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Digital healthcare platform ecosystem design: A case study of an ecosystem for Parkinson's disease patients

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ABSTRACT

This study investigates *how a digital health care platform ecosystem* and its essential core elements can be constructed considering specific characteristics of health care. A single case study of an ecosystem planned for patients with Parkinson's disease was conducted following a constructive research approach.

The study reveals that the keystones for digital platform ecosystem design for health care purposes are as follows: 1) a focus on multi-sided mutual value propositions as a starting point for the design process; 2) understanding the technological core of the platform, including artefacts, interfaces and infrastructure; 3) understanding the actor layer, including actor resources, roles, positions and mutual interactions; and 4) understanding environmental influences in the form of data-related issues, prevailing institutions, practices and regulation. Several recommendations are offered to consider in designing the digital health care platform ecosystem. Managerially, this understanding could facilitate the development of new means of diagnostics, impactful and just-in-time care, functioning data collection and resource coordination in health care.

1. Introduction

Along with the rapid development of digitalisation and related networking (Cohen et al., 2017; Nieuwenhuis et al., 2018), a capability to create *digital platform ecosystems* is becoming critical for coping with competition and generating innovations (e.g., Biancone et al., 2021; Cozzolino et al., 2021; Nambisan, 2017; Yoo et al., 2010). This trend is also significant in health care, where digital transformations create new possibilities for patient value (Hermes et al., 2020; Khodadad-Saryazdi, 2021; Massaro, 2021). In this transformation, digital platform ecosystems provide new types of networked solutions to meet patient needs involving various public and private actors, professionals and patients themselves in collaborative value creation (Rippa and Secundo, 2019; Secundo et al., 2021). From an innovativeness perspective, multi-sided collaboration can also enhance developments in the field where circumstances are changing rapidly (Cobianchi et al., 2020; 2020b). For example, Taylor (2017) suggests that a large and relatively uncoordinated group of ecosystem participants can contribute to the evolution of an ecosystem by producing unprompted innovation and change. Indeed, platform ecosystems and open innovation environments will change post-industrial mantras, such as cost-consciousness, effectiveness and productiveness, to be more capable and community-centred (Letaifa, 2014; Pitelis, 2009; Ramaswamy and Ozcan, 2018), particularly in the health care sector.

However, platform ecosystems are less understood contexts in comparison to more traditional, tightly coupled alliances and supply chain networks (Taylor, 2017), and relatively few studies have been conducted in this area. Extant platform ecosystems focus on users' content delivery, such as the well-known cases of Uber, Airbnb and Foodora (Elia et al., 2020; Hein et al., 2020; Cohen et al., 2017), or on creating customer-driven content delivery applications and systems, such as in the cases of iOS and Android (Nambisan, 2017; Kapoor et al., 2021; Hein et al., 2020). Indeed, few articles discuss platform ecosystems for creating an application for specific needs requiring knowledge-intensive approaches. In addition, researchers in the area face constant challenges because technologies and digital platform

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ecosystems develop rapidly, and new concepts are introduced continuously. While this challenge is prevalent in the general approach to platform ecosystems, an even more profound research gap exists related to *platform ecosystems in health care* (Hermes et al., 2020). Accordingly, there is a significant need for new knowledge related to creating a digital platform ecosystem, especially its design in this specific knowledge-intensive context.[1]

Several studies can support filling in the research gap. For example, Cennamo et al. (Cennamo and Santaló, 2019; Panico and Cennamo, 2020; Tavalaei and Cennamo, 2020) focussed on complementary issues and related challenges in platform ecosystems. Ramaswamy and Ozcan (2018) highlighted the interactional creation in digital platforms, whereas Cozzolino et al. (2021) studied the collaboration of incumbent and novel actors in these networks as well as the related tensions and development of the ecosystems. Jovanovic et al. (2021) examined the coevolution of platform architecture,[2] platform services and platform governance in industrial markets. Gawer (2020) focussed on the variance of digital platform boundaries, including the scope, composition, configuration and interfaces. The digital platform discussion has highlighted digital platform architecture and its different forms (Blaschke et al., 2019). For example, Floerecke et al. (2020) discussed actual implementations of digital platform ecosystems, focussing on the specific context of cloud computing and the related visual description of a complex platform ecosystem.

Our contribution focusses on digital platform ecosystems for health care purposes. There is a need to increase understanding of this topic by studying a platform ecosystem that allows launching various new content delivery applications and application systems for a specific knowledge-intensive area. In health care, the digital aspect includes specific characteristics not sufficiently understood in the traditional platform ecosystem discussion. For example, the level of openness and accessibility of the technology and data might be relevant in health care but not in other platform ecosystem contexts. In addition, digitality highlights an ability to collect, store, transfer and even generate data and knowledge in novel ways, which might have unique implications in the health care setting (see, e.g. Blaschke et al., 2019; Presch et al., 2020; Ramaswamy and Ozcan, 2018; Secundo et al., 2019; Sousa et al., 2019). Floerecke et al. (2020) suggested that the current literature does not provide sufficient guidance for the 'modeling procedure' of the ecosystem. This study aims to answer this call as well. Empirical studies in the health care industry are conducted in an opposite way compared to most previous studies about existing platform ecosystems in the traditional digital industry (e.g. Gawer 2020).

Thus, we aim to answer the following research questions:

What are the core elements of a digital platform ecosystem design for health care?

This question is answered with the help of a case study on a digital platform ecosystem for Parkinson's disease (PD) patients. By providing a concrete description and related definitions of the digital platform ecosystem 'in action' in this specific context, we aim to open new avenues for further research in the field. In this digital platform ecosystem, researchers could monitor and process the data of more than one hundred PD patients. Actors in the ecosystem included health care personnel, platform developers, platform ecosystem operators and various sensor and sub ecosystem providers. In addition, mobile network operators and mobile phone providers were involved. This digital platform ecosystem, based on distributed and virtual computing technology, provides a possibility to introduce specialised global players in health care that can be located remotely. Thus, this distributed health care enabled by the technology can represent a novel way to deliver health services and even to revolutionise health care practices. Furthermore, this study creates a new avenue to study unique digital platform ecosystems in an intensive knowledge area.

The remainder of this paper is organised as follows. First, we review the current literature shaping the discussion around platform ecosystems and digital platform ecosystems to understand the core elements of the design. The tentative digital platform ecosystem design framework is framed based on this theoretical review. Second, we describe the constructive single case methodology used. Third, we introduce the framework based on the design project utilised to form a new ecosystem for PD patients based on the available technologies and value proposition. Finally, we discuss and identify recommendations for the design process.

2. Theoretical background: Digital platform ecosystems

2.1. Literature review

In health care, digital platform ecosystems are becoming critical for coping with competition and generating innovations. This section describes what we know so far based on existing research on the core elements of a digital platform ecosystem design. A tentative theoretical framework, which supports the analysis of the construction of an existing digital platform ecosystem for PD patients, is constructed.

Two complementary viewpoints characterise the platform ecosystem discussion: (1) The ecosystem-as-affiliation view defines ecosystems as actors' communities; and (2) The ecosystem-as-structure perspective focusses on ecosystems as 'configurations of activity defined by a value proposition' (see Elia et al., 2020). Of these two, the affiliation-focused approach highlights the constant balancing between the accessibility of an ecosystem to get new resources when needed and, on the other hand, a need to stabilise the actors, interfaces and activities to maintain collaboration and value creation (e.g. Paparova and Aanestad, 2020). The other, the structural perspective, emphasizes the meaning of value proposition as a starting point for creating structure-supporting activities for joint value creation. The ecosystem is seen to be built 'around the *focal value proposition*, not a focal firm' (Adner, 2017, 55).

