end user companies are responsible for identifying the *"most significant key performance indicators [KPIs] to assess the validity and efficiency of the technology adopted*".

Regarding technology providers and universities, they provide knowledge and expertise pertaining to technologies, methodologies, and practical techniques. Their main objective is to align end user companies' expectations regarding the technology's potential with real-life application possibilities. More than one interviewee highlighted how this exchange of knowledge and expertise was pivotal, especially in the early stages of FermoTech genesis, since it led to defining a *"common language"* that all the actors involved were able to understand.

Lastly, our findings highlight the important role played by use cases, considered the outputs of the single research project developed within FermoTech. Notably, the creation of use cases contributes not only to the growth of the laboratory but also to its entry into the market as an independent entrepreneurial entity with its own value proposition and financial autonomy. Use cases "*feed a portfolio*" and form the basis for new offerings that can be proposed to potential customers. The use cases were described as "*part of the laboratory's assets from which to give rise to very competitive commercial proposals aimed at selling that type of service on the market*." Again, use cases are seen as *"that base of knowledge, skills, and demonstrators to be used according to the type of customer"*.

6. Discussion: the two levels of intellectual capital

The findings, analysed through the collective intelligence framework and the IC literature, show how IC unfolds amongst the genes of collective intelligence. Specifically, the findings shed light on the type of IC embedded in those genes. For example, the "who genes" which describes all the actors participating in FermoTech creation is where HC mostly resides, whilst RC particularly pertains to the "how genes" since this sphere refers to the ways decisions and activities are jointly implemented by all the actors (Elia *et al.*, 2020). It follows that HC and RC components can hardly be clearly distinguished, as they are the result of the IC residing in the actors as well as in their relationships, decisions and actions. As far as the SC is concerned, it has been found that it is not associated with a particular gene, but this component of the IC represents the enabling environment for the entire EE development. Besides, the findings also show how each actor involved in FermoTech has contributed significantly to its genesis by individually bringing various forms of IC. Consequently, to answer the research question, it is necessary to adopt a vision of the contribution of the IC that consists of two sequential perspectives: micro e meso level. The micro level identifies the nature of the IC that each actor has brought within the EE, whilst the meso level refers to the whole ecosystem and comprehends the IC generated during and after the genesis of the EE. The results have been discussed following this approach and are presented in Figure 2. The figure explains the passage from a micro-level to a meso-level perspective of the role of IC in the genesis of an innovation-based EE.

6.1 The role of IC at the micro level

Regarding the HC dimensions – the knowledge, skills and abilities embedded in the human resources employed in FermoTech – all the actors define it as one of the most important assets in the formation and further development of the ecosystem. In fact, whilst the technology providers and universities have contributed HC forms more related to technology and research, the other actors have been carriers of HC that is useful for understanding the competitive and territorial context in which FermoTech operates. In line with past literature, the HC component is the first source of innovation in technology-based new ventures (Criaco *et al.*, 2014), and it is capable of bringing competitive advantage (Feeser and Willard, 1990). In line with Papa *et al.* (2020), the knowledge base of the firm which resides in the people who work for the firm and its management can influence innovation performance.

