PATIENT FACING SYSTEMS

Technological Ecosystems in the Health Sector: a Mapping Study of European Research Projects

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Abstract

The European Union has a substantial investment in research and development and demand side-measures in the health sector in order to promote new initiatives, prevent disease and foster healthy lifestyles. In particular, the European Commission and other European entities have funded research projects focused on the use of technology in the health sector. In this context, health research initiatives have evolved from user-centred monolithic solutions into collaborative partnerships of different stakeholders that gather around different technological platforms. In order to identify the lacks and opportunities in this area, a systematic mapping study was conducted with the aim of identifying and analysing the recent research projects developed in Europe related to technological ecosystems in the health sector. The study covered closed European research projects from 2003 to 2018. This paper aims to extend that systematic mapping study through ongoing research projects. The analysis of these research projects provides an overview of the current trends and identify the lacks and opportunities to define new advances in this research area. Moreover, the comparison between the first mapping study focused on closed projects, and the current study, allows getting an overview of the evolution of technological ecosystems in the health sector.

Keywords Technological ecosystems · Software ecosystems · European projects · Health sector · Systematic mapping · Systematic literature review · European research

Introduction

As the world population ages, so does the occurrence of both cognitive and physical impairments within the citizens, which increases the cost of care and resources needed for attending them. For that reason, many developed countries dedicate a significant number of resources looking for new innovative solutions that could alleviate the increasing economical requirements of the health sector. In this sense, the European Union has performed a substantial investment in research related to the health sector in order to promote new initiatives, prevent disease and foster healthy lifestyles (€449.4 million invested in its Third Health Programme 2014–2020 [1]). Also, it maintains strong collaboration initiatives such as the

European Innovation Partnership in Active and Healthy Ageing (EIP on AHA) [2], the Joint Programme on Neurodegenerative Diseases Research (JPND) [3] and many others.

In this context, health research initiatives have evolved during the last decades from user-centred monolithic solutions into collaborative partnerships of different stakeholders that gather around different technological platforms. Finally, these collaborative environments have evolved into what is known as technological ecosystems [4–6], which provide a general framework that allows defining and developing any type of technological solution, describing how data and information are shared between the ecosystem actors and how those actors interact with each other.

Taking the above into account, a systematic mapping study was conducted with the aim of identifying and analysing the recent research projects developed in Europe related to technological ecosystems in the health sector. The survey covered closed European research projects from 2003 to 2018, reviewing a total of 19 research projects out of a gross of 718 [7].

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This work aims to extend the systematic mapping study of the European research projects about health and technological ecosystems through the analysis of ongoing projects. The report of these research projects provides an overview of the current trends and identifies the lacks and opportunities to define new advances in this research area.

The paper is set out as follows. The first section identifies the need for carrying the systematic mapping. The second section provides a brief introduction to the topic. The third section describes the planning of the mapping process. The fourth section describes the procedure to extract the information. The fifth section presents the answers to the mapping questions. The sixth section analyses the results obtained during the mapping study and compares them with the previous work. Finally, the last section concludes the work with its more significant contributions.

Previous works

The first task before starting a systematic mapping or a systematic literature review is to identify the need for conducting the study. In this case, it is required to identify if there are other mapping studies about European research projects in the health sector focused on technological ecosystems.

Several searches were conducted in different types of sources. First, searches in Google and Google Scholar to find publications, reports or studies related to the European Union were conducted. On the one hand, a report about cross-border cooperation was found, in particular, a survey of mapping EU-funded cross-border healthcare initiatives [8]. On the other hand, two papers were found: an article that describes a systematic mapping study about European research on reducing social exclusion and stigma related to mental health [9]; and a paper about trends in ambient-assisted living platforms [10]. None of this works are focused on the same objectives that the study described in this paper.

Finally, a search in some of the major scientific databases was conducted: Web of Sciences (WoS), Scopus and PubMed. Only one paper found on Scopus could be related to this study, but it compares the projects funded by the European Union about active aging and elderly's quality of life with projects funded by USA [11].