The question of centralised vs. decentralised control of the system is always present in platform ecosystems (Paparova and Aanestad, 2020). Attour and Barbaroux (2016) define *platform ecosystems* as *modular* structures in which several independent components are interconnected through a critical asset: a technological platform. In a platform ecosystem, each actor provides or employs standards or a platform ecosystem's specific resources, among other artefacts, through various interfaces, which can also renew traditional actor roles (Hermes et al., 2020; Nambisan, 2017). According to Adner (2017; see also Adner and Kapoor, 2010). The platform ecosystem can take the form of a product, service, system or technology (see Hahn et al., 2016; Yoo et al., 2010). Indeed, the idea of modularity and related flexibility (to realise joint value creation efforts, as Adner (2017) put it) is prevalent in platform ecosystems. For example, Tiwana et al. (2010) stated that (software) platform ecosystems connect specific platform module developers with the end customer or other developers. In line with this, Thomas et al. (2014, p. 201) noted that 'For the platform ecosystem stream, the platform is a set of shared core technologies and technology standards

[1] Adner (2017, 40) defined *ecosystem* as follows: 'the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize'. Jovanovic (2021, 2) complemented this definition by highlighting the platform aspect: 'a *platform ecosystem* can be viewed as an evolving meta-organizational form characterized by enabling platform architecture, supported by a set of platform governance mechanisms necessary to cooperate, coordinate and integrate a diverse set of organizations, actors, activities, and interfaces, resulting in an increased platform value for customers through customized platform services'. *Digital platform ecosystem* participants use digital technologies to 'exploit and control *digitized resources* that reside beyond the scope of the firm, creating value by facilitating connections across multiple sides, subject to cross-side network effects' (Gawer, 2020, 1).

[2] Our interpretation is that architecture as a concept is more focused on the structure of technological arrangements and related interfaces. While our focus is broader, we have decided to use concept *design*: 'digital platform ecosystem design'.

underlying an organizational field that supports value co-creation through specialization and complementary offerings'.

Although technological aspects are highlighted in these definitions, it has been suggested that platform ecosystems should also be seen 'as a socio-technical phenomenon rather than purely technical artefacts[3] as they encompass both a technical core as well as business networks mediated by a technical core' (Blaschke et al., 2019, p. 574; see also Nambisan, 2017; Rippa and Secundo, 2019). This socio-technical aspect is also emphasised by Kapoor et al. (2021, p. 95), who argued that a platform ecosystem is 'as much of a social challenge as it is a technical challenge'.

Blaschke et al. (2019) stated that the *elements of the digital platform ecosystem* are related to four issues: infrastructure, core, ecosystem and service dimensions. Here, infrastructure refers to resources that enable platform actors 'to facilitate their resource exchange' (Gawer, 2020, p. 578). These resources can be artefacts, such as the Internet, data centres, standards and devices. By core, they refer to stable software and hardware arrangements forming the technological core of the platform. The ecosystem view refers to actors, their interactions and their roles. Finally, the service dimension refers to what we would call value creation: what value the digital platform ecosystem can generate for the participants (see also Ramaswamy and Ozcan, 2018).

In his definition of platform ecosystems, Adner (2017) highlighted the following elements: (1) actor roles, (2) actor positions in the ecosystem and their mutual relations and (3) activities they conduct for the 'value proposition to materialize'. Thus, we can see that Adner's view complements the one represented by Blaschke et al. (2019) and offers substance, specifically for what they call 'ecosystem' and 'service' viewpoints. In this view, platform ecosystems are more about complementary assets (e.g. Teece, 1986). In a platform ecosystem, each actor provides or employs standards or the platform's ecosystem-specific resources, among other artefacts, through various interfaces that enable a combination of applications to create service chains (Newcomer and Lomow, 2005; Yoo et al., 2010).[4] Thus, actors become 'resource complementors' (Kapoor et al., 2021; Panico and Cennamo, 2020; Tavalaei and Cennamo, 2020).

Because resources in the platform are complementary, variation and renewal of resources is critical for the 'ecosystem's innovativeness and capability to generate value for its users' (Cennamo and Santaló, 2019). Therefore, the ecosystem's attractiveness to potential resource contributors becomes a critical strategic question in ecosystem governance (Elia et al., 2020; Panico and Cennamo, 2020; Tavalaei and Cennamo, 2020). Likewise, although interface stability is needed to maintain platform operations and resource integration for value creation, sufficient flexibility for resource renewal and innovativeness is also crucial (Paparova and Aanestad, 2020).

The resource's intrinsic modularity (Kapoor et al., 2021) allows scalability (Da Silva Amorim et al., 2014). It can also enhance functionalities when new actors' accessibility to new resources is enabled via modularity (Hein et al., 2020). Furthermore, the modularity of a software-based platform makes it easier for both external complementors and the platform owner to complement system components while retaining a stable core. Modularity also enables flexibly changing the components when needed without sacrificing the stability of the core (Hein et al., 2020). This statement is supported by Dal Bianco et al. (2014), who suggested that software platforms can be used as a stand-alone product, but at the same time integration with other applications and tools external to the platform (e.g. Google maps) is allowed.

The desires of the specific market are often latent and cannot be identified only by the platform ecosystem owner when creating a new digital platform ecosystem for a particular market. Instead, a platform community is often needed for the innovative design. It is also worth mentioning that all the platform ecosystems constantly interact with their environment. *Surrounding regulations, administrative systems and organizations and institutions influence ecosystem activities*. This observation is especially apt in health care, where patient safety and information confidentiality are crucial.

2.2. The tentative theoretical framework

Based on the previous, our theoretical starting point for further analysis of digital platform ecosystem design in the health care context involves the following elements (see Fig. 1). First, a relatively stable *technological core* is needed to maintain the digital platform ecosystem. A technological core means that technical standards are chosen, and related software and hardware decisions are made (e.g., Blaschke et al., 2019). Concrete technological objects, practices, know-how and other artefacts provide a resource pool that the platform ecosystem's technical core employs. This resource pool could also consist of the Internet, data centres and devices (Bowker and Star, 2000; Mackenzie, 2005). The IT *architecture* refers to the technical design of the digital platform ecosystem and includes the relations and interfaces between various parties that employ core technologies (Newcomer and Lomow, 2005). The implementation of IT architecture includes necessary *interfaces* (API's, IT toolkits, processes, applications and hardware) for resource exchange and integration that enable value co-creation. The intrinsic

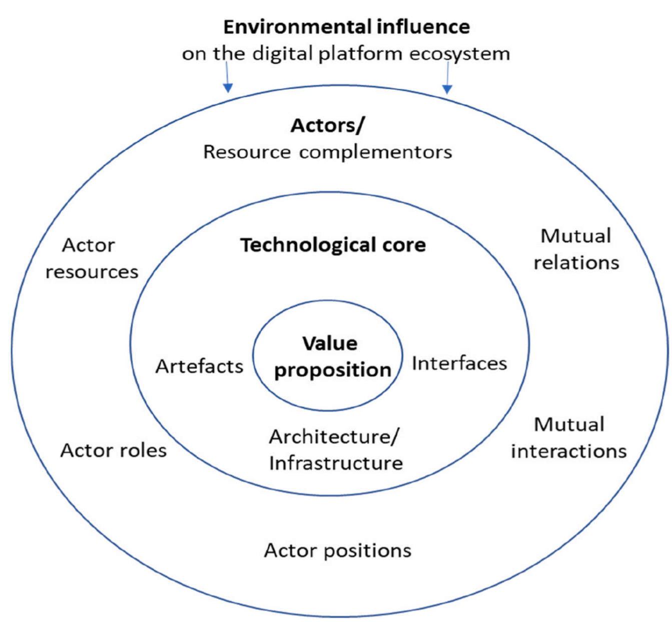

Fig. 1. A tentative theoretical framework: Core elements of a digital platform ecosystem based on the literature.

[3] Knorr Cetina (2006) stated that artefacts are not passive products but rather active partners in knowledge practice; they have the power to produce effects and internal structures. The primary job of the artefacts in a platform ecosystem is dissociative, helping it to stand apart from the real world or knowledge objects through modes that characterise it by disruption, reflection and abstraction. She also stated that this standing apart permits the object to 'speak back' and reveal untapped opportunities. From this perspective, it is possible to create forms of active, reflexive and experientially based relations in which the interplay between the real world and knowledge objects and an actor can occur. Therefore, a platform ecosystem that consists of multiple artefacts needs to be designed well to make the artefacts full members of the actor network.