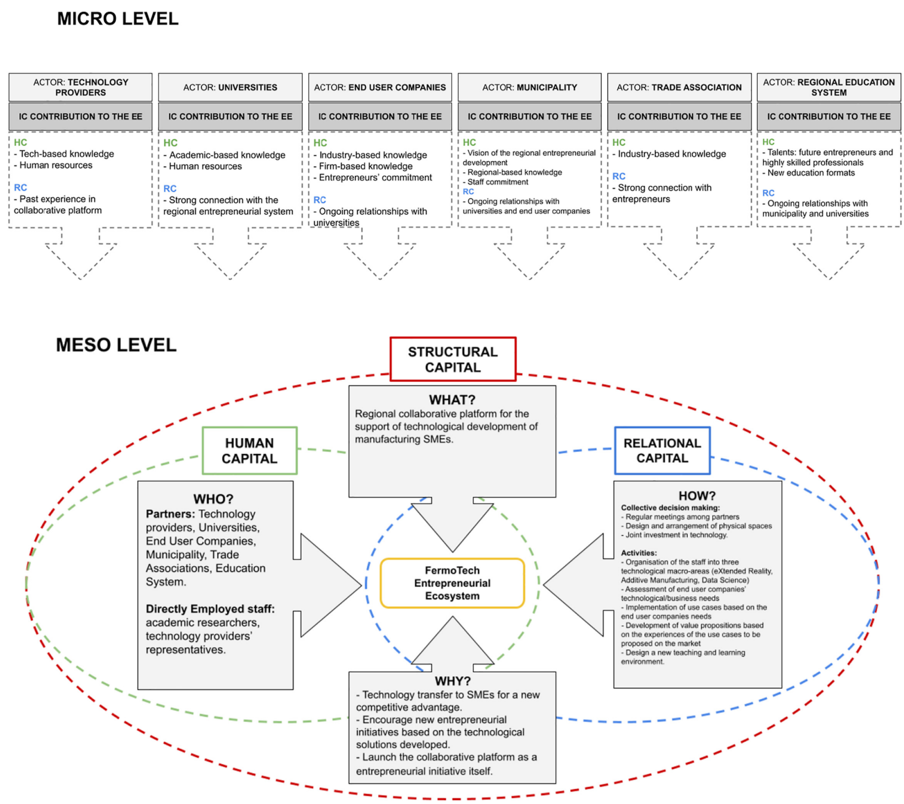


Figure 2.
Role and forms of IC at the micro and meso levels

Specifically, the diverse functional (technical versus non-technical) and educational (economics, management, engineering) backgrounds (Bantel and Jackson, 1989; Hayton, 2005) of the entire team, of the university researchers and of the firms' and technological providers' employees, appeared to be essential for the success of the entire initiative. In past literature about organisational IC (Simons *et al.*, 1999; Smith *et al.*, 1994), heterogeneity of educational background was found to influence a firm's decision-making processes, strategy and performance. In FermoTech, which isn't just a single organisation, each actor (university, technological provider or end user firm) provides people with different backgrounds and skills, thus enhancing interactive knowledge creation and sharing ('contamination'). As a matter of fact, diverse human capital implies different perspectives and cognitive styles, which can boost creativity (Amabile, 1983; Amason *et al.*, 2006) and the design of innovative solutions like those developed by FermoTech. Notably, in the entrepreneurship literature, scholars have begun to study the importance of HC in entrepreneurial teams, as they are usually responsible for the launch of high potential and high growth firms (Clarysse and Moray, 2004; Shrader and Siegel, 2007). In line with Scuotto *et al.* (2022) dynamic capabilities and skills owned by human resources at a micro level can enhance innovation performance, especially in knowledge-intensive contexts.

The findings also confirm the pivotal role of relational capital in the creation of FermoTech (Crupi *et al.*, 2021; Nahapiet and Ghoshal, 1998). RC, meaning the knowledge embedded in the relationships with any stakeholder of the ecosystem, both internal and external, is at the core of the EE formation process. At the micro level, it was possible to observe that the RC created the conditions for individuals to take part in FermoTech (García-Merino *et al.*, 2014; Zardini *et al.*, 2015). In particular, past experiences (Hayton, 2005) in collaborative platform projects led by technology providers have resulted in the ability to interpret the technological needs of end user companies. The RC provided by the universities, represented in particular by their strong connections with the regional entrepreneurial system, proved to be crucial to establishing a climate of trust amongst the project partners. This ongoing dyadic relationship between university and end users has helped to increase the level of entrepreneurial commitment, which then translates into the creation of use cases with uncertain initial outputs. Similarly, the local stakeholders, whose strong connections with the main actors of the territory have represented a further driver (Chen *et al.*, 2004), have contributed to strengthening the project's success guarantee.

