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Digital innovation ecosystems in agri-food: design principles and organizational framework

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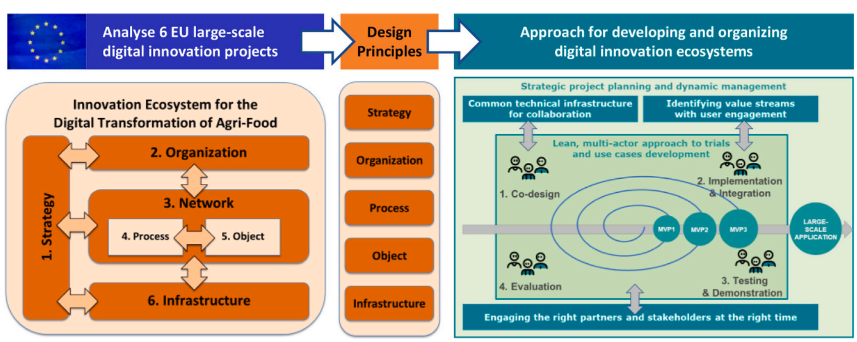
HIGHLIGHTS

- A data economy for food systems based on data spaces requires understanding and optimizing digital innovation ecosystems.
- A conceptual framework is used to analyse the development of large digital innovation ecosystems in agri-food in Europe.
- Lessons learnt are translated into design principles and approach to organize digital innovation ecosystems in agri-food.
- The core is a lean multi-actor approach in use case development interacting with multidisciplinary activities.
- The framework, design principles and approach can be used by stakeholders to foster viable digital innovation ecosystems.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: Digital technologies nowadays play a major role in innovation within the agri-food domain. The evolution of IT systems has currently arrived at a level that involves complex systems integration and business ecosystems in which many stakeholders in different roles are involved. A new paradigm for digital innovation is needed that copes with this increased complexity.
OBJECTIVE: This paper presents an empirically informed framework for analysing and designing viable, sustainable digital innovation ecosystems in the agri-food domain.
METHODS: The research is based on a series of European large-scale public-private innovation projects from 2011 to 2021 with a total budget of 73 M€. They involved hundreds of stakeholders that were developing a large number of digital solutions through which a digital innovation ecosystem for agri-food was formed. In a longitudinal study, a conceptual framework was used to analyse these projects and describe how the digital

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innovation ecosystem has developed. Lessons learnt are translated into a number of design principles and an organizational approach to foster digital innovation ecosystems in agri-food.

RESULTS AND CONCLUSIONS: The conceptual framework consists of 6 key concepts: (i) innovation strategy, (ii) innovation organization, (iii) innovation network that contains (iv) the innovation process and (v) the innovation object and finally (vi) an innovation infrastructure. Along these 6 concepts, lessons learnt and in total 21 design principles are derived from analysing the projects forming a basis for the organizational framework. At the core of this framework is a lean multi-actor approach to trials and use case development interacting with a set of multidisciplinary activities: (i) developing a common technical collaboration infrastructure, (ii) identifying value streams with user engagement, (iii) engaging the right partners and stakeholders at the right time supported by strategic project planning and dynamic management. The most important conclusion is that effective, successful and quick use of appropriate IT in agri-food requires that actors should not be analysed in isolation from both their technological and business environment. Another consequence is that a 'minimal viable ecosystem' only emerges after considerable time, resources and ingenuity is invested and may require outside (government) intervention.

SIGNIFICANCE: Results from this paper can be used both by public and private stakeholders to diagnose and improve digital innovation projects and develop viable, sustainable digital innovation ecosystems in agri-food.

1. Introduction

In the last decade the nature of digitalization in agri-food has evolved and become more complex along two axes (Fountas et al., 2015; Wolfert et al., 2021). According to Wolfert et al. (2021), the IT integration level on the x-axis is shifting from stand-alone applications to a complex system of systems. On the y-axis, the number of involved stakeholders ranges from single process operators to complex business ecosystems in which many different stakeholders are involved. These parallel developments result in a 'digital transformation ladder', as visualized in Fig. 1. A digital transformation is a profound socio-technical change of key business operations that affects products and processes, as well as organizational structures and management concepts (Bernard, 2011; Matt et al., 2015). On the left side of the ladder, the scope of application widens from a single production process, through the farm and supply chain, to food systems (Monasterolo et al., 2016) and a data economy (World Economic Forum, 2021). On the right side of the ladder, the scope of IT systems expands from individual apps, through farm and chain information systems, to data platforms – only a few examples of which exist in the form of food systems (Ge and Bogaardt, 2015) – and data spaces that are in a conceptual phase (Nagel and Lycklama, 2021; Wolfert, 2022).

Wolfert et al. (2021) continued to conclude that the early steps in digitalization were focused on support and automation at process level, shortly followed by the wave of Management Information Systems to support the farmer in managing the farm (Lewis, 1998). The paradigm

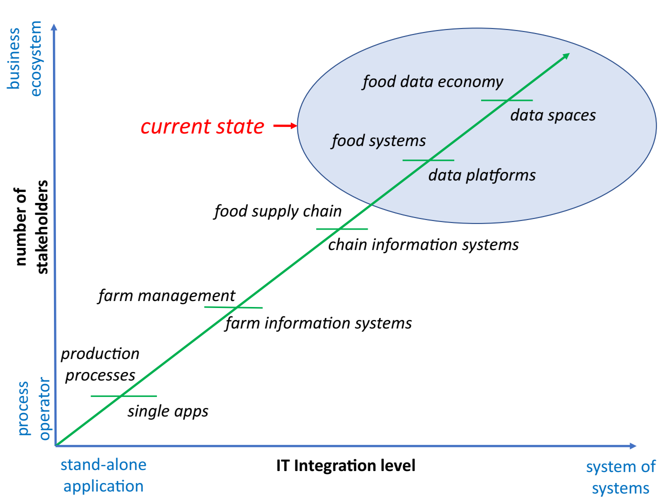

Fig. 1. The evolution of IT systems in agri-food. *Note:* The ellipse points out the current state in which innovation ecosystems have become very complex. Adapted from Wolfert et al. (2021).

here featured strong user involvement in development, testing and demonstration of digital innovations (Sorensen et al., 2010). With the introduction of new technologies such as the Internet of Things (IoT), cloud and mobile computing, digitalization is crossing the borders of organizations. Data sharing across different stakeholders is emerging rapidly. For the food system in particular there are great opportunities to use the vast set of data to combine efficient and sustainable food production supported by integrated services with well-informed consumers and fact-based policies (Wolfert et al., 2017b). Another characteristic of these next-generation information systems is that the user of data is not necessarily the same organization that provides the data. For information systems facilitating different stakeholders, requiring different functionalities, developers are faced with a much more complex challenge. There is the complexity of combining and integrating the different functionalities for a variety of stakeholders and integrating the new application in their existing systems. A new paradigm is needed for understanding and optimizing the function of the current state of food systems and the data economy and the role of data platforms and data spaces. This goes beyond the current paradigm of user-centric software design for single companies or supply chains, but it is subjected to a much more complex ecosystem of stakeholders (Fielke et al., 2019; Wolfert et al., 2021).

Technological innovations provide all kinds of new opportunities for digital transformation in agri-food that may be disruptive (Rijswijk et al., 2021). Many data can be used for various purposes and new business models mainly determine the degree of disruptiveness (Birner et al., 2021; Maringer et al., 2018; Phillips et al., 2019). Business modelling is more a socio-economic discipline than a technical one, but these cannot be seen as distinct. Rijswijk et al. (2021) therefore coined a 'socio-cyber-physical system' not only as a framework to understand but also to support responsible innovation for the digital transformation of food systems. It is expected that digital transformation in food systems can cause big shifts in relationships between various actors in the whole business ecosystem, and several authors have reported on such (actual and potential) shifts (Clapp and Ruder, 2020; Herrero et al., 2020; Mikhailov et al., 2021; Rijswijk et al., 2019; Salvini et al., 2020). While incumbent actors have already started to participate in the digital transformation, there are also many new players on the horizon that are taking an increasing market position in this digitalization field (Mikhailov et al., 2021; Rijswijk et al., 2019). Sometimes these are small start-ups or spin-offs from existing tech companies that use their advantage of being new or having more experience with digital technology (Mikhailov et al., 2021). Again, the technical opportunities that digital technology provides is driving this development, but the process as such is far from technical and requires social and economic insights on governance in particular (Wolfert et al., 2017a).

Together with the evolution of IT in agri-food (Fig. 1), this poses several challenges on how to build robust innovation ecosystems.

Innovation ecosystems thinking has mainly emerged from business innovation studies (e.g. de Vasconcelos Gomes et al., 2018; Walrave et al., 2018) and emphasizes innovation as emerging through multi-actor (human) and 'actant' (non-human) networks and multi-scale and multi-sector interaction for value creation and sustainable development. An innovation ecosystem is hence an integrated system of systems in which no actor, actant or system is greater than another (Pigford et al., 2018). Recently, innovation ecosystems thinking has become more prevalent in studies on agri-food innovation, moving beyond the innovation systems approach, as it is seen as a more dynamic and integrated way to think about how the interaction and collaboration between both human and non-human actors (e.g. plants, animals and digital technologies) produces innovation (Pigford et al., 2018). This resonates with recent thinking on digital transformation taking place in socio-cyber-physical systems (Fielke et al., 2020; Rijswijk et al., 2021). More on innovation ecosystems will follow in the conceptual framework (Section 3).

One of the challenges in building robust innovation ecosystems is determining how research and technology organizations should position themselves in these networks to engage in broader public-private interactions and build relationships with new players, both in agriculture and elsewhere (Espig et al., 2022; Salvini et al., 2020; Schnebelin et al., 2021; Sraml Gonzalez and Gulbrandsen, 2021). Overall, there is considerable discussion in the literature on how best to shape digital innovation and how to build the ecosystems for that, both in agriculture and others sectors (Ayre et al., 2019; Elia et al., 2020; Fielke et al., 2019; Gupta et al., 2019; Mas and Gómez, 2021; Nambisan et al., 2019; Schiavone et al., 2021). Empirical insights into how such ecosystems develop in agriculture are scarce. In this paper, we aim to contribute to this by providing an empirically based framework and approach based on a longitudinal analysis of multiple projects in the agri-food domain, which can support digital innovation and ecosystem building. The objective is to present an approach that can be used to analyse and design viable innovation ecosystems for the agri-food domain. With viable ecosystems we mean an ecosystem that is conducive to the innovation objectives. More specifically, the purpose is twofold:

1. To propose a framework and method for the analysis of digital innovation ecosystems;
2. To present a set of design principles for an organizational approach to develop and organize digital innovation projects.

The paper proceeds as follows. After explaining our research approach, we present a conceptual framework to analyse digital innovation ecosystems, including definitions of the concepts used. This is applied to six large-scale past EU-funded projects, which reveals a number of design principles and an approach for developing and organizing digital innovation ecosystems. In the discussion we derive suggestions for improvement and make recommendations for further research, policy development and use by practitioners. We will also briefly touch upon the development of digital innovation in agri-food outside Europe.

2. Research approach

The research reported upon in this paper is based on a design-oriented methodology, which is increasingly applied to management sciences, inspired by Simon (1996). Design-oriented research focuses on building purposeful artefacts that address heretofore unsolved problems and which are evaluated with respect to the utility provided in solving those problems (Hevner et al., 2004; March and Smith, 1995). The design artefact developed in the present paper is a framework, that is a systematic classification of concepts, for the analysis and design of digital innovation ecosystems in the agri-food domain. The concept of digital innovation ecosystems is relatively new and complex. A case study is a good approach to get a better understanding of such complex phenomena, which are influenced by many factors and cannot be studied outside their rich, real-world context (Eisenhardt, 1989; Yin, 2003). Therefore, the present research has conducted an extracting multiple case study, which is a type of best practice research that aims at uncovering rules already used in practice (Aken, 2004). The case studies should include a rich body of experiences and in-depth insights into the evolvement of digital ecosystems. The selected digital innovation ecosystems developed in successive European projects provide unique and very extensive practices, which are systematically monitored and evaluated, and include many stakeholders throughout Europe and beyond. Furthermore, pragmatic reasons for the selection of these cases were that the authors could draw on their own experience as project coordinators and provide access to all documentation needed for the analysis.