[4] In designing digital artefacts, products or services, the use of service-oriented architecture (SOA) indicates that each of the products should provide a service interface for other applications to employ (Newcomer and Lomow, 2005). Many digital products employ RESTful API interfaces to deliver data in JSON or YAML format. The Swagger tool is often employed to create a YAML-based application protocol interface (APIs) for smooth software development.

modularity of the platform (Da Silva Amorim et al., 2014; Hein et al., 2020) allows for *system scalability and flexibility* of the IT architecture (Dal Bianco et al., 2014; Hein et al., 2020).

Another viewpoint relates to the *actors involved.* An ecosystem consists of multi-sided *actors* (Hahn et al., 2016; Knorr Cetina, 2006). Module developers, as other contributors, provide *complementary resources* for the ecosystem (Cennamo and Santaló, 2019). These complementary resources deliver the *value proposition* for the varied customer groups (Elia et al., 2020; Hermes et al., 2020). Customers themselves are members of the ecosystem. All the actors are resource *complementors* in the digital platform ecosystem. Various resources are needed for innovation and novel value creation to occur as well as for the fulfilment of the value proposition (Cennamo and Santaló, 2019; Hermes et al., 2020; Panico and Cennamo, 2020; Tavalaei and Cennamo, 2020). The core questions here are as follows: *Who are the involved actors, and who should be involved? How can the necessary complementors be attracted and motivated?* Actor *roles* and *positions* (e.g. power relations), their *mutual relations* (Adner, 2017; Adner and Kapoor, 2010; Nambisan, 2017) as well as their *mutual interaction* (Blaschke et al., 2019) must be understood when constructing a digital platform ecosystem entity.

The literature review concludes that both technological and social aspects must be considered when constructing platform ecosystems. The two views presented above, the technological and social, can complement each other (Blaschke et al., 2019; Kapoor et al., 2021) and compose what we call the digital platform ecosystem. In addition, *environmental influence* on the ecosystem in the form of regulations and institutions should be understood in the design. Therefore, an empirical study is needed utilising an appropriate methodology.

Health care is a knowledge-intensive industry. We claim that digital health platforms can offer patients and other stakeholders many benefits. For example, these platforms enable the creation and spreading of knowledge by integrating and involving patients and their caretakers in a collaborative system that facilitates the development of new diagnostic and health care methods (Presch et al., 2020). Platforms can improve the effectiveness of treatment by better monitoring the progression of the disease, the patient's condition and the effectiveness of the medication. The right kind of system enables more responsive and just-in-time health care, for example, immediate medication adjustments by the doctor doing diagnostics online. Because the system's flexibility allows focussing on real value-creating activities with the patient, redundant activities (e.g. extensive waiting times or long-distance travel) can be avoided: platform ecosystems can facilitate the development of care paths in a patient-centric way. Related to this in-depth focus on supporting patients and the professional work of caretakers, the coordination of resources can be facilitated with the help of the platform ecosystem. It can also enable data collection for long-term patient support and health care decision-making in general (Sousa et al., 2019).

In the following section, we move to the empirical part of the paper, starting with our methodological choices in section 3, followed by an empirical analysis of our case example: a digital platform ecosystem for PD patients and their caretakers.

3. Methodology

3.1. Study process

We used *a constructive research approach* (Kasanen et al., 1993) and a *qualitative single case study strategy*. A constructive research approach is a well-recognised approach in accounting research (e.g. Kaplan, 1998; Kasurinen, 2002; Labro and Tuomela, 2003; Tuomela, 2005). In addition, it has gained popularity in other research areas, such as supply chain management, marketing and information system design (see Tynjälä, 2007). Constructive research aims to contribute to theory and managerial problem-solving by creating models and diagrams, such as organizational charts and plans, and explicitly demonstrating the practical usability of the developed solution and its theoretical roots and contributions (Kasanen et al., 1993). The first step of this approach is to build a tentative theoretical model by reviewing the relevant literature (see Fig. 1). The second step is to test the model with field data and to refine it to create a model ('construction') from experience gained from the empirical data (see Fig. 2). According to Kasanen et al. (1993, p. 244): 'Constructions refer, in general terms, to entities which produce solutions to explicit problems. By developing a construction, something that differs profoundly from anything which existed before is created: constructions tend to create a new reality'.

Constructive research can be quantitative, qualitative or both, depending on the aim of the study. Thus, within the framework of the constructive research approach, this study follows a qualitative single case study strategy with an embedded case of a digital platform ecosystem for PD patients. This enables the rich, in-depth description needed to understand the phenomenon holistically (Eisenhardt, 1989; Halinen and Törnroos, 2005; Miles and Huberman, 1994). The qualitative single case study method was applied because understanding of this phenomenon is still relatively sparse (see Hahn et al., 2016; Taylor, 2017). We wanted to get a holistic, yet detailed description of the construction developed. The qualitative case study approach is a way to analyse unexplored phenomena holistically (Yin, 2014). According to Yin (2011, 43), 'Another rationale for selecting a single-case rather than a multiple-case design is that the investigator has access to a situation previously inaccessible to scientific observation'. Thus, in the present study, the constructive research approach and qualitative single case study method complement each other well.

The single case in this study was a project for developing a platform ecosystem and related methods for long-distance diagnostics for people with PD. The project's clinical study measurement plan was made for 150 people: 100 with PD and 50 without as a control group (ClinicalTrials.gov NCT03366558). Measurements were taken in their typical living environments for three days. Prior to these days of monitoring, all the study subjects performed a controlled test procedure at a clinic consisting of collecting background data on diagnoses, medical history, current medication, alcohol use, potential depression symptoms, mental status and status based on the Unified Parkinson Disease Rating Scale (UPDRS) scale (see Jauhiainen et al., 2019). At this stage, an initial walking test was also conducted. Home measurements included smartphone sensors, force sensors integrated into the shoe soles and an accelerometer attached to the wrist. The goal was that home measurement could improve the effectiveness of treatment by enabling better monitoring the disease progression, the patient's condition and the amount and effectiveness of the medication.

The project application and the study plan were created together with two universities and three companies. A hospital joined the project as a subcontractor prior to the clinical investigation executed with the PD patients and control subjects.

3.2. Data collection and analysis

Kaplan (1998, 91) emphasised the interaction part of constructive research practice and theory: 'This process of using new theory to modify critical aspects of organizations and management enables the researchers of management processes to develop and test theories in actual organizations'. In line with this, our constructive approach can also be seen in the nature of our data. It is not based on traditional semi-structured interviews as primary data (often used in traditional qualitative single case studies); rather, the construction was developed in collaboration with different stakeholders as the project progressed over time. Thus, our data are based on knowledge (and related documentation) obtained throughout the collaboration and its various phases:

1. Pre-discussions with medical experts on their clinical needs
2. Creating the plan for the project and schedule for the funding

3. Planning the process for executing the clinical investigation with patients
4. Creating an ethical application for the clinical investigation
5. Creating the IT architecture to support the clinical investigation
6. Creating the IT system with application software for this study project
7. Piloting the IT system first outside the hospital and then in the hospital
8. Executing the clinical investigation and analysing the results
9. Reporting the results of this study project in publications in various science disciplines

Several meetings with project members and stakeholders were organised in the early phase of the project to discuss the details of the construction of the planned digital platform ecosystem. Meetings were also arranged with sensor device manufacturers, a mobile network operator, a pharmaceutical company's representatives, patients and researchers specialising in medical technology. Based on these meetings, the outcome and overall implementation guidelines were presented in various steering group meetings.

The qualitative data were mainly extracted from the minutes of these multiple project and review meetings, arranged monthly and typically lasting from one to 2 h. Many other encounters with various companies and other project partners, such as hospital members, government agencies, the leadership team, top management and individual employees, took place in 2017 and 2018 as well, weekly or biweekly. To highlight the transparency of our approach (Massaro et al., 2019), we have listed these occasions in appendix 1. The meetings were recorded manually. The related emails and memos were archived as part of the data collection. Citations from the data are added to the following empirical analysis to strengthen the chain of evidence from the case study perspective (Massaro et al., 2019).