Thus, no systematic studies about European research projects in the health sector focused on technological ecosystems were found. This work extends a previous systematic mapping conducted by the authors focused on closed European research projects from 2003 to 2018 [7]. It focalizes around ongoing projects, that is, projects that started between 2015 and 2018.

Research method

This study adapts the guidelines provided by Kitchenham and Charters [12] for systematic literature reviews and the guidelines provided by Petersen [13, 14] for mapping studies. In particular, the process is organized into three main phases: planning, conducting and reporting the research.

This section lays out the results of said planning, including the research questions, the inclusion/exclusion criteria, the quality criteria, and the followed search strategy.

Mapping questions

The main objective of this study is to extend the systematic mapping presented in [7] in order to get an overview of the research trends related to technological ecosystems in the health sector according to the investment done across Europe. In particular, it is focused on ongoing projects. The authors maintained the same research questions from their previous study in order to compare the answers from both studies:

- MQ1: What are the trends in the development of technological ecosystems focused on health in Europe?
- MQ2: What is the application domain of the research conducted?
- MQ3: What types of institutions are involved in the project?
- MQ4: How are the stakeholders involved in the technological ecosystems developed?
- MQ5: Which calls fund this kind of research projects?
- MQ6: Which period do the projects cover?
- MQ7: How much money was invested in these projects?

To define the scope of the review Petticrew and Roberts [15] propose the PICOC method:

- Population (P): European research projects focused on software ecosystems in the health sector.
- Intervention (I): conduct a systematic mapping of European research projects in the health sector that define and develop software ecosystems.
- Comparison (C): no comparison.
- Outputs (O): an overview of trends in technological ecosystems in the health sector.
- Context (C): research contexts related to technological and software ecosystems in the health sector.

Inclusion and exclusion criteria

A set of inclusion and exclusion criteria was defined to select those research projects that are relevant to answer the defined

mapping questions. These criteria are based on the previous study, but the IC3 was changed in order to cover ongoing or recently finished projects:

- IC1: The project is focused on software ecosystems or technological ecosystems in the health sector AND
- IC2: The project involves different European countries; namely, it is an international project AND
- IC3: The project is ongoing or is finished during last year since December 2018 AND
- IC4: The project is available in the most relevant databases supported by the European Union AND
- IC5: The project is classified in a call related to health or technology AND
- IC6: The information about the project is available in English.

Regarding the exclusion criteria, they are defined as follows:

- EC1: The project is not focused on software ecosystems or technological ecosystems in the health sector OR
- EC2: The project does not involve different European countries; namely, it is a national project OR
- EC3: The project was closed before December 2017 OR
- EC4: The project is not available in the most relevant databases supported by the European Union OR
- EC5: The project is not classified in a call related to health or technology OR
- EC6: The information about the project is not available in English.

Quality criteria

The inclusion and exclusion criteria allow to ensure a set of projects related to the scope of the mapping study, but they do not allow to assure the quality of the results in order to answer the mapping questions proposed. To assure this quality, the criteria defined in the previous mapping [7] was adapted to review ongoing research projects. In particular, the seventh criteria - Is the project currently operating/available? – was replaced:

1. The website of the project is available?
2. The outputs of the project are available?
3. Is there more information in English available about the project than the project summary?
4. Are there scientific publications associated to the project?
5. Does the project provide a full definition of the ecosystem? (Implements part or the whole ecosystem)
6. Was (or will be) the ecosystem developed? (Proposal, proof of concept or real system)

7. Does the website show the activity of the project?
8. Does the ecosystem support evolution through the integration of new components?

Search strategy

The sources chosen to conduct this study are the same as the ones selected in the previous study in order to be able to compare the results: Active and Assisted Living (AAL) Programme (http://www.aal-europe.eu), Community Research and Development Information Service (CORDIS) (https://cordis.europa.eu), and KEEP Database (https://www.keep.eu/keep/search). These databases were chosen according to a set of requirements [7]:

- It is a database focused on projects that involve several European countries.
- It is a reference database in the research scope.
- It allows using a search string equal or similar to the rest of the selected databases.