The research started with the definition of a conceptual framework for analysis based on an integrative literature review in the Scopus database and Google Scholar. We used a combination of the following search terms: Business Ecosystem, Innovation Ecosystem, Digital Ecosystem, Digital Innovation Ecosystem, Digital Transformation and Digital Innovation. We then selected papers that thoroughly defined the concept, that proposed conceptual frameworks, and review papers. Next, we complemented the review with frameworks from the supply chain network domain. Our conceptual framework for analysis was based on a synthesis of these papers.

The next step was to use this conceptual framework for analysis to systematically describe the digital innovation ecosystem projects. The results of this multiple case study were finally used to derive a number of principles for the design of digital innovation ecosystems in the agri-food domain. These principles are specific guidelines that can be used to advance future design processes and that can serve as a blueprint for projects setting up and developing digital innovation ecosystems. In this way, the generic conceptual framework, based on literature, served as a theoretical basis for abstracting replicable knowledge from case study findings (Yin, 2003).

The case studies for this research are formed by six European projects, the relevant key figures of which are presented in Table 1; more detailed descriptions are provided in Appendix 1. Applying the conceptual framework to these projects will reveal more details of the technical and organizational approaches in Section 4. The next section will introduce the conceptual framework for analysis of the digital innovation ecosystems of these case studies.

3. Theoretical foundations and conceptual framework

3.1. Business and innovation ecosystems

The term 'ecosystem' was coined in the early 1930s by the British botanist Arthur Roy Clapham at the request of the ecologist Arthur Tansley who used the term to draw attention to the importance of transfers of materials between organisms and their environment (Willis, 1997). In general use, ecosystem now refers to a complex network or interconnected system. The term ecosystem is now widely used in discussions of software developments, stakeholder management, innovation and business strategies (Wolfert et al., 2021).

The business ecosystems approach originated in the 1990s from supply chain management (SCM) in response to the then dominant focus on linear supply chains that efficiently push products to the marketplace (Moore, 1993). It expanded the network dimension of existing supply chain literature to include a larger diversity of stakeholders and the dynamics of their interactions (Perkmann and Walsh, 2007; Rong et al., 2015). As a consequence, ecosystem frameworks can be considered as a further development of SCM frameworks, including the authoritative framework of Lambert and Cooper (2000). That framework contains three important interrelated decision components: the supply chain network structure, supply chain business processes and SCM components. The network structure defines the network of key supply chain

Table 1
Some key figures of the EU-funded projects that form the basis of a European digital innovation ecosystem in the agri-food domain. *Source:* Internal project documentation.

Project	Start date	End date	Total budget (M€)	EU funding (M€)	#Public partners	#Private partners	SMEs[1] (%)	Open call budget (M€)	#Use cases	#ICT solutions	Farming	Supply chain	Retail
SmartAgriFood	1-4-2011	31-3-2013	7.36	4.97	12	9	14	–	6	6	x	x	x
FIspace	1-4-2013	30-9-2015	20.14	13.49	14	15	38	1.35	8	31	x	x	x
FIWARE Accelerator projects:													
SmartAgriFood2	1-6-2014	30-9-2016	5.14	4.89	7	53	87	4.00	51	51	x		
FInish	1-9-2014	30-9-2016	6.42	6.10	7	32	82	4.90	31	31		x	
FRACTALS	1-9-2014	31-8-2016	7.30	6.90	8	48	82	5.52	46	46	x		
IoF2020	1-1-2017	31-3-2021	34.09	29.99	32	54	44	6.00	33	235	x	x	x
Total			**73.09**	**66.37**	**80**	**211**		**21.77**	**175**	**400**			

[1] Small- and medium-sized enterprises.

members, their roles and institutional arrangements. The business processes define the structure of business activities that are designed and performed by the supply chain actors to produce a specific output. SCM components include the governance and control structures in the supply chain network. The governance structure revolves around the allocation of decision rights amongst the stakeholders participating in the supply chain. The controlling function provides an overview of the coordination, planning and monitoring of the process performed by the stakeholders and how these processes fall within the governance structure (Ahoa et al., 2021).

The SCM literature focuses on the value-adding network of companies from suppliers to final customers (Verdouw et al., 2008). Business ecosystems emphasize that a loose network of actors with various backgrounds is involved in the creation and delivery of end products. A platform, to products, services or technologies that other actors in the ecosystem can build upon, is used (Li, 2009; Scaringella and Radziwon, 2018). Additionally, organizations within a business ecosystem co-evolve through collective innovation and value creation, in a way that the synergetic value is greater than the sum of the parts (Li, 2009). A 3C framework emerged empirically, addressing three key dimensions of business: context, configuration and cooperation (Zhang et al., 2007). First, context refers to the environmental dynamics of an ecosystem, including driving forces, main strategies and objectives and development over the course of the lifecycle. Second, configuration is about the participating organizations and their roles. Third, collaboration between stakeholders influences the accomplishment of ecosystem objectives, especially the written and unwritten rules of the game, that is the formal and informal arrangements that govern cooperation within the stakeholder network (governance).

Conceptually, Rong et al. (2015) further developed the 3C framework for the context of IoT-based, or digital, business innovation ecosystems. The concepts of cooperation, construct, and change were conceptually developed, and their interconnections elaborated. This resulted in Rong et al.'s (2015) 6C model. Cooperation reflects the mechanisms by which partners interact to reach common strategic objectives and include coordination mechanisms and governance systems. Construct is about the fundamental structure and supportive infrastructure of a business ecosystem. Change reflects the pattern renewal and evolution of a business ecosystem and includes its lifecycle dynamics.

As noted by Adner (2017), the rising popularity of the term 'ecosystem' goes hand in hand with increasing interest and concerns with interdependence across organizations and activities. As a result, ecosystem development has become an important activity in innovation projects where multiple individuals and organizations are involved in different ways (Wolfert et al., 2021). Hence, a related concept is *innovation ecosystem*, which emphasizes the fact that innovation is a collective activity and takes place within the context of a wider business ecosystem (Adner, 2017; de Vasconcelos Gomes et al., 2018; Hekkert et al., 2011). An innovation ecosystem can be defined as 'the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize' (Adner, 2017). This definition highlights three key aspects: (i) multilateral interactions, (ii) alignment and (iii) materialization of focal value proposition. This definition also makes clear that the objective of ecosystem development is to find the most suitable alignment structure that enables the materialization of the focal value proposition. This paper focuses on innovation ecosystems, although from the previous explanation it is clear that these are always embedded in business ecosystems.

3.2. *Digital transformation: towards digital innovation ecosystems*

Increasingly, the term innovation ecosystem has also been applied to digital transformation in agriculture (Mikhailov et al., 2021) and is very much associated with and furthers the innovation system concept (Pigford et al., 2018), which is being applied to understand the support and organization of digital transformation (Eastwood et al., 2017; Fielke et al., 2019). A digital innovation ecosystem typically goes beyond technological development of IT, but concerns flows of technology and information across people, organizations and institutions. As such, the emergence of digital innovation ecosystems is jointly driven by the underlying digital technologies and communities of developers and users, such as suppliers, distributors, outsourcing firms, producers of related products or other stakeholders. In digital innovation ecosystems, value creation is intimately linked to value distribution amongst various stakeholders in the network. An innovation infrastructure, usually some kind of platform to build products, services or technologies upon, is used (Li, 2009; Scaringella and Radziwon, 2018).

An important driver of the emergence of digital innovation ecosystems, which can be seen as a non-human actant in the ecosystem, is the development of relevant and appropriate supporting software, enabled by the Internet of Services (IoS) (Kruize et al., 2016). In the IoS, software components are available as interoperable services through the Internet. The IoS allows to decouple the possession and ownership of software from its usage and thus to use Software as a Service (Turner et al., 2003). Users do not need to buy and install a large software system, but required functionality is delivered as a set of distributed web services that can be configured and executed when needed (Kruize et al., 2016). In contrast to traditional non-modular software systems, it is no longer necessary that components are delivered by the same software vendor.

Software companies can concentrate on the development of components that best fit their core competences. Users can configure customized software systems from standardized components that are supplied by multiple vendors that interact via a common technological platform (Kruize et al., 2016). Such collaborative environments are nowadays referred to as software ecosystems. Software ecosystems are defined as the interaction of a set of actors on top of a common technological platform that results in a coherent set of ICT components or services (Manikas and Hansen, 2013). Consequently, the emphasis of a framework for software ecosystems is very much on the technological dimension. For example, Stanley and Briscoe (2010) consider a business ecosystem as additional technical layers that manage the interaction between multiple software systems. The framework of Kruize et al. (2016) also includes the organizational dimension by adding the actors' roles and coordination of the ecosystem by an open software enterprise.

3.3. *A conceptual framework to analyse and design digital innovation ecosystems*

In this paper we use a framework, that is a systematic classification of concepts, to analyse and design digital innovation ecosystems within the remit of agri-food supply chains. The framework builds upon a synthesis of frameworks from the previous section including SCM (Lambert and Cooper, 2000; Verdouw et al., 2008), business ecosystems (Rong et al., 2015) and software ecosystems (Kruize et al., 2016; Stanley and Briscoe, 2010). It consists of six key concepts: Innovation Strategy, Innovation Organization, Innovation Network, Innovation Process, Innovation Object, and Innovation Infrastructure (Fig. 2). Appendix 2 details the various elements as they appear in the scholarly literature and indicates this paper's contributions.

The bidirectional arrows between the six key concepts and ecosystem principles indicate that they are mutually dependent and influence one another. For example, the innovation strategy will initially set the organization, network and infrastructure, but when deployed it can be expected that the strategy will be adapted. Or, when the innovation network evolves, possibly the organization and infrastructure will need to be adapted.

Concerning the conceptual framework, the next section analyses the projects that were introduced as case studies in Section 2; they exemplify how the use of IT in the agri-food domain has evolved to necessarily encompass complexities not foreseen one or two decades ago. To mention some overall developments: previously separate sub-supply chains (ecosystems) are increasingly interconnected; increasingly, diverse technology, processing and primary production players are involved; the agri-food domain is subject to ever-increasing outside demands and ever more varying production circumstances. Hence, timings, time horizons, values, perceived (strategic) interests,

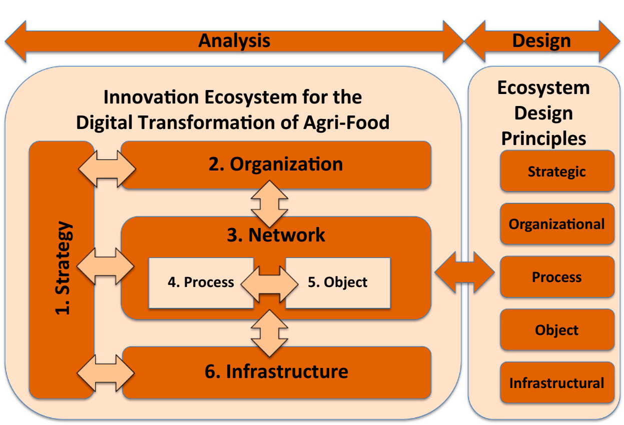

Fig. 2. The Integrated Digital Innovation Ecosystem Framework derived from literature.

uncertainties faced and required levels of investment vary for the players involved. Subsequently, in Section 5 we will derive design principles for developing and organizing digital innovation ecosystems.

4. Application of the theoretical framework to the use cases

From the case study description in Section 2, it can be concluded that the general line of development in the projects was to move digital solutions upwards along the classification system of Technology Readiness Levels (TRLs) as defined in the EU work programme Horizon 2020 (EC, 2014). Fig. 3 positions the projects along this axis indicating the main drivers for change and key results of each project. The Future Internet programme projects SmartAgriFood, FIspace and the FIWARE accelerators logically succeed one another up to the higher TRL levels. For reasons that will be explained later, IoF2020 restarted at lower TRL levels and tried to move upwards from there.

Now we will analyse the development within each case study for the six key concepts of the conceptual framework.