In addition to building the construction as the process progressed, to support our case study approach in the present study, all the data (see the gathering in Table 1) were analysed thematically utilising a content analysis approach (Weber, 1990). This analysis was conducted by multiple researchers in the project team. Initially, the literature on digital platform ecosystems (and specifically concepts it offered to understand digital platform ecosystem design; see Fig. 1) provided the starting point for our analysis, and the consequent findings are organised accordingly in the following analysis section.

The construction, that is, the developed monitoring system, was tested tentatively by several test users prior to tests with PD patients and healthy controls. Thus, the data collection method resembles an action research approach. The authors of this study participated in many of the events described here, and the created design was tested as well (e.g., Kaplan, 1998).

Table 1
Data sets, the intensity of the research process and the contribution of the data sets and research acts.

Research acts and data	Details	Contribution
Meetings Meetings with hospitals employees Meetings with stakeholders (company representatives) Steering group meetings Face-to-face or remote meetings between various teams of the projects Meetings with PD associations	Several meetings in the hospital every month or bimonthly About 20 face-to-face meetings with stakeholders Steering committee meetings took place four times per year during 2017–2018 Weekly or biweekly meetings during 2017–2018 Three times 2017	● Increased general, collective understanding ● Background information ● Support for the construction of the platform ecosystem ● Verification of documentation and plans ● Building relationships ● Sharing outcomes following the progress of various study tasks ● PD associations' meetings were employed to recruit PD patients and controls to this study
Telephone discussions within the project team and with the stakeholders	Usually several calls per week	● Sharing the outcomes ● Verification of document descriptions ● Relationship building
Emails	Weekly or daily active discussion and expression of views on the topics	● Verification of the case descriptions ● Increased understanding ● Shared study material and results of various project study tasks ● Relationship building
Writing scientific papers	Project members wrote several scientific papers together	● Publication of scientific papers to explain the construction of the system and its use related to various science disciplines, e.g. medical, IT, machine learning
Presentations	Presentations at stakeholder events and conferences	● Increased understanding ● Deeper knowledge
Press releases	Several press releases were published	● Attention from the public and research communities ● Formulation of the achievements and visions

4. Case description and analysis

4.1. Health care view on the current Parkinson's disease treatment

PD is a progressive neurological disease that impacts the patient's motor functions by inducing uncontrolled tremors at rest, rigidity and slowness of movement (De Lau and Breteler, 2006; Jauhiainen et al., 2019). Additionally, PD causes difficulties in walking by affecting balance, increasing the frequency of falls or causing an inability to smoothly walk-through visual obstacles (called freezing of gait). The symptoms can be suppressed by taking levodopa medication, which compensates for the loss of dopamine in the central nervous system. PD cannot be cured, but with a successful symptom management plan and medication the patient's quality of life can be retained for decades. Although the effect of the treatment varies on an individual level and is dependent on many factors, individual diagnostics are still challenging, and the severity of symptoms can vary daily.

> The patient's condition varies daily between under- and overmedication. The problem is to get enough real-time information about the patient's condition changes so that the medication can be properly targeted. (Neurologist)

Therefore, occasional appointments at the neurological outpatient clinic provide a limited understanding of the overall situation. Up to one-fourth of diagnoses are inaccurate if the analysis is made based on the initial appointment (Litvan et al., 1998; Rajput et al., 1991). Diagnostic accuracy improves during follow-ups, indicating that a more extended monitoring period would help reach the correct diagnosis and more appropriate level of medication. Unfortunately, one of the problems in health care organizations is scarce resources, and thus organising enough appointments to meet nurses and neurologists can be challenging. Considering these challenges, new kind of digitalized diagnostics can help.

> I find the project important and hope that the research results help improve patient care and drug monitoring. (Neurologist)

The International Parkinson and Movement Disorder Society has created clinical diagnostic criteria for PD (Postuma et al., 2015). The diagnosis eliminates any other diseases with similar symptoms and detects at least two out of three essential PD features. This UPDRS has been widely used to categorise the symptoms of PD, for example, by Eskofier et al. (2016) and Arora et al. (2014). However, currently PD patients are most often assessed based on a subjective evaluation by a neurologist: physical tests and interviews of the patient are employed, but not necessarily using any standard format of questionnaire or test sequence like the UPDRS. In this case, we employed UPDRS to plan the digitalised diagnostics system.

> The digitalisation of the Unified Parkinson's Disease Rating Scale (UPDRS) demonstrates that the platform works and that digitalisation opens up a wealth of opportunities. (Medication company representative)

4.2. Value proposition structure forming a service hierarchy

The platform ecosystem for PD treatment consists of actors and various technologies, including medications, digital technology innovations, nurses, physiotherapists and neurologists with multiple skill sets and educational backgrounds. Platform developers, platform ecosystem operators and various sensor and sub ecosystem providers are part of the ecosystem as well. In addition, it is worth noticing that many actors not directly included in the study produce add value for PD patients, such as various PD patient associations and family members, who can be seen as members of the ecosystem in its broader sense. In addition, with their innovations, several other researchers have incorporated the development of PD treatment. Thus, these various actors have important viewpoints and value propositions in PD treatment.

> Technology opens up new opportunities for monitoring neurological diseases and improves the accuracy of predicting disease progression. (Project team member)

This clinical study primarily focussed on studying and creating a digital platform that could be further developed as an offering to help ensure that the clinical motor symptoms and medications of patients remain within optimal boundaries daily and over the long term. Related measurements would happen in real time in their everyday living environments.

> I cannot rely totally on the PD patients' verbal description of their symptoms on the phone. If the phone rattles against his beard, it indicates the correctness of the medication. More advanced diagnostics should be available than this. (Neurologist)

From the PD patient's point of view, an essential impact of the proposed platform ecosystem in clinical use is that health care quality could be improved without increasing the number of visits to the clinic. In addition, clinic times cannot always be booked quickly. With the help of the digital platform and the information created, individual medication plans could be modified based on the patient's remote online data. Overall, there is a desire to simplify access for PD patients to achieve novel value creation.

> That's important because the timing and amount of medication can significantly reduce the symptoms and improve patients' quality of life. (Medication company representative)

The other side of the coin consists of value that can be consolidated back to the platform value creators. For example, the collected motor function data can be employed to develop better machine learning systems to support the work of neurologists to recognise PD symptoms. In addition, the same data can be used in medication and sensor development by researchers and enterprises: deep brain stimulators have helped many PD patients; new movement detection sensors can be employed to study PD patients' motor function; and machine learning systems can be taught to recognise PD symptoms.

Digitalisation offers new possibilities to develop novel care paths for PD patients and to solve the challenges in their care described previously. Mobile network operators, mobile phone providers and many other stakeholders were also involved in the project.

> Complex, high-performance computing equipment, for example, in the field of data communications are increasingly moving towards virtual environments. The same phenomenon can be seen in medicine. Virtuality can pave the way for innovations and significantly extend the reach of high-quality medical and health care service. (Senior researcher)

The digital platform ecosystem, based on distributed and virtual computing technology, provides a possibility to introduce specialised global players in health care that can be located remotely, representing a novel way to generate health services not bound to a specific time and place.

> This digital health platform ecosystem is unreliant on time and place as long as mobile internet network is available with a specific access network name (APN). Therefore, patients' data can be accessed in real-time safely, although the patients are in Thailand and the neurologists are in Finland, for example. This possibility opens opportunities to support health care in third world countries, for example. (Project Manager)

We suggest that the value proposition of the health care digital platform ecosystem for PD patients consists of several 'sub'-value propositions supporting the formation of a service hierarchy. First-order value propositions address the well-being of the PD patients. The second-order value propositions address the needs of the actors who produce the first-order value propositions, such as doctors, nurses, physiotherapists and family members. The third-order value propositions address the needs of those actors who develop modules in this digital platform ecosystem. The fourth-order value propositions address the needs of digital platform ecosystem developers. Thus, the value proposition in this environment is multi-sided, including a variety of relevant aspects for a variety of actors in different roles. All the stakeholder groups involved and *the core of the digital platform ecosystem*, including the value proposition (see Fig. 1), have a position in this value service hierarchy. The beauty of this platform ecosystem is that this value hierarchy and its sub-values evolve: new sub-values are created, while others fade away.