Regarding the search terms, due to the differences between the search tools provided by the selected databases, different terms and filters were used (Table 1). The AAL Programme database does not provide means to include search terms and all projects are related to technology and health. CORDIS allows filtering by topics so the search was conducted in health topics and the search terms were "platform" and "ecosystem". Finally, two strategies were combined in KEEP, one similar to CORDIS and the other including the term "health".

Data extraction

The data extraction process is an iterative and incremental process that was divided into several stages in which different activities are carried out. A PRISMA flow [16] (Fig. 1) is used to describe the process.

First, the results obtained after applying different search strategies were collected. To do so, results were processed in different ways according to the tools provided by each database. In particular, the results from CORDIS were downloaded in CSV format (comma-separated values), the results from the KEEP database were downloaded in Excel format, and the projects from the AAL Programme were copied one by one. The records from CORDIS, KEEP and AAL were stored in a repository in GitHub and organized in a spreadsheet in Google Sheets (http://bit.ly/2TBm8RH).

Secondly, the summary of each research project was analysed, and the inclusion and exclusion criteria were

Table 1   Search strategies for each chosen database. Source: [7]

	AAL Programme	CORDIS	KEEP (I)	KEEP (II)
Search terms	All projects (there is no search tool available)	platform or ecosystem	platform or ecosystem	platform and health ecosystem and health
Filters	All projects (there is no search tool available)	Closed projects Financing instrument: Project Subjects: Healthcare delivery/ services; Medicine and Health	Closed projects Thematic: Health and social services	Closed projects Thematic: ICT and digital society

applied. The research projects were organized in another sheet of the spreadsheet, and each project was marked as a candidate or not depending on the inclusion and exclusion criteria (http://bit.ly/2Fbv2Sv).

Then, each research project was analysed employing the information provided on its website: deliverables, results, news, scientific publications, etc. During this analysis, the quality questions were answered. This analysis is available in another sheet of the spreadsheet (http://bit.ly/2RykUcf).

Finally, a fourth sheet was prepared with information extracted from each project in order to answer the mapping questions. All the information was organized in a third sheet of the spreadsheet (http://bit.ly/2Vzrxuc).

The results obtained after carrying out this process are described through a PRISMA flow [16] (Fig. 1):

- After applying the search strings applying to each database on December 2018, 368 research projects were collected. 181 were from CORDIS, 65 from AAL, and 122 from KEEP.
- After removing duplicates, all of them from the searches carried out in KEEP, there were 344 research projects.