4.1. *Digital innovation strategy*

The strategy of SmartAgriFood was largely defined by the scope of the Future Internet Public-Private Partnership (FI-PPP) programme (see Appendix I). Some background to this programme is that, at that time, Europe was amongst the leaders in terms of internet diffusion, but it was slower compared to some other regions in the world to capture the benefits of internet-based innovation (Ballon et al., 2013). The FI-PPP programme had to build synergies between stakeholders originating from multiple industry verticals to create and operate a sustainable Future Internet business ecosystem in Europe (Ballon et al., 2013). The mission was to stimulate innovation by developing the FIWARE core platform with so-called generic enablers (GEs) as a shared objective, allowing: (i) creation, publishing, managing and consuming the Future Internet services; (ii) deploying the Future Internet services on the cloud, that is using cloud computing technologies; (iii) accessing, processing and analysing massive data streams, as well as semantically classifying them into valuable knowledge; (iv) leveraging the ubiquity of heterogeneous, resource-constrained devices in the IoT; and (v) accessing the networks and devices through consistent service interfaces (Havlik et al., 2011). In that respect, the FI-PPP programme was also focused on collaborative business models.

Within that overall strategy, it was SmartAgriFood's mission to formulate use case scenarios that were based on such a common core platform. Leveraging on that, SmartAgriFood's objective was to boost the application and use of Future Internet technologies to improve the agri-food sector in the areas of smart farming, logistics and food awareness.

In the follow-up project FIspace, this strategy and vision had not really changed in comparison to SmartAgriFood except for an additional focus on business collaboration beside the core platform integration approach (Kruize et al., 2014). This meant that more attention was paid to collaborative business modelling and stakeholder engagement.

With the FIWARE accelerator projects, the strategy changed significantly from developing a core platform and testing it for various domains to creating a business and software ecosystem around it. This was operationalized by attracting many start-ups and app developers and indirectly generating co-financing by external, often private, capital (cf. Rodriguez et al., 2018).

IoF2020 was not part of the FI-PPP programme anymore. Nevertheless, the funding party, the EU, expected that new projects such as IoF2020 would build on results from that programme. Although IoF2020 was again part of a set of large-scale IoT pilots in other domains, it was not defined as tightly as the FI-PPP programme (Guillen et al., 2017). In that sense, IoF2020 had a more dedicated sector-oriented objective, namely to foster a large-scale take-up of IoT in the European farming and food domain. Nonetheless, the IoF2020 project clearly

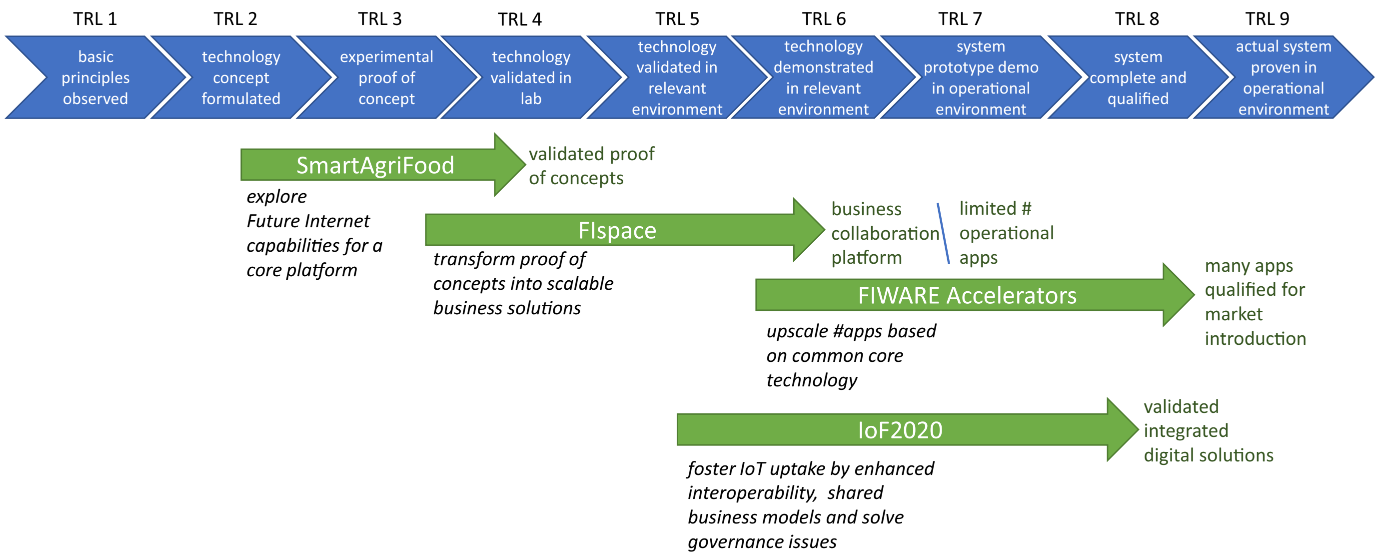

Fig. 3. The case study projects mapped along the innovation lifecycle from TRL1 to TRL9 (EC, 2014). *Source:* internal project documentation.

built on the achievements of the previous projects by using and extending the ecosystem that was built up, driven by several partners that were key players in those projects. Based on the learnings from those projects, the strategy could be characterized by demonstrating the business case and accompanying shared business models of IoT for multiple application areas in farming and food. At the same time, the need for integration of IoT solutions by end users was taken into account by focusing on user acceptability and addressing user needs, including security, privacy and trust. This meant for example that start-up companies from the FIWARE accelerators were now included in a multi-actor use case developing integrated digital solutions starting at a lower TRL level (6–7) instead of focusing on market introduction and expansion (see Fig. 3). The whole project structure was designed to ensure the sustainability of IoT solutions beyond the project by validating the related business models and setting up an IoT ecosystem for large-scale take-up. To that end, project visibility to create identity was of utmost importance. Having a strong, professional communication partner and substantial budget for this purpose played a crucial role. Ultimately, IoF2020 was not considered just another project but a strong brand.

4.2. Digital innovation organization

SmartAgriFood and FIspace were so-called collaborative projects funded by the EU 7th Framework Programme and subject to its formal rules and regulations (EC, 2015b). The process started with a consortium of partners writing a joint research proposal. A common consortium agreement was defined and signed by all parties that set relevant governance rules concerning, for instance, roles and responsibilities, liabilities, intellectual property and access rights, confidentiality. The project was typically divided into work packages (WPs). The overall WP structure targeted an integrative approach for bridging the gaps between the vertical supply chain dimensions (i.e. from farm to fork) and, from a technological point of view, the required domain-specific capabilities and the potential for realizing Future Internet Core Platform instances. Overarching, supporting tasks were defined for: (i) harmonizing use case scenario characterization and analysis approach, which could be considered as coordination by standardization; (ii) development of agri-food domain-specific capabilities and conceptual prototypes, which could be considered as coordination by plan; and (iii) user involvement. Mostly, WP teams worked independently on their tasks, but regular meetings (supervised by a small coordinating team) were organized between the WP teams to monitor and steer the project and guide the necessary interactions, which could be considered as coordination by plan and mutual adjustment. Because important decisions on technology development were expected to be taken in the project, a scientific-technical committee was installed with technical representatives from all relevant partners. Moreover, an executive board was installed with representatives from all project partners that made decisions about important steps in the project. Thus, a clear structure was in place to determine allocation of decision rights. Finally, an external advisory board was installed, consisting of members representing industrial companies from the agri-food and IT sectors, to obtain advice on project progress and direction. A few project members were also members of various bodies and committees in the overarching FI-PPP programme.

A new element in FIspace was an open call mechanism in which app developers were invited to develop commercial applications on top of the FIspace platform and conceptual prototypes that had already been developed in the SmartAgriFood project, enhanced by the FIspace core project partners in a first phase of the project. The open call was completely organized by the project itself, although the procedure had to be approved by the European Commission (EC). This meant that the use cases in the project were defining the specifications for the apps and independent evaluators were hired to select the winners. The selected app developers became full partners in the project.

In conclusion, the organization of SmartAgriFood and FIspace was, first, coordinated by a plan that was described in detail in a proposal document. Second, the various sub-use case domains operated autonomously on their own innovative developments while an integrating and harmonizing approach for each use case was followed, focusing on standardization. Third, room for changes in the project was created and final results were delivered by mutual adjustment influenced by stakeholder involvement and feedback at various stages.

The organization of the third-phase projects (FIWARE accelerators) completely changed by setting them up as accelerator programmes in which start-ups or small- and medium-sized enterprises (SMEs) were selected. The focus was on successful market introduction of a number of apps. Much attention was paid to mentoring, business-modelling and pitching solutions. Open calls were organized by so-called cascade funding, which was invented in the Future Internet programme (EC, 2015a) and has subsequently been applied successfully in many other EU projects (cf. Cecchi and Dario, 2020). In the end, much attention was paid to acquiring external funding from, for example, venture capitalists for further market expansion. Different from the open call in FIspace, the app developers did not become full partners in the project but received the money as grants. This reduced the risks and administrative burdens of onboarding official new partners but increased the app developers' freedom. An important condition was that app developers had to build their applications using the FIWARE core platform. The purpose behind this was to create a FIWARE software ecosystem and increase the scalability of the applications, which could be considered as coordination by standardization. The overall aim of the EU to create more open software systems was also an important backdrop to this. In conclusion, there were clear incentive mechanisms in place in which desirable behaviour was rewarded and undesirable behaviour prevented. The money was provided by the EU, but the open call and further selection rounds were completely organized by the projects with formal approval of the plans and procedures by the EC, which could be considered as coordination by plan.

With the FIWARE accelerators, the FI-PPP programme came to an end. However, it is important to mention that, after that, the FIWARE Foundation was established, which defined Smart Agri-Food as one of its focus domains, alongside Smart Cities, Smart Energy and Smart Industry (FIWARE, 2022b). The FIWARE Foundation continues to drive the definition and adoption of open standards and a large part of the developer community lives on in FIWARE, maintaining and deploying the software and standards developed in the preceding projects.

In IoF2020, many learnings and elements from the previous projects came together, but the objective and context were quite different. IoF2020 was focused on large-scale application of IoT in farming and food in Europe and not so much on developing a core platform like FIWARE. This meant that the heart of the project was formed by use case projects that were developing IoT solutions – using a multi-actor approach (MAA) that did not target a single app developer – that took the whole IoT value chain from technology provider to end user into account (Verdouw et al., 2017). However, the minimum viable product (MVP) approach was taken as a basis to develop the solution. At the same time, support on technical, business, governance and ethical issues was offered to the use cases from separate WPs that acted as task forces that could learn from the use cases and share the learnings between the use cases, reusing knowledge and experiences. This greatly enhanced the scalability and large-scale application of the IoT solutions that were developed. This was further stimulated by a separate task force on ecosystem development supporting the use cases in demonstrating their solutions to a wider audience by organizing events and developing a range of communication materials. Last but not least, all use case projects were set up in a harmonized way and were monitored and evaluated by another dedicated task force in a separate WP. All WP leaders met regularly not only to discuss the progress in the use cases but also, more importantly, to align the various activities so that the use cases were supported in an integrated way. Although use case partners sometimes found this a bit annoying initially, in the end it created much trust in the project, which resulted in high commitment, also in terms of personal investment in the use case. IoF2020 also contained an open call that was organized in a similar way as before. The objective was to expand the number of multi-actor use case projects and to increase impact in various ways. Replication – and therewith sharing and reuse of knowledge – of the original use cases was targeted. For example, a use case on data-driven potato production in Northwest Europe was conducted in the Baltic states.

In 2020, IoF2020 came to an end, but the ecosystem continued in follow-up projects such as SmartAgriHubs, Atlas and Demeter, and the legacy is sustained by organizations such as FIWARE, GS1 and AgGateway Europe. Moreover, many of the digital solutions that were developed in the use cases were successfully introduced into the market and adopted by the farming and food community.