6.2 The role of IC at the meso level

The HC that appears to be crucial in the EE is the presence of highly skilled staff who are fully dedicated to running the activities and eventually any future ventures. The ability to employ full-time staff that work around the clock, such as the six university researchers with different areas of expertise, was very important in the FermoTech EE formation process. As most respondents pointed out, the future development of the entire ecosystem is strictly linked to the possibility of continuously running and developing new solutions that are tailored to the needs of individual firms in the market. The only way to achieve this is to create a team that is not only heterogeneous in its background but also fully committed to FermoTech. Moreover, the lack of employees with the right skills to implement highly technological solutions within SMEs operating in the Italian context has been conceived as one of the main reasons that these firms reached out to FermoTech and asked to participate. This lack of knowledge and skills will eventually lead to the creation of new laboratories or new ventures that are able to convey the necessary resources, skills and knowledge to the firms operating within the region.

Regarding RC, one of the main benefits of being part of FermoTech is the constant communication that occurs between organisations from different sectors and fields. Furthermore, RC played a fundamental role in establishing a climate of trust that was not entirely present in the initial phase. In fact, during the establishment of the partnership, some entrepreneurs showed scepticism about the results of the initiative, but the previous relationships with universities, as well as the presence of trade associations as local stakeholders, contributed to reducing the level of mistrust in FermoTech.

Meetings, calls, round tables and workshops increased the exposure to and dialogue amongst partners, thus boosting spill over effects across industries. For example, networking activities can allow a company to discover the existence of a technological solution implemented in a different industry and consequently decide to apply that solution, suitably adjusted, to its own business. However, the COVID-19 pandemic, which has reduced the possibility of meeting face-to-face and restrained relationships to online meetings and phone calls, has partially hindered the formation of strong relations between FermoTech partners. Nonetheless, all the partners agree to increasing the relational activities as soon as the pandemic subsides.

In the initial phase of the formation of the ecosystem, several all-stakeholder meetings were scheduled in order to explain the potentials of the solutions developed by FermoTech. Indeed, potential customers, local institutions and trade associations benefited from this knowledge exchange, but the technological providers also gained useful insights about the stakeholders' needs and expectations; these insights were crucial to developing and improving the solutions. Moreover, thanks to the active relationships and the constant communication, it was possible to set up the physical space as well as purchase the equipment and machinery necessary to conduct the work.

Concerning SC, meaning the system and structure of an organisation, three aspects emerged. First of all, pertaining to the most tangible part of the structural capital (Edvinsson and Sullivan, 1996), physical shared spaces and technological infrastructures are recognised as two important drivers of ecosystem success. As a matter of fact, the SC is the only IC component that can be entirely traced back to the meso level, since its development is made possible by the joint contribution of the actors. Therefore, in the FermoTech case, the SC that has been created can be recognised as the first tangible result of the joint contribution of the single actors both in terms of HC and RC. The possibility of sharing a co-working space with different actors of the ecosystem fosters synergies and networking, thus creating a breeding ground for innovative solutions. This is in line with the literature that sees structural capital as the element most able to create favourable conditions for the utilisation of human capital and allow it to realise its fullest potential, thus boosting innovation capital (Chen *et al.*, 2004). Secondly, organisational culture (Chen *et al.*, 2004; Edvinsson and Sullivan, 1996) in the form of entrepreneurial and top management support acts as an enabler in the creation of EE. As a matter of fact, CEOs' and entrepreneurs' willingness to participate in the ecosystem's pervasive innovation culture is what drove companies to invest in FermoTech.