Fig. 1 PRISMA. Adapted from [16]
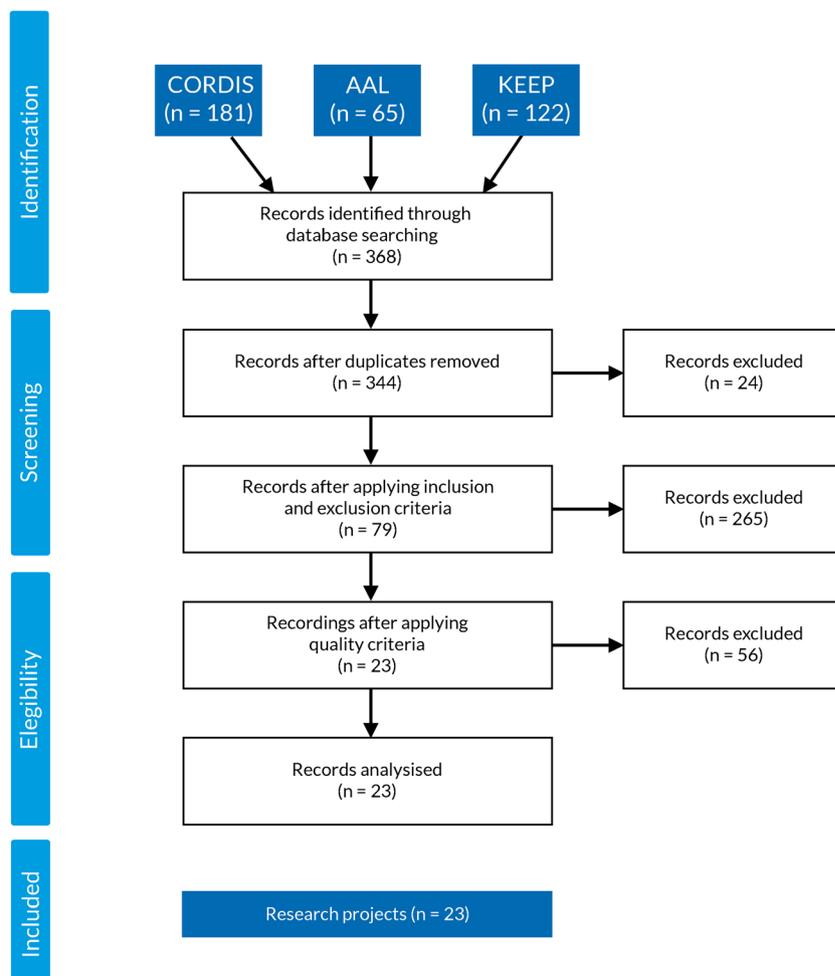
- Once the criteria were applied to both the title and summary, 79 research projects were obtained (22.97% of the unique research projects retrieved).
- After applying the quality criteria to the information mainly provided in the project website, 23 research projects were obtained (6.69% of the unique research projects retrieved).
- Finally, a total of 23 research projects were fully analysed.

Results

This section presents the results obtained after the data extraction process and the analysis of the selected research projects. To analyse the data, a Jupyter notebook (http://jupyter.org) written in Python and developed for the previous mapping study was adapted [17]. The notebook extracts the data from the spreadsheet in Google Sheets (http://bit.ly/2NQM5dJ). The code repository is available on GitHub [18]. This script is based on the work developed by Cruz-Benito http://bit.ly/2tS9JgF.

MQ1: What are the trends in the development of technological ecosystems focused on health in Europe?

According to the previous mapping study, the programmes and calls mark the trends of the funded projects. However, each project employs different types of technologies to achieve its objectives. Table 2 shows what the leading technologies involved in establishing relationships between the different ecosystem actors are. It can be observed that web-based ecosystems are the most frequently developed, but sensors are present in most of the eHealth ecosystems.

MQ2: What is the application domain of the research conducted?

Table 2 Type of technology used in the ecosystems for the 23 selected projects

| Type of ecosystem technology	Count
Web-based	8
Sensors + mobile	6
Sensors + Hardware	2
Sensors + mobile + web	2
Sensors	1
Sensors + cloud	1
Sensors + robots + mobile + cloud	1
Smart-TV	1
Web + cloud	1

The main focus of the projects is the improvement of the healthcare system using different solutions (11), followed by independent living (8) and Quality of life (4). Other domains include assistive services (2) and well-ageing (2). Also, there are several ecosystems focused on research in bioinformatics (1), biomedical engineering (1), diseases spread (1) and big data (1). Fig. 2 shows detailed information, considering that some projects belong to more than one application domain.

MQ3: What types of institutions are involved in the project?

To answer the third mapping question, the institutions were classified in seven categories: R&D (universities, research centres, etc.), SME (small and medium enterprises), End-user (associations, care homes, NGOs, etc.), Consortium, Business (big companies, hospitals, etc.), Public body (regional/local governments, health management, ministries, etc.), Multi-stakeholder. Fig. 3 shows the distribution of institutions per category. There is a total of 194 institutions involved in the selected projects. On the other hand, regarding the country, Italian institutions have more presence than those from any other country, followed by Germany, Austria, and Greece. It should be highlighted, the presence of non-European countries such as USA, Kenya or Uganda (Fig. 4).