4.3. Digital innovation network

In Digital Innovation Networks we observe a number of ecosystem roles as described in Appendix 2. These roles are assumed by different actors in different projects. In SmartAgriFood, Wageningen University and Research (WUR) – as a major research institute in the agri-food domain – played an important role in setting up the project consortium and acted mainly as an *ideator* to identify the innovation objects. In that respect, WUR could also be identified as a *keystone player*. In this case, the overall FI-PPP programme was dominated by large IT companies and some were included in SmartAgriFood too, making a strong connection with the programme. Because it was in a conceptual phase, the use cases involved relatively many research institutes and consultancy companies that acted as *designers* of innovative smart farming, logistics and food awareness solutions. Also intermediaries, such as auditors and standardization organizations, contributed significantly. End users, such as farmers and supermarkets as well as specialized agricultural technology providers and supply chain companies, were involved but played a modest role.

In FIspace, the innovation focus shifted to prototyping and piloting of IT solutions and therefore software developers and end users were more involved. This is reflected in the network composition seen in Table 1 by a higher share of SMEs and private partners. Beside ICT solutions in terms of apps, the FIspace platform was developed in which large IT companies were dominant. This resulted in some tension between these companies on the one side and the mostly small software companies that developed use case solutions in close interaction with user organizations on the other side. But because the FIspace platform was still in an early stage of development, the large ICT companies could not be defined as value or physical dominators in an active business ecosystem.

In the FIWARE accelerator projects, the network composition was completely different from the preceding projects. SmartAgriFood2 and FInish were coordinated by basically the same partners as FIspace and SmartAgriFood. FRACTALS was led by a newcomer from Southeast Europe, a geographical area that then could be identified as a 'white spot' on the map in Europe of the FI-PPP programme. The consortia consisted mainly of partners good at networking and business incubation. This was important to reach out to the many potential app developers all over Europe, playing an intermediary role. In the end, approximately 130 app developers were included via open calls that could be identified as *niche players* because 'differentiating from competitors' was a key principle to be successful in the project.

While IoF2020 focused on more integrated digital solutions, less focus was on app developers or start-ups as such. Nevertheless, they were still part of the various use cases as the central partner to turn the solutions into a marketable product or service. For that purpose, they were bound to *physical* or *value dominators* such as large, multinational machine manufacturers or input suppliers. In between, intermediaries such as platform providers and umbrella organizations such as industry associations and standardization organizations or farmers' associations were involved at the project level.

Fig. 4 illustrates how the different organizations in the digital innovation network were involved in the projects and how their involvement changed over time. The next sections on the digital innovation process and -object will explain how they were related to one another. Reading from left to right, it can be observed that, ultimately, all types of organization were involved in IoF2020. This reflects the objective to have large-scale application of IoT in agri-food. It can be concluded that end users and their umbrella organizations gradually became more dominant in the network, although keystone players (e.g. WUR) remained important to coordinate and sustain the network. The accelerator phase in particular helped diversification of the network, onboarding many creative niche players.

4.4. Digital innovation process

The conceptual approach in the first two phases of the FI-PPP programme with SmartAgriFood and FIspace could be identified as a *transformational innovation* process. With the *Future* Internet, big steps forwards were supposed to be taken in the areas of smart farming, logistics and food awareness, on a completely new basic framework that

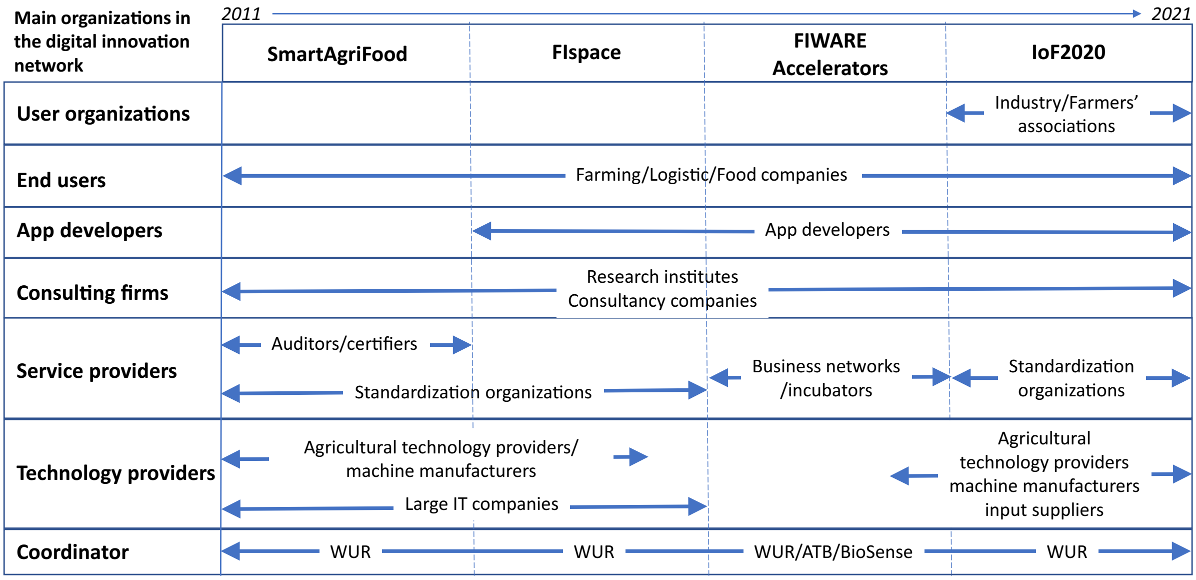

Fig. 4. Organizational involvement in the projects. *Source*: internal project documentation.

later developed into FIWARE. In FIspace, an open call was mostly targeted at improving the prototypes that had been developed for the various application areas. This could be characterized as a more *incremental innovation* process, which was boosted in the accelerator phase. The selection phase, in which only a few start-ups remained, can also be considered as an *incremental* process: in each round, the remaining start-ups were asked to make a next, extended version of their product. It is important to mention here that this requirement concerned not only the technical prototype but start-ups also had to improve their business model.

IoF2020 could be characterized as a strong combination of *transformational* and *incremental* innovation: transformational, because IoT was expected to radically enhance smart farming processes both technically and by introducing new business models; incremental, because use cases were set up according to a 'lean' MAA, that is a combination of the lean start-up methodology (Ries, 2011) and MAA that was mandatory to apply for this project (EC, 2021 p. 19–21). The MAA is a specific aspect of Responsible Research and Innovation (Stilgoe et al., 2013), amply applied nowadays in digital agri-food innovation (Jakku et al., 2022; Metta et al., 2022; Rijswijk et al., 2019). It aims to make the research and innovation process and its outcomes more impactful and demand-driven, ready to use in practice, widely disseminated and relevant to society. End users of project results should get a feeling of co-ownership and become more eager to use the results thanks to the MAA. IoF2020 extended the MAA with elements of the lean start-up methodology, which had already been applied in the FIWARE accelerators. The use cases comprising multiple actors went through several cycles of development that consisted of three steps: (i) design, (ii) implementation and testing, and (iii) evaluation. Depending on the outcome of the last step, use cases started to redesign, going through the cycle again. To guide this cycle, it was important to set clear objectives for the use case project, for example to increase yield, reduce pesticide use or improve transparency for consumers. Each cycle was supposed to lead to a next level, determined by MVPs (Lenarduzzi and Taibi, 2016). An MVP is a version of a product or service with just enough features that can be evaluated by the users (Ries, 2011). Each subsequent MVP adds more features until you reach the stage at which the digital solution is mature and can be introduced on a large scale. This means that an MVP is more than a technical prototype to see if it works: features should also include aspects of practical use, costs and benefits. Support of use cases was organized in a flexible way, which also meant that budgets within the project were reallocated based on learnings and shifting needs. For example, where business development support was underestimated in the beginning, it was extended substantially during the project. Or, when several use cases indicated that data sharing was a challenging issue, a team with a budget for data sharing and ethics was included in the project. In IoF2020, the open call approach was not really focused on improving existing applications incrementally, but more on expansion of the network and number of applications. But it did focus on sharing and reuse of IoT components, knowledge and experiences that were gained from the first phase of the project, which could be considered as *incremental innovation*.

It can be concluded that the digital innovation process started as transformational but gradually became more incremental, while in IoF2020 the two processes were combined to create more integrated, sustainable digital solutions.

4.5. Digital innovation object

SmartAgriFood focused on three particular parts of the supply chain: the farm, logistics and food awareness. At *the farm* level, both product and process innovation were addressed. Technology providers focused on product innovation concerning the development of smart sensing devices in the field to support advanced precision agriculture for farmers (Kaloxylos et al., 2014). The latter could be considered as process innovation. *Logistics* primarily focused on process innovation concerning real-time virtualization, logistical connectivity and logistical intelligence, mainly targeting logistics service providers (Verdouw et al., 2016). But this also included the use of advanced sensor-actuator networks that were developed and improved by technology providers, which can be considered as product innovation. With regard to *food consumption*, the focus was on information transparency to increase consumer awareness of food, which meant that the whole process – from farm to fork – was involved, so this can be mainly characterized as process innovation (Gonzalez-Miranda et al., 2013). Technology providers were also involved in enabling change in this part of the supply chain with product innovations.

As a direct continuation of the SmartAgriFood project, FIspace contained virtually the same use case projects on farming, logistics and food awareness. The main difference was that the innovations moved out of the conceptual phase into the phases of prototyping, piloting and demonstrating at the higher TRL levels (Fig. 3). The Digital Innovation Object focus remained on product and process innovation. Additional activities were included, such as value network mapping for the whole

FIspace platform and embedded apps, which could be considered as business innovation. The FIspace platform could have been turned into a new business, but this did not happen. Instead, parts of it were transferred to and sustained by the FIWARE Foundation. For the eight use cases, some preliminary exercises were conducted to explore possible viable business models, but they did not result in any new business.

In the three FIWARE accelerator projects the focus was basically on product and business innovation. In comparison to the FIspace project, the focus shifted from prototyping and piloting to initial market introduction and market expansion (Fig. 3). On the one hand, start-ups were challenged to develop new products – in terms of apps and services for smart farming and logistics – targeting specific processes. On the other hand, this was the time that accelerator programmes in Europe and beyond were gaining traction and much attention was being paid to business-modelling aspects. Start-ups were required to pitch their solutions in which market analysis and business models had to be addressed. In a typical accelerator approach, the start-ups that made it to a next round were encouraged to focus even more on the business-modelling aspects. However, they also received training and got support from mentors who helped them to improve their products and services, both for technical and business aspects.

The accelerator phase was successful in that several start-ups were introduced to the market and attracted substantial support from private investors. However, when setting up the IoF2020 project, it was realized that the IT market for farming was already overwhelmed by a plethora of apps. Usually, apps target just one or a few processes (see Fig. 1). Farmers worldwide are complaining about the poor integration of all kinds of apps on top of poorly integrated IT systems. And although several start-ups were able to establish a foothold in the market, it remained to be seen how sustainable this would be. In other words, a high TRL level does not always mean a high level of readiness to scale (Sartas et al., 2020); it means that if an app or single technology needs to be integrated into a higher-level solution, you need to go back to the lower levels of prototyping and piloting. Taking this into account, the IoF2020 project continued to focus on product and business innovation, but now also aimed to get more integrated solutions into the market (see Fig. 3). Therefore, the duration of the use case projects was much longer (up to four years) and more attention was paid to technical integration, user acceptance testing and demonstration. In that respect, more attention was paid to the redesign of business processes that were involved, so in that sense process innovation was also targeted.

In conclusion, the focus of development in the last project, IoF2020, shifted from product innovation to a more integrated approach of product, process and business innovation.

4.6. Digital innovation infrastructure

Establishing a common technical core platform was the key objective of the overall FI-PPP programme. In the first phase, the focus was on defining the necessary requirements and specifications. SmartAgriFood contributed to that objective from the agri-food domain. The various use case projects defined a conceptual architecture of how the common FIWARE platform could serve their specific purposes. Gradually, the idea of one central platform was replaced by the vision to provide common building blocks (or GEs) that use cases could use to develop their own solutions in an affordable and robust way. In the second phase of the FI-PPP programme, a first version of the FIWARE repository of GEs was ready and the FIspace project built a domain-specific platform based on that (Fig. 5).