4.3. The technological core of the ecosystem; artefacts, architecture and interfaces

In this development, project artefacts for supporting gait analysis were based on raw data collected from PD patients. Several sensors and applications from different manufacturers were employed to monitor their gait, including, for example, acceleration sensors, force sensors and an application used to register medication intake. These sensors and apps were used to collect and analyse the data and meet the needs of the use case of home monitoring. Suunto's Movesense system is one example. This sensor is an intelligent wrist or chest band device that is used for collecting acceleration, angular velocity and heart rate information. Suunto provides various tools and open APIs for outside developers to build their solutions, and several companies have already launched commercial products that have been developed on top of the Movesense platform. In addition, the Forciot company provided smart insoles with a standard low-energy Bluetooth interface.

The choice was made to employ Android phones for data collection and transfer. After collecting the data through various sensors, it is necessary to synchronise the data, harmonise the sensor data presentation format and concatenate the data from brief data intervals into a continuous data stream. To do so, the researchers created an interface that decodes the raw data that is readily available for those who employ machine learning systems for patient analysis.

Linux-based machines were used for the data collection and analysis. Furthermore, Python-based open-source analysis libraries were employed for movement and gait analyses. Various machine learning libraries were employed, and they were developed for Python and Matlab analysis tools. As mentioned, the researchers concentrated on analysing the gait of PD patients. As we analyse specific conditions, such as PD patients' motor functions, relevant features are identified and extracted from the patients' data for use by machine learning algorithms. The researchers extracted the features that are meaningful for studying this disease. With the help of these software tools, a system was created to detect and further analyse walk segments. The creation of this system was iterative, as learning and consequent creation of new features occurred as the project progressed. There was a continuous discussion with software developers on its use for this specific clinical investigation topic.

Each sensor provider provided their solution with a REST API and employed the JSON data format using the Swagger (YAML) approach, which is the standard for documenting *application interfaces.* The REST API interface works on the top of the Internet Protocol, leading to distributed solutions. Each instant of the various applications can be run independently in various parts of the globe, where the data can be delivered on IP networks.

Thus, the final data were collected from various sources. These 'sub'-platforms were integrated by employing standard REST API interfaces in which data were formatted to be compatible with the JSON standard. The critical elements were various mobile microservices introduced via the Android base platform ecosystem: each sensor can be accessed with standard IP protocols. Regarding the digital platform ecosystem, the researchers proposed a tentative arrangement on how the data should be stored to be available to other actors and how access to the data could be further refined.

The researchers tested several sensors for real-time remote data collection to create the technological core and related artefacts. Suunto's Movesense provided movement data as initially planned along with information on heart rate, heart rate variability and ECG (Electrocardiography). In addition, Mindwave's EEG (Electroencephalography) device was tested. Mindwave provides a portable EEG device that has been employed in several studies. Nowadays, there are a few mobile EEG devices with even more advanced functionalities (Sawangjai et al., 2019). This technological flexibility to add new devices leads to a situation where the same initial digital platform ecosystem can analyse other potential patient groups and diseases. For example, human gait can be employed to study other disorders, such as multiple sclerosis, Alzheimer's disease and other neurological diseases. Software developers need to build relevant machine learning systems trained to analyse disease-specific symptoms for these diseases.

We employed mobile operators' services to securely access the smart mobile phones used in this study without any third-party cloud services. This *distributed architecture* means that, for example, a patient can be in Thailand, while the doctor monitoring the patient's status could be in Sweden. This technology approach could result in hospitals specialising in treating specific diseases even globally.

The scalability of the proposed digital platform ecosystem can be defined based on three aspects:

(1) It is based on mobile microservices that can be run on Android phones, and these mobile microservices can be accessed through a mobile network such as LTE. Typically, mobile operators provide APN services that allow other IT elements to access smart mobile devices' IP addresses securely. The sensor data from the smart mobile devices can be collected by an individual computer and cloud-based virtual computers. If we need to scale the platform ecosystem massively, cloud-based virtual computers can be employed: they can be duplicated, usually in less than a few seconds. Such virtual computing capacity is provided by all major players, including Amazon, Google, Microsoft and many others. Data anonymity must be ensured prior to using cloud services.
(2) New services can be developed without needing to solve connectivity issues, as this digital platform ecosystem provides a high-level connectivity layer. The technology providers of this digital health care platform provide various tools at the outset to help collect data from new sensors.
(3) Two scalability aspects need to be addressed related to the unpredictable behaviour of users (Da Silva Amorim et al., 2014):
   a. The scalability needs to be done incrementally to be prepared for possible scalability issues;
   b. Scaling up the volume requires identifying the process and analysing this process while the volume increases.

The aim of constructing this health care platform ecosystem was to make it attractive to use and thus support the ecosystem's creation. Therefore, the consortium discussed providing the study project development results based on the open-source principle to make it easy for third parties to contribute. The open-source principle means that the source code is available to actors inexpensively or freely, usually through various easy-to-access repositories.

4.4. Actors: resources, roles, positions, mutual interactions and relations

> The project participants have engaged in a fruitful collaboration that cuts across multiple disciplinary and industry boundaries and has produced excellent research results and business ideas. (University leader in the press release)

In addition to the technological layer of the platform ecosystem, it is crucial to analyse the actors as well as their roles, positions and interactions. There are several relevant actors involved. Those who create value for the digital platform ecosystem consist of general *complementary technology developers.* They provide various artefacts and general complementary assets for the other platform developers, such as sensors, smart mobile devices, programming libraries and communication technologies meeting the requirements of the health care regulators. *The platform developers* provide value by transforming the general complementary assets (Teece, 1986) into a format that enables *module developers to construct applications* for nurses, physiotherapists, neurologists, family members and other module developers. In addition, the platform developers provide tools for module developers that deliver unprompted innovations and support a multi-sided market approach: the module developers' artefacts can be further employed by the other module developers.

There were several actors involved in offering a variety of resources for ecosystem design in this case. Anonymous University[5] was the leading platform developer. They applied for the study project funding for the consortium from the government agency aiming to study PD patients' gait outside the hospital automatically and remotely. They also had a role in leading the study project and investigating how to build a platform ecosystem based on the inputs from the study project members, market and general and commercial technology platform ecosystem providers for desired complementary assets. The other university partner, *Munich Technical University*, was responsible for developing signal processing solutions to analyse the gait patterns and other collected sensor data.

Satasairaala Central Hospital provided academic knowledge of clinical science, medical treatment of PD patients and the study design. The hospital also provided personnel to deal with patients and controls and premises for the clinical tests for PD patients. *Orionpharma Co*, one of the significant manufacturers of PD drugs, provided PD knowledge, with an interest in learning more about the medication's effects. Sport equipment developer and manufacturer *Suunto* provided electronic sports devices, such as smartwatches and bands for various sports activities with proper matching, because the intention here was to monitor patient movements. *Forciot* is a Finnish start-up that designs smart insoles for

[5] 'Anonymous' until blind review is conducted.

sports activities, which can also contribute to obtaining the required gait information.

Thus, this study project was set up with academics, industry and health care providers. The various actors' roles are described in Table 2.

4.5. Environmental influence

In this specific context, there are highly influential issues in ecosystem design. In particular, requirements for data handling and the impact of technological regulation are worthy of closer analysis and description. Hospitals are anxious to ensure there are no violations of their patients' data security, and thus *data security is imperative.* All regulations, especially the General Data Protection Regulation (GDPR), which came into effect in the EU in 2018, need to be followed. Based on the interviews and various discussions, data security is one of the most significant issues in designing digital platforms. The platform provides tools to support patients' safety. First, only a few hospital staff members knew who data were collected from. Second, the data were collected securely from smart mobile devices, and the mobile operator allocated a dedicated APN to our project. The APN ensures that we operate a private mobile network that does not allow external access to the data. Third, we collected data from the smart mobile devices to a private computer that has access to our private mobile network. Therefore, we did not need to employ any cloud services.