MQ4: How are the stakeholders involved in the technological ecosystems developed?

Fig. 5 shows the different types of stakeholders involved in the selected projects. It can be observed that the main target
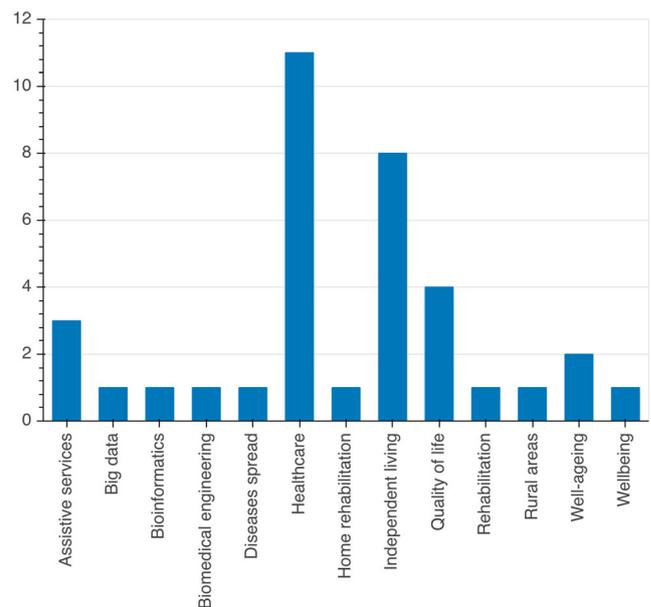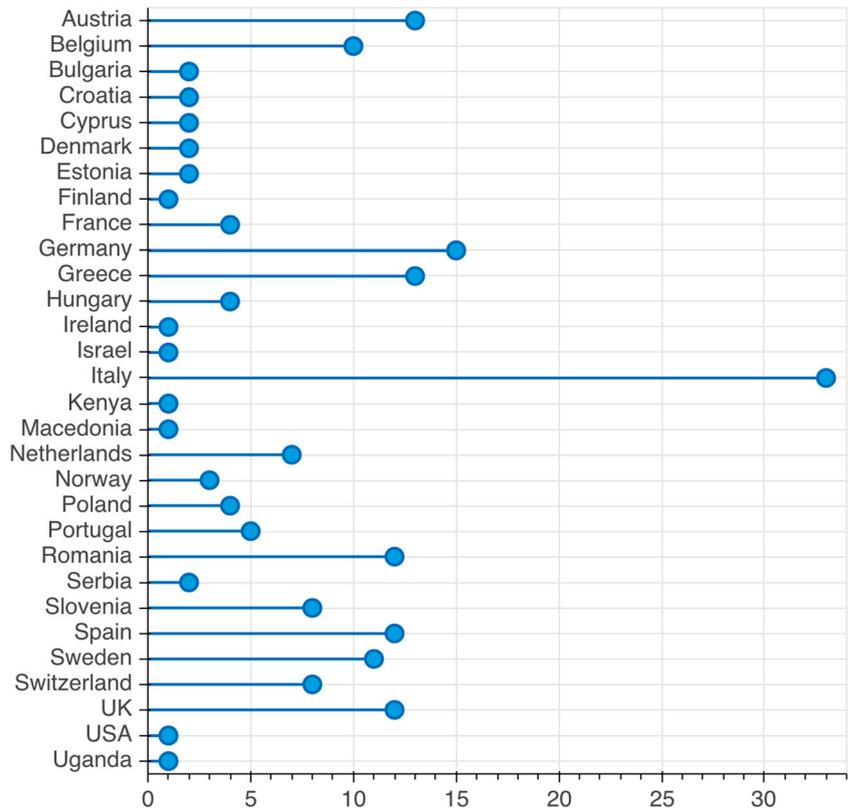