In FIspace, so-called Domain-Specific Enablers (DSEs) were built on top of the FIWARE GEs, which were meant to serve specific applications in the agri-food sector (Verdouw et al., 2014). Apps using these GEs and DSEs were developed in eight trial projects for smart farming, logistics and food awareness. In this way, the FIWARE and FIspace platforms were tested and validated by the applications in the trials. This validation was extended in the accelerator projects in which start-ups were invited to build other applications on top of these FIWARE enablers. However, during the project execution it turned out that not all enablers were yet mature enough to develop robust applications. For this reason, developers could use other infrastructure components from commercial players such as the Amazon, Google or Microsoft stacks. Based on that experience, this approach was continued within the IoF2020 project in which the use of FIWARE was not mandatory but still recommended and strongly encouraged. In the meantime, the FIspace platform was no longer supported, but knowledge and experience were transferred to FIWARE, the ‘mother platform’. In IoF2020, the focus shifted from using a designated platform infrastructure, such as FIWARE, to the application of reusable components based on common architectures and standards. A key aspect of the IoF2020 reference architecture is the so-called Minimum Interoperability Mechanisms (MIMs) that have been adopted and maintained by the FIWARE SmartAgriFood community. A description of this reference architecture is beyond the scope of this paper but can be found in several IoF2020 project deliverables (cf. Cantera et al., 2018) or a recent book chapter by Wolfert (2022).

5. Design principles for an approach to digital innovation ecosystems in agri-food

Table 3 in Appendix 3 summarizes the main lessons learnt from the case studies and derives a number of Design Principles (DPs) that form

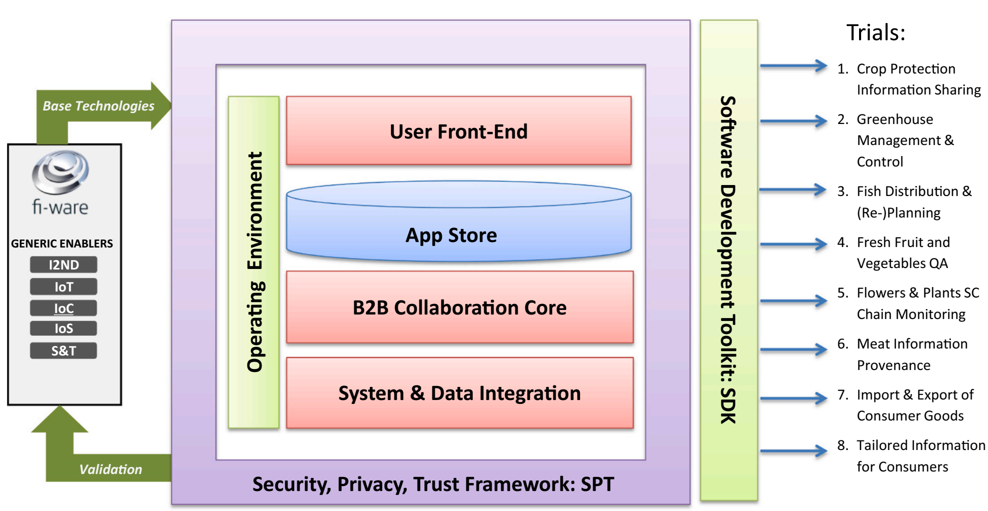

Fig. 5. The FIspace platform architecture built on FIWARE GEs the left) and the eight trials (Kruize et al., 2014).

the basis of an approach for developing and organizing digital innovation ecosystems described in this section.

5.1. Fostering multidisciplinary and agile collaboration in digital innovation ecosystems

As described in Section 4 and visualized in Fig. 3, the project approach for digital innovation in agri-food evolved along the pathway of TRL levels from conceptualization and market introduction to expansion. Each time, experiences and lessons learnt from the preceding projects were taken into account and, if necessary, refined while new aspects were gradually added. This led to a state-of-the-art approach in the last project, IoF2020, in which all design principles from Table 3 were applied. Hence, we will take the IoF2020 project structure as a basis for the approach that is introduced in the following subsections. Fig. 6 captures this in one picture that could serve as a blueprint for projects that want to set up and develop digital innovation ecosystems in the agri-food domain.

User-driven use cases form the heart of this method, which are actively guided and supported by three overarching, horizontal activities, ensuring that the use cases drive the digital transformation of the complete ecosystem. First, a common technical architecture and infrastructure is needed to facilitate sharing, reuse and integration of digital components from the use cases. A second group of activities identify value streams with user engagement providing support in terms of monitoring key performance indicators, business models, market analyses and governance aspects. Third, activities for the development and expansion of the ecosystem are needed to engage the right partners at the right time. Although these three groups of activities are presented here in separate blocks, there is much interaction and overlap between them (Wolfert et al., 2021). For example, the choice of a particular business model will influence the way you build your information architecture; it could be open or more closed. And, ethical choices can lead to inclusion or exclusion of certain types of organizations and thus influence the way the ecosystem develops. Finally, all these activities should be coordinated and managed by strategic project planning and dynamic project management to be able to react to changes that are difficult to predict.

The following subsections will elaborate on these activities, referring to the design principles (DPs) and numbering from Table 3: (DPa.b), where 'a' is the part of the conceptual framework (from 1 to 6) and 'b' is a sub-number.

5.1.1. Organizing a lean, multi-actor approach to trials and use cases

The lean MAA is an innovative combination of the MAA and lean start-up methodology that overcomes major barriers to adoption of digital innovations. It does this by fostering co-creation of technology in a balanced set of trials in which end users are actively involved during the entire development process aiming at cross-fertilization, co-creation and co-ownership of results (DP4.1, DP5.3). Each trial is composed of well-delineated sets of use cases that aim to develop digital solutions with a specific value proposition for all actors involved (DP1.6). IoF2020 consisted of five trials classified by subsectors (arable, dairy, fruits, vegetables, meat), each embracing four to seven use cases (Verdouw et al., 2017). Development of the solution goes through an iterative cycle of four steps (see Fig. 6):

1. Design – based on a set of clear objectives or challenges (e.g. increase yield, reduce pesticide use or improve transparency for consumers) (DP1.6);
2. Implementation and integration – building the solution in a real-life environment;
3. Testing and demonstration – to see if it meets the objectives and to communicate this;
4. Evaluation – considering performance, fitness for purpose and the extent to which the objectives are met.

The spiral in Fig. 6 indicates that development follows this cycle, trying on each revolution to attain the next level, which is determined by MVPs. Depending on the outcome of the evaluation phase, the design is adapted and the cycle is repeated. This can mean that objectives are changed because new insights are gained. In some cases expectations

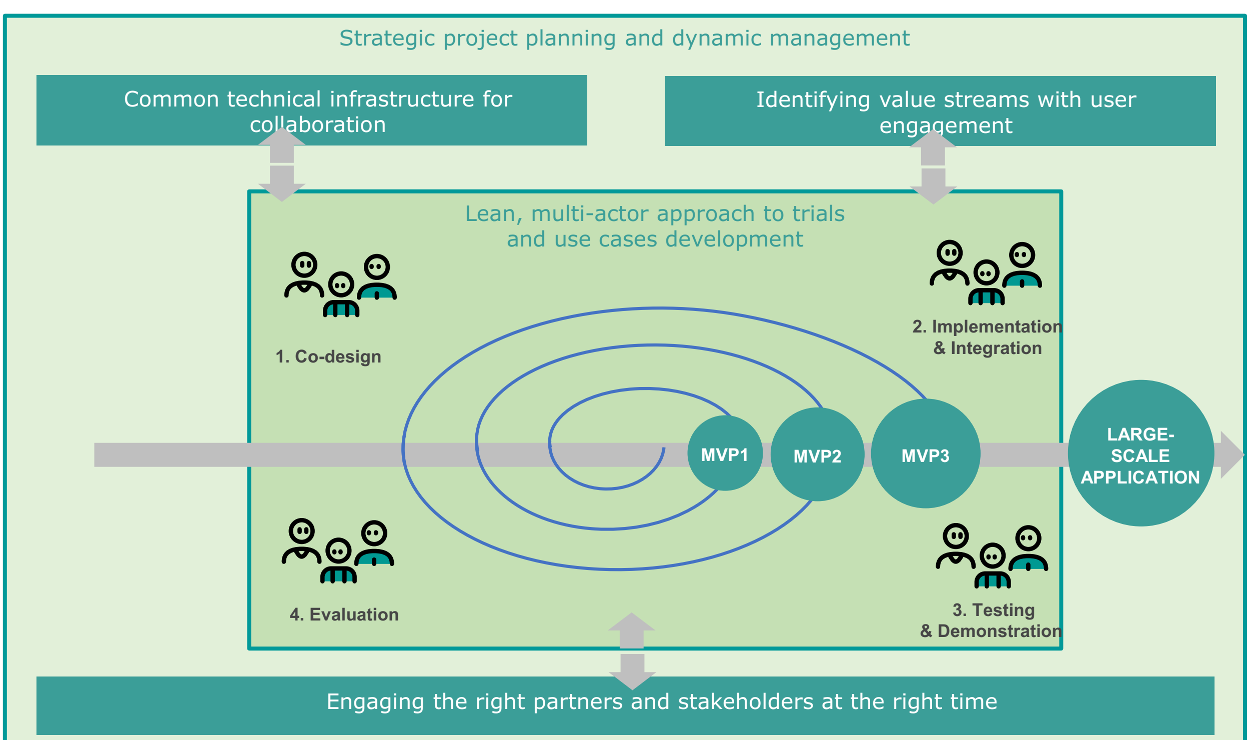

Fig. 6. A blueprint for a multidisciplinary, collaborative, agile approach for digital innovation. Adapted from Wolfert et al. (2021).

must be lowered, but it can also be that expectations were not ambitious enough. In the worst case, a use case must start with a complete redesign or it must be conceded that a certain solution simply does not work. In any case, lessons learnt will always be valuable and need to be shared in the ecosystem.

Usability and user acceptance remain the key principles to guide this development (DP2.2), therefore it is important that all relevant stakeholders are involved throughout the cycle. Stakeholders can be, for example, technology providers, farmers, logistics providers, consultants or researchers. The goal is to achieve large-scale implementation and adoption of the innovation. Depending on the specific context and scope of an innovation, a use case project can last from several months to several years. Also, the period of the development cycles can vary from weeks to months or years.

A use case project usually takes place on a small scale: a few organizations and persons form the core (DP2.2). This is inherent to the character of a use case in which you want to create a safe and trustful environment. The involved stakeholders want to learn by making mistakes without being watched by too many people. However, the risk is that a use case becomes too isolated and lacks input from state-of-the-art knowledge. It is important that digital technologies build on existing standards so they can scale up afterwards. Moreover, there can be external factors, such as laws and regulations, that determine the success of the innovation. Therefore, it is important that a use case is well embedded in and supported by the complete ecosystem, as will be addressed in the next sections (DP2.1, DP2.4).

5.1.2. Establishing a common technical infrastructure for collaboration

In digital innovation ecosystems, participants collaborate via a common platform (DP5.2). Consequently, such an ecosystem should carefully design, develop, and implement the shared technical infrastructure for effective collaboration (DP6.1). At the same time, a single use case or solution that is developed within the ecosystem should not be constrained by rigid technology choices on platforms (DP6.2). Digital innovations flourish if they have the freedom to apply the technologies that best fit their specific purposes and challenges. However, this freedom needs at least some restriction if the ecosystem aims to develop robust, integrated solutions that are successful for the long-term: digital innovation ecosystems should avoid a proliferation of stand-alone applications but seek instead to enhance the development of interoperable solutions. A core principle of a successful digital innovation ecosystem is that it functions as a system of systems, that is a network of autonomous use case systems maximizing synergies across multiple use case systems by ensuring interoperability and facilitating the reuse of technical components across them, amongst others (DP4.2, DP3.2). Fig. 7 shows the architectural approach that was followed in IoF2020 to achieve this (Verdouw et al., 2017).