Another important area of regulation is medical device *regulation*, which sets requirements for products used to treat patients. As in our case the developed system was used as a prototype for evaluation and data collection and was not used for making treatment decisions, it only had to fulfil the requirements for being safe as an electrical device. However, in the future, when the system is further developed to be suitable for clinical use, it must have a single responsible manufacturer. This manufacturer will ensure that all the ecosystem pieces (i.e., physical devices, software components, data analysis algorithms, etc.) work together correctly, producing correct and easily interpretable information for clinical decision-making, thus not jeopardising the patient's safety. Medical device regulators, national authorities and notified bodies will step in as relevant ecosystem actors in this phase.

5. Discussion and conclusions

As stated in the introduction, in this paper our goal is to answer the following research question: 'What are the core elements of the design of a digital platform ecosystem for health care?' The research gaps found in the state-of-the-art literature made it clear that platform ecosystems have been scarcely studied. Indeed, platform ecosystem developments are less understood than traditional product development networks (e.g., Hahn et al., 2016; Taylor, 2017) or more tightly coupled alliances and supply chain networks (Taylor, 2017). An even deeper research gap exists related to platform ecosystems in knowledge-intensive industries, such as health care (Wang et al., 2020). This study helps to increase the understanding of this topic by demonstrating the development of a digital platform ecosystem for health care.

Based on our theoretical and empirical findings, we suggest that it is crucial to understand all the different layers in digital platform ecosystem design: 1) its reason for existence, in the form of its various value propositions for different stakeholders; 2) its technological core, in the form of artefacts, interfaces and infrastructure; 3) the involved and potential actors as resource complementors, their roles, positions, mutual interactions and relations; and finally 4) the environmental influence, in the form of institutions and practices of the health care domain in question (neurology and PD in this case), as well as the related regulations, for example, on data handling and medical devices and how these influence all the other layers. These issues in this specific case are illustrated in Fig. 2. The main characteristics of the different 'layers' of the digital platform ecosystem were gathered based on the tentative framework described previously (Fig. 1).

We provide a unique data view while developing the platform ecosystem based on a qualitative approach that justifies executing this single longitudinal case study (see Yin, 2014). We provide a unique view of how this digital platform ecosystem for health care was developed and discussed with the various stakeholders: who the involved actors were, how their roles evolved and what they provided. As we stated earlier, we studied a scantly discussed area in the platform ecosystem literature. We demonstrate the construction of a platform ecosystem in a knowledge-intensive industry that has been neglected in the literature. Health care provided by professional staff with many years of education

Table 2
Actors' roles in the health care digital platform ecosystems in this study.

Actor	Type	Initial role	Planned final role	Resources
Platform and module developers				
Anonymous	University	Platform developer	Platform developer, Module developer	Medical technology expertise, machine learning knowledge, software expertise, mobile phone and mobile networking knowledge, took care of project management and finance sourcing,
Munich Technical University	University	Module developer: machine learning	Module developer	Machine learning skills, international connections, medical technology skills
Complementary resource providers				
Suunto Co.	Private company	Complementary resources provider: movement sensors	Complementary resources provider	Motion detection expertise, motion detection equipment, embedded systems expertise
Forciot Co	Private company	Complementary resources provider: smart insoles	Complementary resources provider	Embedded systems expertise, smart insoles, stepping skills
Orionpharma co,	Private company	Complementary resources: medication for PD patients	Complementary resources: medication for PD patients	Knowledge of the effect of medication and how to use it
Users				
Satasairaala Central Hospital	Public entity Service provider for patients	Testing provider: clinical study Meet the market demands: PD patient's health care needs	User of the platform	Knowledge of the care practices and evaluation of the technology opportunities; execution of the clinical investigation
PD patients	Private persons	Data: motor functions	Beneficiary: improved quality of life	Data for development
Artefact providers				
Public domain tools or publicly available commercial tools	Artefacts	General complementary resources: Spyder, smart mobile device, IP protocols, LTE, APN, computing capacity	Enhanced complementary assets	General complementary resources (see column 3)

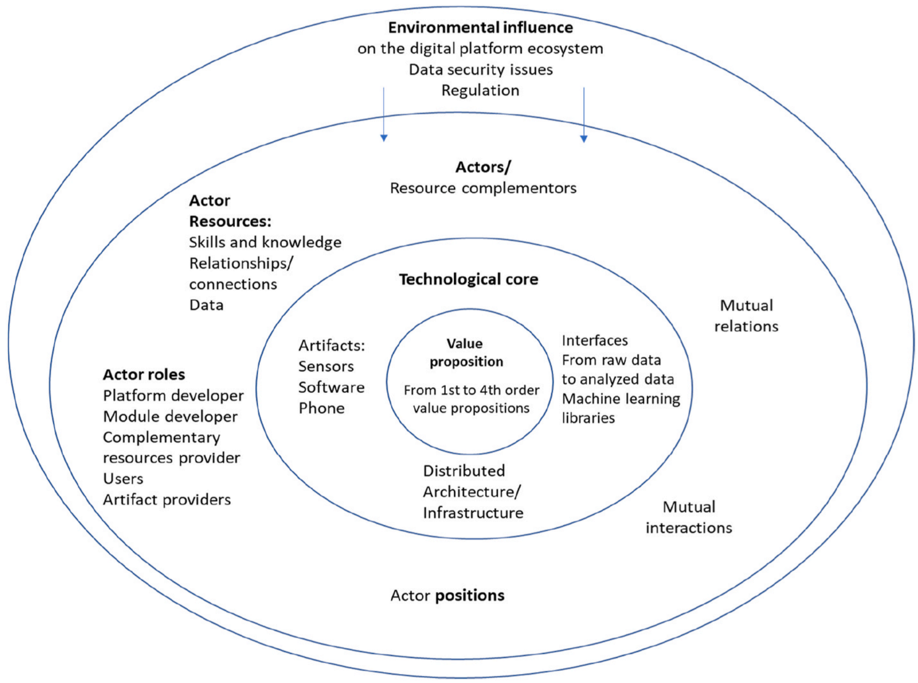

Fig. 2. Empirical findings: Design of digital platform ecosystem for health care.

represents a knowledge-intensive industry. Thus, we contribute to the platform ecosystem literature. We also contribute to the R&D literature on how platform ecosystems are built and how they enhance the creation of content application and application systems. Finally, we contribute to the business network literature by examining the actors' roles in this new digital platform ecosystem.

5.1. Propositions and future research avenues

We conclude our empirical analysis with the following propositions highlighting the core findings. These propositions can be tested in future studies.

This digital health care platform ecosystem was constructed from the complementary resources of related sub-platforms and value-adding services produced by the platform ecosystem's module developers. A platform ecosystem *should not be seen as a final set-up* but as a living system with ideas and innovations that can be implemented on top of the existing system. However, innovations must be aligned with the platform's objectified knowledge, standard interfaces, artefacts and practices. Thus, our first proposition (P1) is as follows:

> *In the digital platform ecosystem for health care, new value-creating services and other innovative elements need to follow the commodified and objectified knowledge of the platform ecosystems in question so as not to jeopardise extant value-creating services. Thus, the value creation in this health care platform ecosystem is based on the standard interfaces and basic set of artefacts and practices that help implement the novel innovations more fluently.*

In addition, related to *innovativeness* and the *ability to change* its design, some issues make this context different from others in health care. In 'ordinary' platform ecosystems, as the technology evolves constantly, the digital platform needs a vital ecosystem to provide new views and innovativeness to accelerate its development. However, the situation is almost the opposite in the regulated medical domain. Due to the regulatory requirements, all changes to the system design need to be carefully evaluated, their effects analysed and the changed system verified. Thus, the legal manufacturer needs to have agreements in place with the technology providers of the ecosystem to guarantee that the providers inform the manufacturer in advance if they make any changes to the devices or software they provide to the platform. In other words, there are several lock-in effects, and the system becomes very tightly coupled, which can hamper its innovativeness. This phenomenon also results in an increased importance of having an active ecosystem during the design phase of a new platform to include all needed state-of-the-art technologies in the platform *from the beginning*.