Fig. 2 Number of projects per each domain
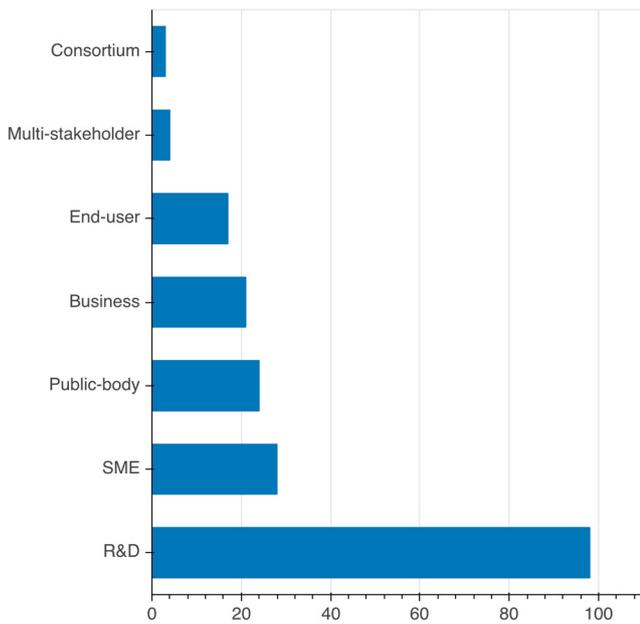
Fig. 3 Number of institutions involved in the selected projects organized by type

MQ5: Which calls fund this kind of research projects?

Fig. 6 shows a circle chart that represents the percentage of projects found in each programme. It can be seen that the AAL programme (34.78%) and Horizon 2020 (30.43%) cover more than 60% of the total selected projects. The other projects are 2014–2020 INTERREG [19] from different cross-border regions (34.79%), one of the key instruments of the European Union (EU) supporting cooperation across borders through project funding in fields such as health, environment, research, education, transport, sustainable energy and more.

MQ6: Which period do the projects cover?

Fig. 7 shows the distribution of the selected projects over time. As the mapping study is focused on ongoing projects, the period covered is short, from 2015 to 2020. Regarding the duration, it can be seen that most of the selected projects have European funds for two or three years. Six projects started in 2015 and finished in 2018, followed by four projects which started in 2017 and finished in 2020.

MQ7: How much money was invested in these projects?

Finally, the last mapping question is answered through two tables; one that shows the total investment per

groups of technological ecosystems proposed are older persons (11) and patients (6) from an end-user point of view; formal (8) and informal carers (6) regarding the health area; software providers (8) and health device companies (6) from the technological sector point of view.

Fig. 4 Number of institutions involved in the selected projects organized by country