On the contrary, a third element related to SC at the meso level emerges in FermoTech. The lack of routines, shared information systems and patents within the ecosystem reveals the limited importance of another important part of SC. Usually, a part of SC consists of codified knowledge that occurs through structured, repetitive activities (Nelson and Winter, 1982); its systematisation manifests through various manuals, databases and patents that organisations use to accumulate and retain IC (Subramaniam and Youndt, 2005). FermoTech does not seem to score high on SC, since the actors reveal a lack of any type of established processes or codified guidelines to follow when creating solutions or approaching clients. This is something they are working on and certainly something important to establish in order to maximise the future return of each project. Currently, the high level of personalisation of each technological solution disincentives the definition of standard procedures. Directly linked to this oversight is the recognised importance of developing *'use cases'* as tools to increase competitive advantage. These are defined by all actors as the most important output of the research projects developed within FermoTech. This type of asset can be considered part of the structural capital because it acts as an intellectual tool encompassing all the knowledge, skills and experience accumulated in FermoTech. However, constraining the use cases as a part of SC can be limiting, as its value in terms of competitiveness also depends on a combination of heterogeneous human capital and the specific network of relationships FermoTech has evolved.

7. Implications

7.1 Theoretical implications

The FermoTech case study allows us to contribute to a rather unexplored topic in the existing literature on EE and IC, namely the formation process of EE and the role played by IC within that process. Additionally, the paper provides a new framework based on the collective intelligence approach (Malone *et al.*, 2010) that can be applied to business-oriented ecosystems and is useful for creating and managing IC at both a micro and a meso level. Consequently, the paper contributes to the literature on IC and EEs in different ways.

First of all, the paper offers new insights into the fourth stage of IC literature (Pedro *et al.*, 2018) by considering the role of IC from a collective perspective rather than a single company perspective. The findings shed light on a broader meaning of the three dimensions of IC that occurs at an ecosystem level and goes beyond the simple creation of wealth in terms of business outcome (Borin and Donato, 2015; Edvinsson and Lin, 2009). Specifically, the paper shows that the IC plays a relevant role at both micro (single organisation) and meso (ecosystem) levels and that only by considering this wider perspective it is possible to really understand how to manage IC in the EE formation process. Additionally, integrating the micro and meso-level perspectives of IC into the collective intelligence approach (Malone *et al.*, 2010) allows us to provide additional knowledge on how to apply this approach to a business-oriented context. In the past, this approach has mainly been used to study the public sphere (Secundo *et al.*, 2016), and its applicability in other contexts has yet to be proven.

Secondly, the findings corroborate the positive impact of IC components on innovation and corporate entrepreneurship (Crupi *et al.*, 2021; Hayton, 2005) and also show the importance of new forms of knowledge assets, such as the use case. In doing so, the paper contributes to a deeper understanding of how different types of IC can be integrated into the dominant triad classification of IC (Pedro *et al.*, 2018) as new social and technological advances continue to appear. The use case, which appears to be one of the most important intangible assets for the actors involved in FermoTech, emerges at the meso level because it is the result of a combination of human capital and the relationships that are found in all ecosystems. Consequently, it can be considered a new form of intellectual asset that integrates all three components of IC. This allows us to answer to the calls of past literature (Buenechea-Elberdin, 2017; Crupi *et al.*, 2021; Pedro *et al.*, 2018).

Thirdly, the findings show how IC components can help to meet some of the challenges faced by actors in the EE formation process, such as the lack of trust perceived at the beginning of the project. Specific to this case, important local assets inside the Fermo area emerged as potential drivers for the formation of the entrepreneurial ecosystem. For example, the presence of important players located in Fermo that strongly believed in the benefits that such an ecosystem helped to create local growth; also, the financial and human resources needed to start the ecosystem were comparatively easy to obtain, and the local education system (e.g. Istituto Tecnico Montani in Fermo) already focussed on additive manufacturing innovative solutions. Operating in an area characterised by these IC assets allowed the FermoTech ecosystem to create value that goes beyond the single organisation, thus impacting a wider territory (Malhotra, 2001; Schiuma and Lerro, 2008).