The starting point for ecosystem design is the *value proposition* for the patient and related value generated, for example, better accessibility of services or more balanced and data-driven medication (Adner, 2017). Therefore, a focus on the value proposition is needed to understand how digital platform ecosystem design can be built in a customer-centred way, not for the sake of the defined technology or network actors (e.g. Hermes et al., 2020). However, our understanding of the value proposition as a guiding force should not be too narrow. During the process, the ecosystem was built around a multi-sided value proposition for its many actors. Some of the benefits are fairly self-evident, such as the system's support for neurologists of physiotherapists in their professions (e.g. Biancone et al., 2021). Some are more hidden, such as opportunities for individual service developers to increase their innovativeness based on new customer data gained from the ecosystem or the opportunities provided for digital platform developers related to the ecosystem's technological core or actor base. The empirical analysis referred to 'sub'-value propositions and the related service hierarchy. Our second proposition (P2) is as follows:

> *The digital platform ecosystem for health care is built around various (mutual) value propositions forming a service hierarchy.*

Some questions can be asked: How can this service hierarchy be formulated to allow the digital platform developers to deliver a deeper understanding of a platform ecosystem's value. Would it be a part of the platform ecosystem IT architecture?

The third proposition concludes that this initial platform ecosystem's complementary resources and contributing complementors consist of other extant platform ecosystems. For example, we employed the IP networks' Linux- and Python-based platform ecosystems in this study. Thus, proposition (P3) is that the platform ecosystem can include other platform ecosystems as complementary assets:

A platform ecosystem can bring together various platform ecosystems, as in this study of a digital health care platform ecosystem, and the other platform ecosystems provide complementary assets to fulfil multi-sided value propositions.

Teece (1986) introduced the complementary asset concept, referring, for example, to the way in which digital cameras utilise memory cards to their usability. This study shows that multiple platform ecosystems' complementary resources can be integrated to create a new platform ecosystem. How has the complementary asset concept evolved toward the concept of complementary resources? How might these complementary concepts evolve further, supporting the creation of new innovative artefacts that are not yet known?

This initial platform ecosystem needs to serve the needs of the module developers. In this study, the platform allows various remote sensors to be accessed easily using commodified and objectified knowledge and technologies. This highlights the attractiveness of the ecosystem (Cennamo and Santaló, 2019; Panico and Cennamo, 2020; Tavalaei and Cennamo, 2020) for potential resource complementors, which can be extremely important in such a highly regulated environment. Our fourth proposition (P4) is as follows:

Platform ecosystems need to innovatively meet (not existing similarly in any other platform ecosystems) module developers' desires to construct value-added solutions to be provided by the platform ecosystem in question.

Various types of platform ecosystems provide their APIs to module developers. A question can be raised about what kind of API could generate active module developer groups that can provide innovative solutions for various platform ecosystem actors. In this study, the platform ecosystem provides commodified and objective knowledge and technologies with APIs especially for those who are not experts in mobile platform ecosystem programming. This is an important topic that requires more profound investigations.

In this case, the actors involved shared a strong vision of the future of health care and the direction in which it should go. For example, the actors could see the many benefits of measuring patients continuously in their everyday living environments. The ecosystem actors also shared a vision of improving health care globally. All this created a positive attitude and stability in the ecosystem (Cennamo and Santaló, 2019; Hurmelinna-Laukkanen et al., 2021), keeping the actors motivated for the task. Our fifth proposition (P5) is as follows:

The actors' willingness to participate in the ecosystem and their vision of related benefits need to be strong enough to create social bonds, interaction and mutuality, keeping multi-sided actors involved.

These propositions can pave avenues for future studies on digital platform ecosystems in health care. More case studies could enrich the understanding created in the present study. In our view, a specific focus on the actor layer is important in the future. Specifically, actors as active resource complementors, their positions, mutual interaction and relations would be an exciting focus for future studies. In addition to qualitative, in-depth case studies, future research could also quantitatively approach this question by surveying stakeholder views on participation in and orchestration of the ecosystem. A future study could also examine what kinds of visions various platform ecosystems' actors have or whether they have mutual visions at all. A question can be asked: How do the visions impact platform ecosystem development in various platform ecosystem cases?

Based on this research project, it would be interesting to analyse how the digital platform ecosystem can be constructed for other health care purposes than presented here. As the project manager states:

> The goal of the research is not only to increase our understanding of Parkinson Disease but also create a unique new ecosystem based on the hospital district's vision for patient care as well as new research and industry innovations. Our research results are likely to be applicable across a range of diseases that hold similar characteristics to Parkinson disease.

5.2. Societal and managerial implications

From a societal and managerial perspective, there are many implications related to digital health platforms. While offering many new means of knowledge content sharing, involving patients and caretakers in value co-creation and providing enhanced on-time diagnostics with the help of the digital health platform ecosystem (Presch et al., 2020), the impact of medical treatments could be improved. This would lead to better health resource coordination (Sousa et al., 2019), providing new insights into decision-making processes in health care. A more in-depth focus on patients' lives and the constant interaction supported by digitalisation could enable the multi-sided development of care paths and the work of professional caretakers.

According to Sousa et al. (2019), future decision-making in health care organizations can be facilitated by big data. Platform ecosystems enable the use of big data in personalised patient health care. One of the anticipated impacts is that new knowledge about treating a disease can be created with the help of data collected remotely by digital health care platforms. The creation of specific knowledge can also be concentrated in one place. This concentration of expertise means centres could be dedicated to certain diseases, even globally. The patient could be followed up in real time anywhere as long as mobile networks are available. At its best, the platform ecosystem can equalise society, as it makes health care available relatively quickly and inexpensively, even in remote locations.

The idea of a digital platform ecosystem can be implemented based on the empirical evidence presented in the present study. In brief we would describe the steps as follows:

1) Find a relevant use case.
2) In the proposal, employ a clinical study to determine the feasibility of the solution to the clinical problems together with relevant partners (in this study, the partners were Orionpharma, Suunto, Forciot and several universities).
3) Train the hospital staff and agree about collaboration with your partners (in this study, the Central Hospital and the physiotherapist and neurologist).
4) Collect and analyse data (in this study, the university researchers developed machine learning algorithms to help to recognise PD symptoms in patients).
5) Publish the findings to contribute to platform ecosystem development.
6) Come to an agreement with partners on how this platform ecosystem will be employed to provide care to patients.

5.3. Study quality and limitations

The quality of this single case study can be assessed employing the eight 'big-tent' classification approach (Tracy, 2010).

The value of this study topic is based on the extensive literature study that helped create the tentative framework (see Fig. 1). A single case study was employed to support the platform ecosystem construction. We refined the tentative framework with empirical data, which are seldom available, and ended up with an updated version (see Fig. 2). We created value to research by exploring a relatively scantly discussed topic in the literature and providing propositions for future studies.

Rigorousness was achieved by concretely demonstrating a platform ecosystem with real cases involving actual patients, control subjects and hospital staff in a real hospital environment. Table 1 illustrates the research intensity of this study, with multiple activities contributing to this study. The study's sincerity is ensured by openly explaining the research perspective and methodology. We recognise the limitation of a single study, but we also emphasise the uniqueness of this single case study and the data it provides. We also propose that the results could be verified by further research, and we created propositions to facilitate that process.

The credibility and validity of the study lie in multivocality with a researcher from various science disciplines. This study employs triangulation using the perspectives of various science disciplines on the empirical domain data. We have reported our results in multiple articles in the biomedical engineering discipline, which thoroughly review the related research in this area.

Tracy (2010) emphasizes that naturalistic generalizations or transferable findings can help in reaching resonance in an audience. In the present paper, this resonance was achieved by discussing the generalisation of the results and by drawing on various science disciplines and field data in creating the theory. Meaningful coherence was achieved by discussing the methods and achievements and connecting them to the literature. The significance of the results was demonstrated by introducing policy recommendations.