Fig. 5 Total count of the different stakeholders involved in the ecosystems along all the projects
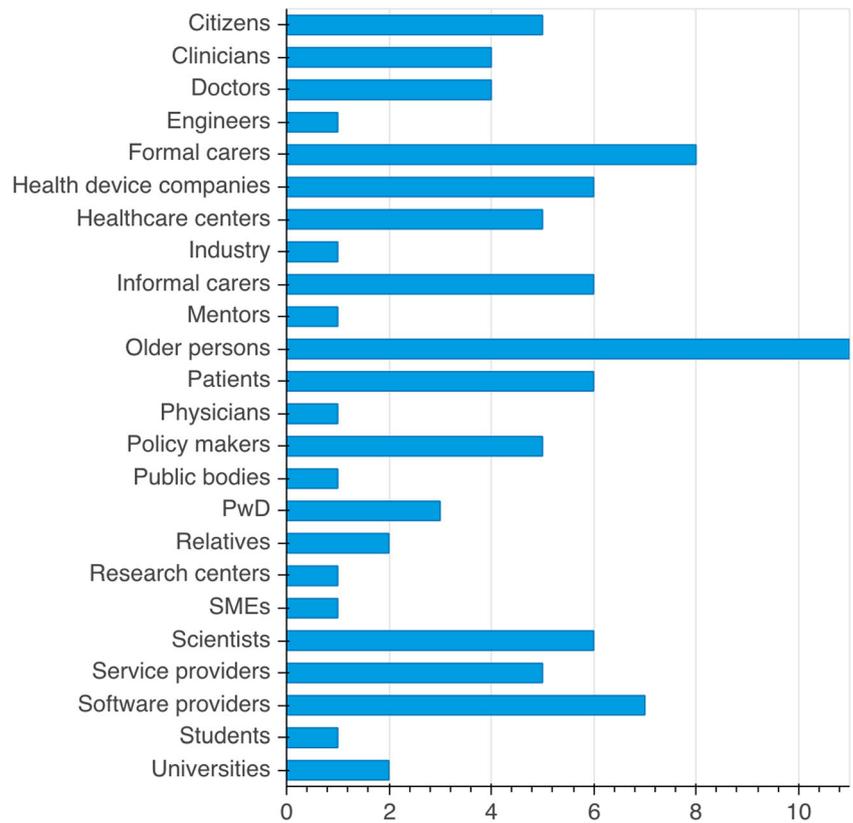
programme (Table 3) while the other per year of the call (Table 4). Regarding the programmes, H2020 provides more funding than the other programmes in health and technology areas, although the number of considered projects from H2020 is lower than from the other programmes. On the other hand, INTERREG programmes provide less than 50% compared to H2020 and less than 30% compared to the AAL Programme.

Results analysis

In this section, the obtained results to the mapping questions will be discussed, comparing them with the results obtained in the previous mapping study that focused on finished projects that ranged developed from 2003 to 2018 [7], in order to obtain an overview of the evolution of the EU funded health ecosystem projects.
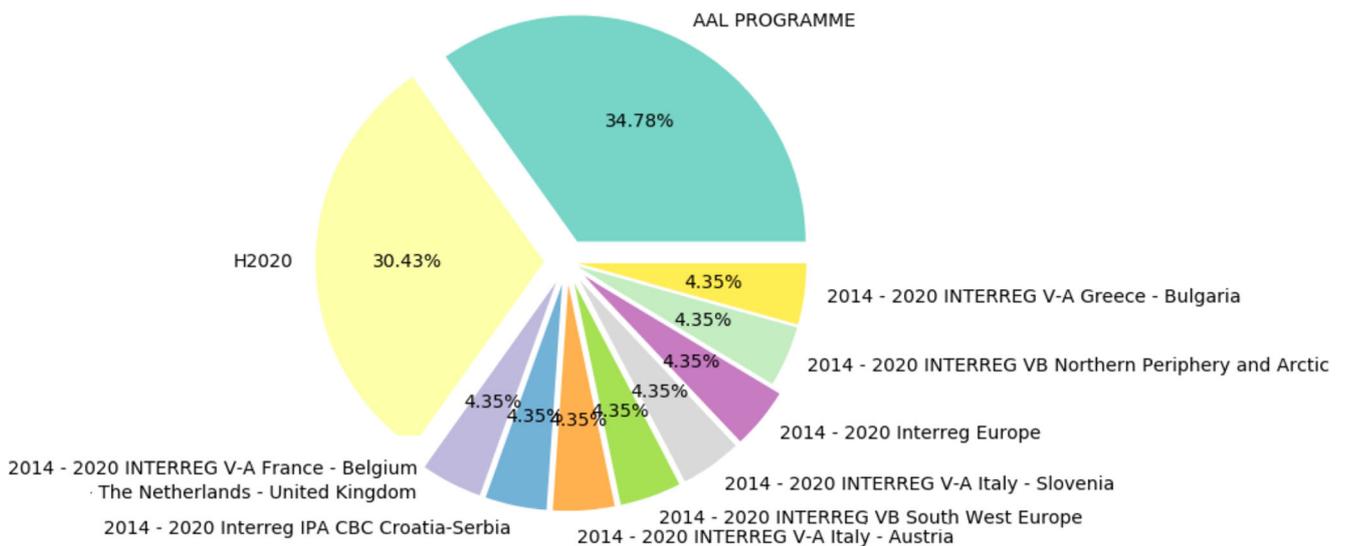
Fig. 6 Percentage of selected projects per funding programme