Finally, another contribution to the EE literature can be drawn from the findings. The FermoTech ecosystem started from a regional funded project that involved six actors and aimed to support collaboration toward development of innovative technological solutions. Consequently, according to Thompson *et al.*'s (2018) classification, FermoTech's genesis followed a top-down model in which exogenous factors (such as government projects) acted as major drivers, especially in the early stages. However, the important role played by IC shows how endogenous factors, which emerged as a consequence of the processes, networking and contamination amongst the different actors inside the ecosystem, are essential in the EE genesis process. In other words, the ecosystem formation was not an automatic process derived from the project; it was an evolutionary process determined by the interaction of different IC components.

7.2 Practical implications

In shedding light on the dynamics underlying the genesis of an innovation-based EE and the consequent role played by IC in this process, the paper offers some useful and practical implications. Firstly, the results support all those actors, such as policymakers, institutions or large companies, who have an important role in top-down ecosystems and must identify guidelines to ensure its formation process. In particular, the case shows that where the EE outcomes are the acquisition of a competitive advantage through innovation or the development of new business initiatives based on these innovations, the partnership between the academic world and entrepreneurship is fundamental and should be fostered. Additionally, the importance of balancing knowledge pertaining to different actors within the EEs also emerged from the study. Consequently, adopting the perspective of an 'architect' of an EE, the IC exchange and spill over amongst actors of different natures should be especially favoured.

Secondly, it is appropriate to reiterate the importance of both the policy makers, who create the financial conditions needed to activate generative processes, and the actors leading the project, who are responsible for intercepting those resources and coordinating the entire workflow. A financial incentive also acts as a form of guarantee used by the actors to take part in research and development projects. However, it emerged that these favourable conditions of a financial nature were not sufficient on their own to allow the successful creation of the ecosystem. Rather, it is more important that RC have a strong presence in the case of FermoTech, this resides in the various previous or ongoing relationships that exist between the actors. Particular attention should therefore be paid to the relational aspect, especially in an ecosystem in which, although the initial value proposition is well explained, the final outcome is still uncertain.

The third implication is closely related to the second: another element that is crucial for the sustainability of a top-down innovation-based EE is the HC component. The case clearly shows that although the heterogeneity of knowledge, know-how, skills and expertise are of significant importance, the stable presence of full-time employees seems to be the form of HC that has contributed most to the genesis of FermoTech's EE. These human resources are university researchers who are experts in the three technological areas of competence of the laboratory. Moreover, they represent a linkage between the various actors; they serve both as a first contact with new potential end user companies and as a support to technology providers in the development of technological solutions.

The study also provides indication of the need to develop use cases that represent both tangible evidence of the project's outcomes and the starting point from which to build a portfolio of solutions offered within the EE.

A final reflection is necessary on the issue of the regional context in which FermoTech's EE has developed. The results show that the commitment of local actors should ideally be gained during the start-up phases of the ecosystem, although the forms of support may vary, such as the provision of a physical space in the case of the municipality of Fermo, the diffusion of communications amongst companies in the case of the trade association and the constant contribution of the regional education system in the form of qualified human resources.

8. Conclusion, limitations and future research

This paper addresses important gaps in the EE and IC literature. Specifically, applying the collective intelligence approach, the work investigates the role of IC in the formation of an EE. The underlying assumption behind this framework considers EEs as collective intelligence systems in which intellectual assets are coordinated through collaboration between different stakeholders. Particularly, the collective intelligence approach integrated with IC literature, has been used to unravel how human, relational and structural capital acts in the formation of an innovation-based EE through the analysis of a real Italian case, the FermoTech ecosystem. The case shows how IC components occur at two different levels: the micro and the meso levels. HC and RC play major roles at both levels, whilst SC only occurs at a meso level, representing the environment in which the whole ecosystem takes place.

The HC element at the micro level consists of the different types of knowledge, human resources, and commitment that each actor brings to the ecosystem as a single entity. Similarly, RC at a micro level encompasses past experiences and connections previously developed by each actor participating in the ecosystem. These two dimensions mutually influence one another. At a meso level, HC and RC components are represented by fully committed staff and constant communication between partners through meetings, calls and round tables that help build trust and relationships. Regarding SC, physical shared spaces, technological infrastructure, organisational culture and use cases seem to be the most important elements in the EE creation process that only emerged at the meso level. Specifically, the paper pinpoints the importance of use cases as a new IC asset that can be considered to be the output of interactions between the other three IC components.