The ethical conduct of the study included the application of a carefully defined clinical protocol. A favourable statement regarding the study was received from both the local ethics committee and the competent national authority prior to starting the subject recruitment. In the event of changes to the clinical protocol of the study, an amendment was submitted to the ethical committee. We also reflected on the findings with the project's steering committee, which included representatives from the university, hospital, financial body and companies.

Like any study, the present one has some limitations. The limitations of this study are related to the culture, maturity, construction specificity and methodology:

1. The study's construction was built for a hospital located in Finland, and so far it has not been tested in any other countries or in any hospitals in Finland. However, this study leans on theoretical frameworks based on the literature and empirical studies, and thus we argue that this risk is limited. Nevertheless, we encourage repetition of this study in various cultures to increase the knowledge on this topic.
2. The construction used in the study can be called immature because it has not yet been commercialised for wider professional use. In addition, the participants did not have similar financial interests as in the case of fully commercial platform ecosystems. However, we would like to point out that even getting the management involved in supporting the initial construction is relatively challenging for any new similar construction (Kasanen et al., 1993). In this study context, an ethically sound and detailed clinical study plan was needed for the ethical committee formed by the medical experts. Nevertheless, it is a step toward commercialisation, as we learned in building this construction.
3. This study's construction was built for PD patients. Thus, it can be argued that this construction was specific. To some extent, this is true, as it was built for and tested with the patients of one specific neurological condition. However, the benefit of the platform ecosystem is related to the reusability of its platform components and knowledge. Of course, when dealing with other diseases, we need to shape our platform components and knowledge accordingly. Still, depending on their proximity, we can employ the previous knowledge domain in this new domain.
4. The results of case studies are not considered to be generalisable to a large population due to their inductive approach. Eisenhardt and Graebner (2007) noted that case studies can be employed to create constructs, measures and testable theoretical propositions, which deductive studies can then use to complete the cycle by employing data to test the theory. However, the results of this qualitative case study could be applied to similar cases, as our theoretical framework leans heavily on the literature and is complemented with empirical information. All ecosystems have their own characteristics, making them unique, but at the same time they can have similarities. With its propositions, this study paves the way for future studies to investigate this topic further.

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Appendix 1

CONSTRUCTION DEVELOPMENT PROCESS AND RELATED DATA

Collaboration among different stakeholders in constructing the digital platform for PD patients

Meetings in a Central Hospital. Visits to the hospital were often related to different stages of the patient process: the design and simulation of the process, deployment and testing of basic digital artefacts, expansion of the system, addition of new equipment to the clinic and then to the patient and updating of new software versions. There was a lot of discussion about what kind of configuration is suitable and at what stage. For example, Forciot insoles were not given to everyone because it was thought that changing the battery would cause problems for some patients, etc. It was thought that updating the software would not be easy for a physiotherapist, and therefore the Project Manager had to be present, usually with a few university colleagues. All the hospital visits are listed as follows. *Present* (depending on the focus of the meeting): Physiotherapist, System Programmer, PhD Researchers, Neurologist, Hospital Physicist, Machine Learning Programmer, Hospital management representatives.

04.05.2017	Briefing hospital management
02.06.2017	Designing ethical application and clinical study
13.06.2017	Designing ethical application and clinical study
21.11.2017	Designing ethical application and clinical study
12.12.2017	Inducting physiotherapist, designing and testing clinical processes
12.01.2018	Introducing the data collection system and piloting the system with physiotherapist
26–27.02.2018	Introducing the data collection system for the physiotherapist

(*continued on next page*)

(*continued*)

03.04.2018	Testing the data collection system in the hospital for clinical use; piloting with hospital staff
17–18.04.2018	Implementing the enhanced version for the hospital fit and start the piloting with PD patients
03.05.2018	Training and problem solving and putting Forciot insoles into clinical use (UPDRS)
23.05.2018	Finalising the collection systems for full roll-out
14–15.06.2018	Shadowing physiotherapist work and full roll-out for out-of-clinic and in-clinic use
26–27.06.2018	Taking Movesense sensors and setting up phones for clinical use (UPDRS)
20.08.2018	Configuring phones to use APN
04.10.2018	Updating the phones and introducing the machine learning concept for the hospital staff
08.11.2018	Updating the phones and introducing the new version of the UPDRS data collection system
19.12.2018	Finalising the first full data collection round for the machine learning study
23.10.2019	Repeating the collection with more patients
18.11.2019	Updating the phones with new version
08.01.2020	Project closing

Stakeholder/Company representative and project personnel meetings (lasted from one to 2 h). The face-to-face meetings were arranged with the various stakeholders to discuss stakeholders' commitment and interest in the project. The project applied Suunto's and Forciot's pre-commercial versions of their wearable sensors. Discussions were held with both companies about how their product would fit the planned platform ecosystem. Discussions were also held with Orionpharma's representative regarding how the project's output could benefit the development of new drugs for patients.

16.03.2017	Suunto Research Director
20.03.2017	Orion Director, R&D Data Science
11.04.2017	Forciot CEO, R&D Manager, Principal designer
18.04.2017	Orion Director, R&D Data Science
04.05.2017	Pori, Machine Learning Expert, Head of Hospital F&C, Principal Neurologist
11.05.2017	Orion Director, R&D Data Science
15.06.2017	Suunto Research Director
21.06.2017	Orion Director, R&D Data Science
17.08.2017	Orion Director, R&D Data Science
23.08.2017	Suunto Research Director
29.08.2017	Suunto Research Director
27.10.2017	Suunto Research Director
18.01.2018	Suunto Research Director
02.02.2018	Suunto Research Director
09.02.2018	Forciot R&D Manager
05.03.2018	Suunto Research Director
03.12.2019	Orion Director, R&D Data Science
02.02.2018	Forciot CEO, R&D Manager

Project steering committee meetings. The project steering committee was established based on the investors' requirement to support the project execution and complete the investors' budget reports. The steering committee members represent industry: Orion pharma (chair the committee), Suunto, Forciot, and Tampere University (meetings facilitator). In addition, the extended steering committee meetings included the project group members.

22.01.2017	Formation of the committee
20.04.2017	Progress and financial reporting
29.08.2017	Progress and financial reporting
07.03.2018	Progress and financial reporting
15.08.2018	Progress and financial reporting
14.12.2018	Progress and financial reporting – concluding the project

Patient association meetings/patient recruitment for development and patient views. Face-to-face meetings were arranged with the Parkinson's disease association in the Satakunta district. The purpose of the meetings was to recruit PD patients for the clinical study. The clinical study was introduced with the help of a neurologist and a physiotherapist. The neurologist provided the medical background for the clinical study, while the physiotherapist handled practical arrangements of the study protocol. The meeting participants asked questions related to the study, and the project representatives provided the answers. At the end of the meeting, those who were interested in joining the project were asked to stay and provide their contact information.

Kankaanpää's Parkinson Association 4.4.2018.

Rauma's Parkinson Association 18.4.2018.

Pori's Parkinson Association 28.2.2018.

Publications. Evidence of the construction has emerged since the research group attended the conference and published journal articles in the field of medicine and medical software technology (and preliminary versions of this article at the conference). This work mainly adds to the evidence base regarding the design and construction of a digital health platform.

List of publications: Ruokolainen, J., Halidijan, J., Juutinen, M., Puustinen, J. Holm, A., Vehkaoj, A., Nieminen, H. (2021). Mobilemicroservices Architecture for Remote Monitoring of Patients: A Feasibility Study. In P. Otero, P. Scott, S. Z. Martin & E. Huesing (Eds.), *MedInfo 2021 Proceedings, Studies in Health Technology and Informatics volume 290*, (pp. XXX-XXX), iOS press, https://doi.org/doi:10.3233/SHTI290, forthcoming.

Juutinen, M., Wang, C., Zhu, J., Haladjian, J., Ruokolainen, J., Puustinen, J., & Vehkaoja, A. (2020). Parkinson's disease detection from 20-step walking tests using inertial sensors of a smartphone: Machine learning approach based on an observational case-control study. PLoS One, 15(7), e0236258.

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