The main elements are a common reference architecture, a catalogue of reusable system components (DP4.2), and a digital innovation lab (DP6.3). First, the use case architectures are based on a common technical reference architecture to create a shared understanding and to maximize synergies across multiple use case systems (Van Grondelle et al., 2018). Each use case designs a version of the reference architecture to address its specific user requirements. A key element of the reference architecture is the data models and ontologies that enable semantic interoperability as well as standards for technical interoperability, such as the MIMs of IoF2020 (Cantera et al., 2018). Second, the ecosystem provides a catalogue of reusable system components, which can be integrated into the application systems of multiple use cases to facilitate large-scale uptake. This repository goes beyond a checklist to include practical guidelines and implementation tools (Van Grondelle et al., 2018). An example is the web-based IoT Catalogue that includes validated solutions with components, assembly guides, the farming problems addressed and value propositions (IOT Catalogue, 2022). Third, a digital innovation lab is needed to support the implementation of reusable IoT components in a test-bed environment and to provide a virtual working environment for collaborative development. It is an integrated development environment that allows the publication, development, testing and (optionally) deployment of smart agri-food solutions. An example is the FIWARE Lab, a non-commercial sandbox environment where innovation and experimentation based on FIWARE technologies take place (FIWARE, 2022a). This lab includes a cloud hosting environment that guarantees privacy and which is free of charge but at the same time facilitates the automated deployment of the main FIWARE platform components.

5.1.3. Identifying value streams with user engagement

As suggested by Adner (2017), digital innovation ecosystems are essentially arrangements of interdependent value creation and capture through digital solutions. Besides the technical development of digital solutions, the involved stakeholders should develop shared business models that help to define the added value of the digital solutions at stake (DP1.6). For digital innovation ecosystems to develop and thrive, it is important to identify value streams with user engagement. Value

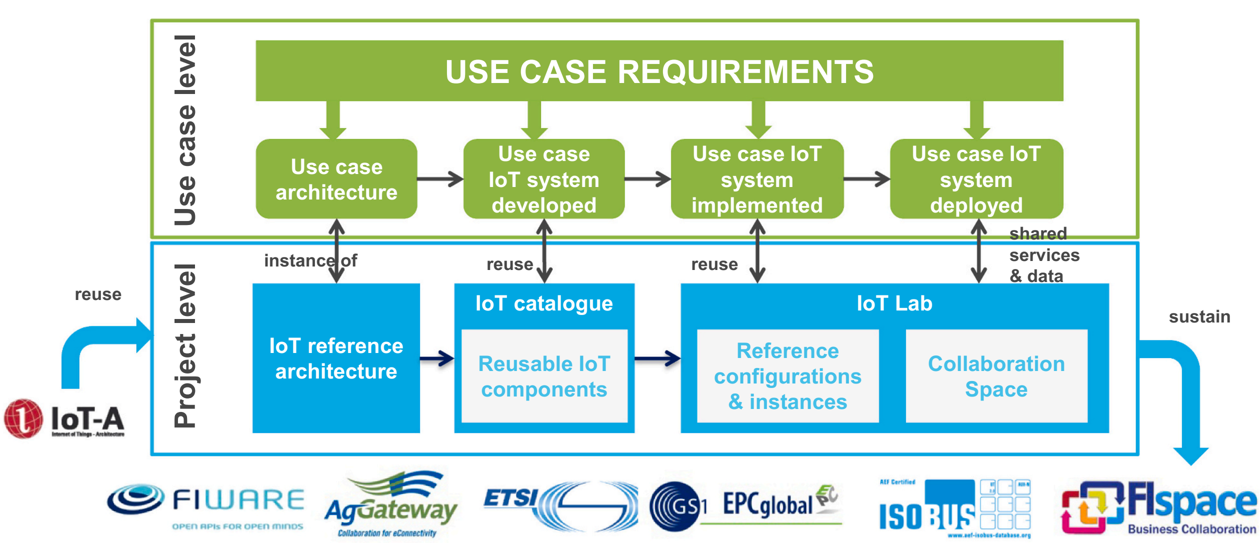

Fig. 7. The architectural process in IoF2020 (Verdouw et al., 2017).

streams are one of the fundamental constructs of lean thinking (Ries, 2011). A value stream is a series of actions or activities that create and deliver values for the user or customer. What are the costs and benefits? How are they shared between the involved stakeholders? Answers to these questions are not usually clear in advance, but insights will develop around the development cycle in tandem with the technical design (DP5.3). In IoF2020, several workshops with the use cases were organized supported by a business-modelling toolbox containing several generic components that could be used to speed up the process. Also, business-modelling visualization by artists was a valuable way of communicating between stakeholders. Every use case had to develop product factsheets with which they were encouraged to pitch their services and solutions (DP1.6). Finally, price-setting strategies were exercised to apply the solution to the market.

As explained in the introduction, data and data sharing are playing an increasingly crucial role and it can appear that many data get into the hands of a particular stakeholder. How do you want to deal with that? That is where governance and ethics come in. What are the underlying values that determine who you want to do business with, and what kind of agreements do you make about sharing data? It is important to include these aspects also in the development cycle. In IoF2020, this was done by organizing workshops on value-sensitive design supported by clear guidelines and serious gaming. It became clear that several governance-related issues could not be solved at use case level but required development at higher levels (sector, branch, international) (DP2.3, DP3.3). In that respect, IoF2020 not only contributed to the development of the European Code of Conduct on agricultural data sharing (Copa Cogeca et al., 2018) but also critically reflected on it (van der Burg et al., 2021).

5.1.4. Engaging the right partners and stakeholders at the right time

Selecting partners is an essential task at the beginning of an innovation project – or even before that at the proposal phase – and should be addressed at both use case and project level. With whom are you going to work to develop the digital solution? It is important to stimulate an interactive and integrated approach in which product, process and business innovation are addressed simultaneously (DP5.3). A typical use case team in IoF2020 consisted of end users (e.g. farmers), technology providers, input suppliers, food processors, researchers or consultants, and sometimes also infrastructure providers. Team members should form a minimum viable ecosystem to create a sustainable digital solution with a viable business model for all stakeholders involved; a model that has the potential to be upscaled after the project (DP3.3). Concerning scalability, it could be good to include big players with the potential to reach farmers, for instance, although striking a balance with smaller, often more innovative partners (DP1.6) is also recommended. Moreover, involving influential keystone players as a constant factor through a series of innovation projects to develop the ecosystem can be considered as another critical factor for success (DP3.1).

In the later stages of the development cycle it can be necessary to involve other players for testing and demonstration, for example. And if you want to scale up the innovation you must find new investors and the right communication and dissemination channels. At the project level, it is important to include partners that can provide the necessary knowledge and support to the use cases from the three surrounding activities, including partners that communicate and disseminate at project level and umbrella organizations like farmers' associations or standardization organizations that represent target groups (DP1.6). Such partners can also play a role in solving issues that are difficult to solve by competition and help to create level playing fields (DP3.2). An essential success factor in IoF2020 was the organization of physical group meetings at various levels: within use cases, between use cases at trial level and in interaction with various task force teams. This can be done at a small regional level, but large-scale events also contribute much to the coherence of the whole ecosystem.

5.1.5. Strategic project planning and dynamic management

In creating a viable ecosystem, the visibility of the project is extremely important and a substantial budget needs to be allocated to achieve that (DP1.6). A reputation of being 'the place to be' attracts new, additional partners without being budgeted for, so creating an 'open' setting is attractive for current and new partners. However, the setting must be managed carefully because the commercial interests of the formal private sector partners need to be respected. Finding the right balance between openness and respect for commercial interests requires delicate skills in project management. From the case studies and their analysis, it can be concluded that the digital innovation ecosystem in this study was built up through a series of large projects (DP2.1) that, in turn, were often part of a larger programme addressing multiple domains (e.g. health, logistics or manufacturing) facilitating cross-domain exchange (DP1.1). Use case projects should be independent and self-contained to a certain extent but be guided and supported at project/programme level in which platforms play a key role (DP2.2). This should be reflected in the WP structure characterized by the monitoring and support afforded by experts and peers, which instils confidence in companies to invest their innovation resources in such a project. In IoF2020, each of the activity blocks in Fig. 6 was represented by a WP consisting of a dedicated and competent team of experts. Bi-weekly meetings between the WP leaders were essential to support the use cases in an integrated way, solving any issues that arose and to change procedures where necessary (DP2.3). In this way, synergies and learning between use cases can be stimulated, resulting in better standardized solutions that facilitate upscaling of the digital solutions (DP2.1). Moreover, it is important to have strong central coordination based on a clear vision that is translated into clear, ambitious objectives to stimulate digital transformation both at project/programme level as well as at use case level (DP1.6). Issues, transcending use cases, should be addressed at project/programme level and possibly solved by umbrella organizations and/or public authorities (DP2.3). In IoF2020 for example, standardization issues were addressed by organizations such as GS1 or ISOBUS, and governance issues were addressed in the Code of Conduct for agricultural data sharing. Addressing both types of issues also helps to solve competition and creates level playing fields, for instance by developing open standards (DP1.6), because innovation is about managing uncertainty and having an open mind for opportunities. This requires agile management and means not only that a project should function as a learning organization (DP2.1) but also that budgets may need to be reallocated during a project where necessary.

6. Discussion

Academic contribution. Drawing on several research projects focusing on the development of IT for agri-food sectors in the last 10–15 years and embedding them in an integrative literature review, this paper develops a framework that facilitates a deeper understanding of what makes digital innovation ecosystems tick. Critically, then, this paper is rooted in empirics and does not remain at a conceptual level (cf. Pigford et al., 2018). In addition, the paper proposes a diagnostic tool with actionable pointers that ecosystem participants in general and policymakers in particular can use. As such, the paper adds to earlier work that has reflected on agri-food digitalization programmes and the role of research institutes, but which were less focused on innovation ecosystem building (Bellon-Maurel et al., 2022; Espig et al., 2022; Jakku et al., 2022; Rijswijk et al., 2019). Moreover, the paper develops earlier work on innovation systems for agri-food digitalization (Eastwood et al., 2017; Fielke et al., 2019) by providing an insider's view of the business and management aspects of digital innovation ecosystems as opposed to a more distant systemic analysis of actors and development phases in digital agri-food innovation.

The most important insight is that effective, successful and quick use of appropriate IT tools in agri-food require that actors should not be understood in isolation from their environment, what might be referred to as a *system-level approach*. At this system level the focus should not be just on the business environment (cf. Mahdad et al., 2022) but also on the technological environment, and the interplay between the two. IT solutions that are not embedded in an agri-food system will not have the intended outcomes and are more likely to fail. Technical and business-strategic considerations are interrelated, however, in agri-food as much as elsewhere (Ozcan and Eisenhardt, 2009): use of IT in agri-food requires that the entire system is innovated (cf. Dolfsma et al., 2021). Several consequences follow from this fundamental requirement. First, technical (e.g. IT), business, sociological and ethical insights from multiple disciplines need to be considered and aligned. A second consequence is that what might be called a *minimal viable ecosystem* may emerge only after considerable time, resources and ingenuity have been invested. Given the fragmentation of at least some agri-food sectors, the orchestration required to make use of IT in agri-food successful may not easily emerge and may require intervention by an outside or dominant player, including government intervention for instance. This will become increasingly true not only as agri-food sectors adopt longer food-processing and distribution systems that involve more and different actors, but also as food quality and perishability concerns deepen as there are more parties involved and the demand for technological and business alignment increases. For this reason, more recent studies have adopted research designs that not only include the disciplines involved and the TRL levels considered (see e.g. Vik et al., 2021), but also consider broad sustainability impacts (Metta et al., 2022). The digital innovation ecosystem design principles that we suggest building into the analysis reflect the interrelatedness of the insights derived and the interdependencies between actors. Especially at early TRL levels, and because of the extent of the orchestration required, intervention by governments at different levels is needed yet is potentially problematic. Actors involved may need to be continuously aware that funding is sourced partially from public coffers since that brings legitimacy, allows to upscale to a larger ecosystem and can create subsequent learning opportunities, with strings and expectations attached. Governments, for instance, have a lower tolerance for risk or failure, so they may be inclined to involve only trusted actors, which may negate an ecosystem's requirement to be sufficiently open to new actors with diverse resources, needs and interests.

Design insights. While this paper contributes academically, we submit that it also contributes insights for the design of agri-food – and possibly non-agri-food – digital innovation ecosystems. These insights can be derived from the Integrated Digital Innovation Ecosystem Framework (Fig. 2) and take the shape of design principles (Table 3) that can guide new innovation projects. Technically, the *infrastructure* supporting an ecosystem should be state-of-the art, yet collaboration in the *network* of actors should be balanced in several ways, including *objects* (technologies, knowledge, etc.) that foster openness and flexibility. A balanced network of collaborators should be properly *organized* so that ambitious innovation *process* goals following from a focused overall innovation *strategy* can be pursued.