The study design is subject to several limitations, some of which offer interesting avenues for developing future research. Firstly, the study is exploratory in nature, relying on a single case study – the FermoTech ecosystem – and on a specific context – innovation-based EE in a restricted area of Italy. Consequently, the chosen methodology may limit the generalisability of the observations to other contexts and countries. Though generalisability was not the aim of the study, a trait shared by the majority of qualitative research (Strauss and Corbin, 1998), future researchers should investigate the role of IC in other types of EEs that are characterised by different assets and different historical and institutional contexts. This would help to validate the proposed investigation of IC at the micro and meso levels, since the framework certainly offers opportunities for refinements. Future research could also extend our findings in both business-oriented and public EEs. In fact, even if every ecosystem is unique and has its own distinctive characteristics, future research should try to identify recurring aspects of IC that can facilitate the genesis of EEs and thus increase the significance of our results.

Secondly, the study relies on interviewees with some key informants inside the EEs. Although a strict methodological protocol was followed to ensure the informants' reliability, this made available for analysis only the internal perspective on the investigated phenomenon. Future studies might gather additional insights from a wider range of stakeholders, such as citizens, customers and exponents of the local education system, in order to better triangulate the results and evaluate all elements that might foster the creation of an EE.

Finally, the paper is focussed on a narrow aspect of the lifecycle of an EE, namely the genesis. As a consequence, the intangible assets required, and their interactions, are strictly related to this stage. Future development should eventually consider other elements that interfere with the management of an EE, ideally over a longer period of analysis. Doing so might reveal antecedents and potential outcomes at a both regional and organisational levels.

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About the authors

Luca Marinelli: Researcher at the Department of Management of Polytechnic University of Marche. He holds a PhD in Business Administration at Polytechnic University of Marche. His topics of research are SMEs' digital transformation, shopping behavior analytics in retail, and social media marketing. He is Lecturer of Laboratory of Digital Strategy and Data Intelligence Analysis at Polytechnic University of Marche and of Digital Marketing at Luiss Business School.

Sara Bartoloni: Research Fellow at Polytechnic University of Marche where she teaches digital marketing and sustainability management. Her research interests include digital marketing and social media marketing, sustainability and digitalisation with particular reference to SME.

Federica Pascucci: Associate Professor of Marketing and Fundamentals of Digital Marketing at Polytechnic University of Marche. She received her PhD in Economy and Management of Firms in 2002. Her research interests are mainly focussed on knowledge management, digital marketing, digital transformation strategies with particular reference to the small and medium-sized firms and Industry 4.0, and she is author of various articles and monographs on these subjects. Federica Pascucci is the corresponding author and can be contacted at: f.pascucci@univpm.it

Gian Luca Gregori: Rector of Polytechnic University of Marche and Full Professor of Economics and Management at the Management Department of the Faculty of Economics "Giorgio Fuà". He is author of numerous publications both national and international. His main research areas are distribution and sales channels management, internationalisation and SMEs business models. He is member of the presidential committee of the Società Italiana Marketing. He is chairman of the CUEIM steering and supervisory board.

Massimiliano Farina Briamonte: Research Fellow in Business Management at the Department of Economics and Business of the University of Sassari. In the academic year 2018/2019, he was research fellow at the University of Campania "L. Vanvitelli", and between 2014 and 2020, he was Contract Lecturer at the University of Naples Parthenope and the Link Campus University of Rome. In 2013, he obtained the PhD in Business Economics and Corporate Governance at the University of Naples "Parthenope" and held the position of visiting PhD at Washington University in St. Louis. His current research interests relate to earnings management, valuation, knowledge management, digital innovation, tourism marketing and Industry 4.0.