The balance hinted at just now differs by phase in the development of technologies that could form the core of a digital innovation ecosystem as it evolves. The extent to which technologies do shape the core of a digital innovation ecosystem depends on the way in which it takes shape. Three further design-relevant conclusions for digital innovation ecosystems can be drawn at this stage. First, technology and the underlying business cases for actors involved should be developed in tandem. Second, actively looking for shared interests and synergies will strongly promote ecosystem development. Third, while active partners in a digital innovation ecosystem will naturally focus on their (shared) interests, consumer concerns can be quite different, so end users must be actively engaged.

Limitations. This study has several limitations, mostly related to the specifics of the data collected for the analysis. Necessarily, this study looks back for guidance on how to design future research. Expected IT and business-related developments, let alone societal ones, relevant for agri-food, might be different in the future than they were for the studied period. Moreover, technological development, in part drawing on development in other adjacent sectors, is likely to follow different paths in the future. The same holds for the business part of the ecosystem: new players might have emerged within or entered from outside, bringing new and upgraded expertise, for instance in how to strategically position, manoeuvre and leverage an information advantage in a digital innovation ecosystem.

Finally, the results of this paper are based on European projects while the digital transformation of agri-food is also taking place in other continents, albeit at a different pace and in different contexts (Ebrahimi et al., 2021; Hansen et al., 2022; Khanna et al., 2022; McFadden et al., 2022; Schroeder et al., 2021; Trendov et al., 2019). Several comparable projects have emerged as a result of booming investment in agri-tech (Klerkx et al., 2019). Examples are the French #DigitAg programme (Bellon-Maurel et al., 2022), the Australian DigiScape programme (Espig et al., 2022) and the New Zealand Bioeconomy in the Digital Age programme (Jakku et al., 2022). In these programmes, research organizations are orchestrators or intermediaries in the innovation networks and broader innovation ecosystems, as shown by Eastwood et al. (2017). Research organizations broker partnerships not only to enhance competitiveness of the local digital innovation ecosystem but also to induce reflection on ethical aspects and sustainability trade-offs of digital technology development (see Metta et al., 2022). Thus, a process of learning and institution building starts, in which organizations take up roles for digital innovation (Jakku et al., 2022; Rijswijk et al., 2019). Yet, to the best of our knowledge, even though *innovation system* perspectives have been used (Eastwood et al., 2017; Fielke et al., 2019), this paper is the first to empirically analyse and diagnose this through the perspective of *innovation ecosystems*, bringing together the technical, social and business dimensions of digital innovation. Using the same conceptual framework, further research could compare developments in Europe with developments elsewhere and see whether the same design principles apply.

7. Conclusions

Digital innovation in agri-food systems has become more complex because of developments towards a system of systems for both the technical and organizational dimensions. An integrative ecosystems approach is required to address this challenge. Until now, most literature on digital innovation ecosystems has been rather conceptual and has focused on sectors other than agri-food. Yet, much practical experience has been gained from European innovation projects in agri-food. Hence, a longitudinal analysis conducted within a conceptual framework – as presented in this paper – provides an empirical basis upon which to analyse digital innovation ecosystems in agri-food. Concurrently, the design principles and approach derived from this analysis can be used as a blueprint and practical guideline for future innovation projects and activities.

Declaration of Competing Interest

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

Data availability

Data will be made available on request.

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Appendix 1. Description of projects used as use cases

1. The Future Internet Public-Private Partnership programme (FI-PPP)

Around 2010, the European Commission identified the challenges of the rapid development of the Internet and future technologies. The Future Internet Public-Private Partnership (FI-PPP) was a European programme aiming at accelerating the development and adoption of Future Internet technologies in Europe, advancing the European market for smart infrastructures and increasing the effectiveness of business processes through the Internet (EU, 2022b). It followed an industry-driven, user-oriented approach that combined R&D on network and communication technologies, devices, software, service and media technologies and their experimentation and validation in real application contexts. The programme contained a total investment of about €400 million and was divided into three phases.

Phase 1 (2011–2014) aimed at laying the technical foundation of a core platform, which later became FIWARE and was built to facilitate access to services, cloud hosting, IoT connection, data and context management or security (FIWARE, 2022b). During this phase, infrastructures were tested and evaluated, and reference architectures were created. The latter was done in eight use case projects in which SmartAgriFood represented the agri-food sector alongside other projects representing other sectors such as Smart Cities, Smart Energy and Smart Industry, etc. (Brewster et al., 2012). SmartAgriFood consisted of a relatively small consortium with a balanced representation of private sector ICT and agri-food companies and larger public sector organizations (mainly universities and research institutes) (see Table 1). The main objective was to build a conceptual information architecture for the agri-food sector based on a common core platform. However, six use case projects were also conducted to validate this concept in real application contexts (Kaloxylos et al., 2012; Verdouw et al., 2013).

Phase 2 (2013–2015) aimed to further develop the core FIWARE platform components and implement FIWARE nodes. Instead of developing one central platform, FIWARE developed a library of reusable, interoperable and open platform components (GEs) that could be flexibly customized, used and combined for particular platforms in multiple usage areas. Large-scale trials tested the versatility of these GEs in the domains of energy, agri-food and logistics, the creative industry, smart manufacturing, and health and wellbeing. FIspace was the large-scale trial for the agri-food and logistics sector and was based on the SmartAgriFood and FInest projects of the previous phase (Wolfert et al., 2014). Both former project consortia were basically merged but extended with several new partners. For the first time, this extension was largely done through an open call, mainly focusing on involving SMEs, which was strongly encouraged by the EC. In the first phase of the project, the FIspace platform was developed, based on the FIWARE components, and was tested by eight use cases ranging from smart farming and logistics to retail (cf. Kruize et al., 2014; Verdouw et al., 2014). SMEs were asked to build apps for these use cases, based on the FIspace platform. In this way, apps that were developed by different, independent builders could be approached by users (e.g. farmers, logistics providers, retailers) in an integrated manner, while their interoperability was guaranteed by the FIspace platform. In total, 31 apps were developed.

Phase 3 (2014–2016) focused on entrepreneurs, start-ups and SMEs aiming at improving a stable infrastructure for large-scale trials and at creating a sustainable ecosystem for SME-driven innovation. In total, 16 business accelerator projects were started in the FIWARE accelerator programme, of which 3 were in the domain of agri-food: SmartAgriFood2, FInish and FRACTALS (see Table 1). These projects were coordinated by a relatively small consortium of 8–10 partners that basically had to organize the open call for start-ups and support them to build their applications based on the FIspace/FIWARE platform components developed in the second phase. In total, around 150 start-ups were involved to build ICT solutions for the agri-food sector. Each accelerator project developed a dedicated business acceleration method and defined their own open call conditions. FInish organized separate hackathons and competitions for SMEs and maintained the initial number of companies involved. SmartAgriFood2 and FRACTALS went through a cascaded knock-out process in which the best solutions were supported at the end. A number of start-ups succeeded in acquiring more money, mostly from private investors.

At the end of the FI-PPP programme, a vast and heterogeneous ecosystem for digital innovation in agri-food was built comprising over 200 large, medium and small public and private sector organizations. It should also be mentioned that the actual number was even larger, because many use cases involved stakeholders (especially farmers) who were not formal project partners. Table 1 shows that, in the whole FI-PPP programme (so excluding IoF2020), about 165 ICT solutions for agri-food were developed. Although it is likely that many solutions never made it to market, some were successfully introduced and many other components and new knowledge found their way into practice.

2. The Internet of Food and Farm 2020 (IoF2020)

In 2017, a new opportunity to expand and foster the innovation ecosystem came with the Internet of Food and Farm 2020 (IoF2020) project, which was funded by the EC (€30 million over four years). Like the Future Internet programme, it was part of a larger programme with other IoT large-scale pilots in other sectors and domains (EU, 2022a; Guillen et al., 2017). IoF2020 built on the ecosystem that was formed in the previous projects with existing and new partners (Sundmaeker et al., 2016; Verdouw et al., 2017). The heart of the project was formed by 19 use case projects that were organized in five trials, representing several agricultural subsectors such as arable, meat, dairy, fruit, etc. Experienced partners from the previous projects combined all their knowledge and experience in an integrated, multidisciplinary project approach to facilitate large-scale implementation of digital IoT solutions designed to have a real impact. A mid-term open call of €6 million added another 14 use case projects that reused and replicated the results from the first phase of the project to test, evaluate and expand the ecosystem. In total, about 235 ICT solutions were developed, many of which made it to market.

3. More project information

More information about the projects can be found at the Cordis portal of the European Commission:

SmartAgriFood	https://cordis.europa.eu/project/id/285326
FIspace	https://cordis.europa.eu/project/id/604123
SmartAgriFood2	https://cordis.europa.eu/project/id/632861
FInish	https://cordis.europa.eu/project/id/632857
FRACTALS	https://cordis.europa.eu/project/id/632874
IoF2020	https://cordis.europa.eu/project/id/731884

Appendix 2. Conceptual framework and foundation in literature

This appendix describes in more detail how we arrived at the conceptual framework that we used to analyse the digital innovation projects. Table 2 synthesizes the main frameworks on digital innovation ecosystems identified in the integrative literature review (Section 3). The last column indicates what this paper contributes to these frameworks. Below the table, the six key concepts of the conceptual framework are described in more detail, with references to scholarly literature.

Table 2
Synthesis of the main ecosystem frameworks in the literature.

Ecosystem dimensions		Previous studies (selection – see main text)						This paper
		3C ecosystem Zhang et al. (2007)	6C ecosystem Rong et al. (2015)	Stanley and Briscoe (2010)	Kruize et al. (2016)	Lambert and Cooper (2000)	ISAfruit Verdouw et al. (2008)	
0	Ecosystem remit	Business	Business	Digital	Software	Supply chain management	Supply chain network	digital innovation, businesses, agri-food
1	Strategy	Context	Context	–	–	–	Strategies & tactics	positioning of organizations, strategies, (societal, technical) context, policies (including ethical guidelines)
2	Organization	Configuration	Cooperation	–	Open software enterprise	Management	Management	(emerging) agreements on how to collaborate, governance, including property and decision rights, and standardization, planning and mutual adjustment coordination mechanisms
3	Network (Collaboration)	Configuration	Configuration	–	Actors	Network	Actors	actors, their strategic position, nature of interaction, type of exchanges
4	Process	Configuration	Configuration, change	–	–	Business processes	Business processes	incremental versus transformational innovation approach
5	Object	Capabilities	Capabilities	–	Business Services, ICT components	–	Product	functional view of what is improved: product, business process, social and business model innovation
6	Infrastructure	Configuration	Construct	Resource layer, Coordination layer, Service layer	Platform	–	Resources	resources, configuration of network, technical (digital) platform

1. Digital innovation strategy: why innovate?

This strategic dimension of a digital innovation ecosystem looks outwards to monitor how the ecosystem needs to be adapted to remain viable in fulfilling its mission, also known as its 'raison d'etre' (Beer, 1984). Subsequently, it innovates the actual business ecosystem accordingly to survive and to grow in providing distinctive value. As such, a digital innovation strategy makes overall decisions to balance demands from different parts of the innovation ecosystem and it steers the organization as a whole. It develops the strategies to achieve the innovation ecosystem's objectives and policies to govern its implementation, including ethical guidelines. Strategies may include a vision and mission statement, long-term objectives and a business model and plans to achieve these objectives. Strategic alignment and collaborative business models, including agreements about benefit sharing, are important factors for the success of a digital innovation ecosystem (Verdouw et al., 2011).

2. Digital innovation organization: organizational rules of the game

The organizational dimension defines how the innovation process and the collaboration between actors in the ecosystem is governed and coordinated, both formally and informally (i.e. trust, power relations). The formal organization consists of governance and coordination structures. Governance is about the allocation of property and decision rights amongst the different involved actors. Generally speaking, it determines who has power, who makes decisions, how other stakeholders make their voice heard and how account is rendered (Termeer et al., 2010). When studying hybrid forms of organization such as a digital innovation ecosystem, two main dimensions should be identified: the allocation of decision rights (in other words, who has the authority to take strategic decisions within the ecosystem), and the interorganizational incentive mechanisms aiming at rewarding desirable behaviour and preventing undesirable behaviour.

Coordination is about the management of interdependencies between actors within a particular governance structure. Thompson et al. (2017) distinguished three basic types of dependency: pooled, sequential and reciprocal interdependence, which require different types of coordination. Based on his work, which is refined by many others, three basic coordination modes can be defined (Galbraith, 1974; Mintzberg, 1981; Thompson et al., 2017):

- *Coordination by standardization*: specifies the necessary activities, output or skills in advance, which eliminate the need for further communication during execution;
- *Coordination by plan (direct supervision)*: central planning by a coordinating manager who takes responsibility for implementation by others, issuing instructions to them and monitoring their actions;
- *Coordination by mutual adjustment*: decentralized alignment through mutual feedback processes for joint problem-solving and decision-making, relying heavily on informal communication.

Last but not least, the informal organization of a digital ecosystem is about the unwritten rules that influence the social interaction and trust between the stakeholders, including cultural and ethical considerations.

3. *Digital innovation network: who contributes, in which role?*

The network demarcates the boundaries of a digital innovation ecosystem and defines the main participants or actors, their roles and how the relations in this network are formed. Three types of ecosystem actors can be distinguished, based on the dynamics of an industry and the complexity of relationships (Iansiti and Levien, 2004):

- Niche player: an organization that develops its own specialization to differentiate from competitors. This strategy is appropriate when an organization faces rapid and constant change, and when the relationships with other ecosystem actors is relatively simple.
- Physical dominator: an organization that operates in a mature industry and a relatively stable environment. A complex network of external assets and relationships is in place. Physical dominators may choose to acquire their partners in an attempt to control essential assets.
- Value dominator or keystone player: an organization that is the centre of a complex network of asset-sharing relationships within a turbulent environment. Keystone players carefully share (the wealth generated by) their assets to stimulate ecosystem innovation and deal with disruption in the environment.

Ikävalko et al. (2018) suggested that value co-creation is the interaction between organizations and their customers, suppliers, business partners, competitors and other third parties. They distinguished alternative archetype roles within an ecosystem, including ideators, designers and intermediaries. An ideator brings knowledge to the ecosystem in a one-way knowledge flow, providing input for service innovation. A designer integrates existing knowledge components in the ecosystem to develop service innovation, using reciprocal knowledge flows. An intermediary acts as a broker and communicates knowledge to multiple ecosystems. The roles differ in operating logic and ecosystem activities.

4. *Digital innovation process: how to innovate?*

For the digital innovation process, two main approaches can be distinguished: incremental and transformational innovation (Verdouw et al., 2005). *Incremental innovation* is an evolutionary approach of continuous evolutional improvements in small steps (Deming, 2012). Improvements take place within the existing dynamic equilibrium (steady-state) and involve some extent of control. *Transformational innovation* is a revolutionary approach of periodic radical and fundamental changes to realize drastic improvements (Hammer and Champy, 2009). It implies breaking out of a current situation and moving towards a new equilibrium (from one steady-state to another). Transformational innovations are characterized by a certain degree of chaos, which may be temporary at the expense of productivity. Incremental and transformational innovation processes are complementary and reinforce each other. Both should be embedded and integrated in the entire innovation ecosystem (Wolfert et al., 2021).

5. *Digital innovation object: what to innovate?*

The object of an innovation concerns a functional view of what is improved and can have many dimensions. First, a distinction should be made between product and process innovation (Grunert et al., 1997). *Product* innovation is related to the output of production systems: new goods and services, including inherited attributes and market proposition. *Process* innovation is broadly defined as innovation of the complete system that generates the required products. It involves all elements of these systems including technical and natural resources, and human capital. Processes of the involved enterprises are the core of this system. Processes are structured and measured sets of business activities designed to produce a specific output of value for a particular customer or market (Davenport, 1993; Van der Vorst et al., 2005). Activities are performed by coordinating people with technical resources.

Digital innovations address all these object dimensions. New digital techniques give new opportunities for product, process, social and business model innovation. Information is part of the product and is of increasing importance in consumer communication. An example in agri-food production is adding traceability information that can be viewed by a consumer in the supermarket. Also in process innovation, digital technologies have become vitally important. Information is crucial to enable the execution and management of business processes. New ICT techniques create new opportunities for process improvement. Examples are logistical optimization by integrated enterprise systems or radio frequency identification(RFID), optimization of the growing process by advanced sensor techniques and technical decision support systems, alignment of chain processes by data exchange and integrated chain information systems. In combination, digital innovation has the potential to reshape business along the complete agri-food supply chain.

6. *Digital innovation infrastructure: enabling technologies*

In digital innovation ecosystems, diverse participants collaborate via a common platform. An open or external platform can be defined as ‘products, services, or technologies developed by one or more firms, and which serve as foundations upon which a larger number of firms can build further complementary innovations and potentially generate network effects’ (Gawer and Cusumano, 2002). These platforms can vary from a physical asset like specific manufacturing capabilities, to intellectual assets like Windows' software platform (Iansiti and Levien, 2004). In such a self-contained system, actors create, generate and produce new output, structure or behaviour, without any input from the focal actor. Overreliance on such a system may lead to uncontrolled creative output, which may damage the health of the ecosystem (Wareham et al., 2014). This emphasizes the urgency of adequate business ecosystem governance. In the frameworks for digital innovation ecosystems, a platform is usually a cornerstone concept. Gawer and Cusumano (2002) defined such a platform as: 'A foundation technology or set of components used beyond a single firm and that brings multiple parties together for a common purpose or to solve a common problem.'

Appendix 3. Summary of the lessons learnt from the case studies and derived design principles

Table 3 summarizes the main learnings from the case studies for each concept of the conceptual framework presented in Section 3.3. The last column shows the design principles (DPs) derived from the case studies, which form the basis for the approach to digital innovation ecosystems described in Section 5.1.

Table 3
Case contributions and derived design principles.

Concept	Learnings from case studies		Design Principles
1. Digital Innovation Strategy	SmartAgriFood	Improve and boost digital innovation in the agri-food sector by hooking into the EU overall strategy to build a common, open core platform for multiple domains in the Future Internet.	DP1.1: focus a project on a particular domain, but embed it into a cross-domain environment. DP1.2: set clear, ambitious objectives to stimulate digital transformation both at project/programme level and at use case level. DP1.3: create a collaboration space around common, open platforms and underlying (cross-domain) architectures and infrastructure. DP1.4: develop a well-balanced ecosystem of technology developers and end users, large and small players. DP1.5: development should be driven by end-user acceptance, common values and viable, shared business models. DP1.6: develop an open ecosystem that is attractive for existing and new players
	FIspace	Build an open domain-specific internet platform for the agri-food sector that benefits from and contributes to the development of a multi-domain platform. Also, create a flexible, multi-actor collaboration space stimulating scalable, flexible and interoperable digital solutions.	
	FIWARE Accelerators	Enlarge the developer community and select the best digital solutions for the agri-food end users, in a technical and business sense.	
	IoF2020	Foster a large-scale take-up of IoT in the European farming and food domain by developing more integrated, sustainable digital solutions that enhance interoperability and shared business models. At the same time, address governance and ethical issues that should be solved at higher integration levels. Emphasize reuse of technology, knowledge and experience by showcasing and demonstrating solutions. Project visibility and openness of the ecosystem are essential to balance public and private interests.	
2. Digital Innovation Organization	SmartAgriFood	Besides the usual organization of a project, pay attention to integration, standardization and harmonization between the various use cases based on the development of a common core platform.	DP2.1: develop large-scale projects with multiple well-delineated use cases with attention to integration, standardization and harmonization and facilitate mutual learning and creating synergies. DP2.2: use case projects should be independent and autonomous to a certain extent, but be guided and supported at project/programme level in which common architectures, reuse of platform components and standardization play a key role. DP2.3: issues, transcending use cases, should be addressed at project/programme level and possibly solved by umbrella organizations and/or public authorities. DP2.4: guide, monitor and steer use cases based on output instead of time sheets.
	FIspace	Use an open call mechanism to involve more partners from the private sector to test and validate core concepts.	
	FIWARE Accelerators	Use an accelerator programme approach selecting the most promising start-ups to organize the project. Make project consortia responsible for organizing the process rather than the funding agency. The financing construction was based on cascaded funding and subgrants to facilitate organization.	
	IoF2020	To foster large-scale uptake of digital solutions, integrate different organizational concepts around use case projects. Set up the use case projects using the MAA, but also create synergies between use cases. Monitor and evaluate use case projects in a systematic, standardized way.	
3. Digital Innovation Network	SmartAgriFood	The network was driven by an important keystone player from agricultural research and by (large) IT consultancy companies.	DP3.1: create ecosystems that are driven by large, influential keystone players as a constant factor complemented by large numbers of small creative players. DP3.2: use independent network organizations to solve difficult issues by competition and create level playing fields. DP3.3: focus on integrated, shared value networks.
	FIspace	SMEs from the IT and agri-food sides were more involved. The large consultancy companies focused on developing the core platform.	
	FIWARE Accelerators	Many small companies (start-ups) were added to the network. The role of network organizations became very strong.	
	IoF2020	Focus shifted towards more integrated value networks that had to define shared business models. End users (e.g. farmers, machine manufacturers, etc.) were much more involved in the innovation process, leveraged by their umbrella organizations.	
4. Digital Innovation Process	SmartAgriFood	Explorative use cases focused on requirement definition and proofs of concept aiming at digital transformation.	DP4.1: develop an iterative, lean MAA in use cases in which user acceptance leads development of digital solutions. DP4.2: facilitate reuse of knowledge, standards, data, models by open, common architectures and infrastructures.
	FIspace	Development of a common platform, which was applied and validated in use cases. Technology focus on infrastructure development and validation by an incremental process.	
	FIWARE Accelerators	Careful selection of promising ideas and development of near-to-market apps based on FIWARE enablers. A more incremental accelerator programme approach was followed, including both technical and business support.	
	IoF2020	Lean, MAA: the iterative development of MVPs focusing on user acceptability, stakeholder engagement and sustainable business models. This development is enhanced by an open IoT	

(continued on next page)

Table 3 (*continued*)

Concept	Learnings from case studies		Design Principles
		architecture and infrastructure of reusable components based on existing standards and a security and privacy framework.	
5. Digital Innovation Object	SmartAgriFood	Conceptual use cases developed new digital product solutions aiming at supporting and transforming agri-food production and business processes.	DP5.1: use state-of-the-art digital technology, knowledge and experience. DP5.2: build solutions based on common, open platforms using GEs where possible. DP5.3: interactive, and integrated approach towards product, process and business innovation.
	FIspace	Move conceptual digital solutions to higher levels of application looking at potential business collaboration models. The role of a platform, which eventually could become a new business, became more important.	
	FIWARE Accelerators	The FIWARE/FIspace platform formed the core for further product and process innovation, but much attention was paid to business innovation by supporting and accelerating start-ups and their solutions.	
	IoF2020	An integrated approach to product, process and business innovation was stimulated. Although use of the open FIWARE platform components was still encouraged, use of other (commercial) platforms was also permitted.	
6. Digital Innovation Infrastructure	SmartAgriFood	Definition of the requirements based on independent use cases; proofs of concept used their own technologies. There was no common digital infrastructure at the time.	DP6.1: pull-push mechanisms to develop common core platforms in which end applications in use cases ultimately validate them. DP6.2: stimulate the use of domain-independent GEs as much as possible, but remain flexible when developing end-user solutions. DP6.3: set up and foster developer communities and experimental laboratory environments.
	FIspace	Focus on the design and development of a common digital platform. The use cases applied and validated this platform.	
	FIWARE Accelerators	Focus on using the FIWARE infrastructure of GEs to develop near-to-market apps.	
	IoF2020	Application of reusable components including FIWARE enablers (not mandatory) based on common architectures and standards. Start of digital labs for sharing technology components and collaborative experimentation.	

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