Fig. 7 Distribution of the 23 projects over time. The 'y' axis represents start year and the 'x' axis the end year
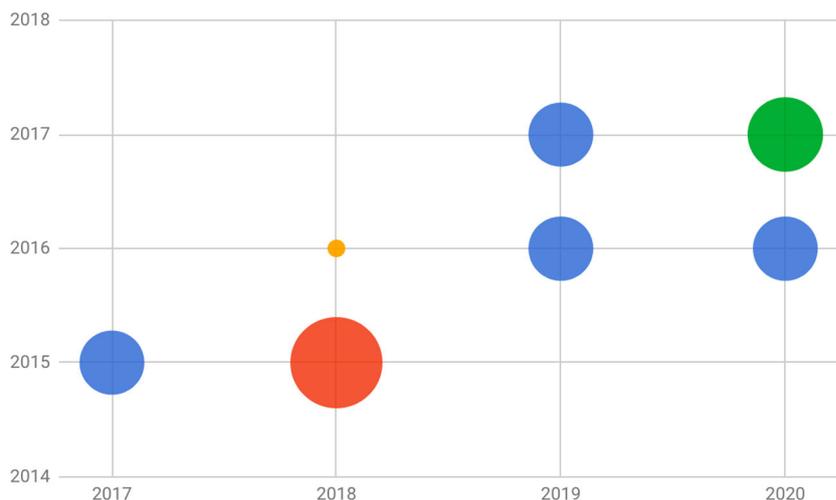
In general terms, the obtained results are framed according to the different calls found in the three selected databases. As many of these results are interrelated, the following discussion is better understood taking into account the nature of the programs funding the obtained projects. For that reason, the discussion starts by the fifth mapping question regarding the calls the obtained research projects belong to. In this respect, the projects found in the CORDIS database are of multidisciplinary nature focused on health-related fields, ranging from cancer, stroke, Parkinson or Metabolomics. Projects found in the AAL database are mainly focused on technology hubs based on previous projects, which are primary focused on providing services for the older citizens. Finally, projects found in the KEEP database are mainly focused on establishing networks between ecosystem actors of very different nature in different European regions (public authorities, technology providers, patient organizations, etc.) with the objective of sharing good practices through the use of technology.

From a point of view of the technological trends in the development of health ecosystems, results show that a great amount of solutions are platform-centric and employ open platforms for facilitating the interaction of the different actors. On the other hand, most of the rest of ecosystems make use of sensors in combination with other technologies, such as robots, cloud or mobile technologies.

These and previous [7] results show that the trend is maintained regarding the use of available web platforms as the core technology for the information exchange and actors interaction in health ecosystems. However, while the projects from the

previous review that mainly developed sensor-based solutions belonged to the AAL program, the projects obtained in this study from H2020 and INTERREG also incorporate sensor technologies to their solutions. On the one hand, this indicates that there is a higher level of standardization and regulatory compliance of the medical devices and sensors, which allows incorporating them into web-based platforms that are generally developed in areas not related to care provision. On the other hand, it also shows that the monolithic services (such as fall detection, heart-rate monitoring, etc.) that were offered in the previous studied ecosystems are increasingly being more integrated with other higher level services.

Regarding the type of partners involved in the projects, it can be observed that research institutions are the main institutions that participate in this type of proposals, followed by SMEs, public-bodies, large companies and end-user organizations. As for these results it has to be noted that the number of large companies is remarkably high taken into account that they are usually not eligible for funding.

Compared with the previous study, the percentage of large business companies has increased when compared to the rest of the involved partners' categories. This may be due to a greater awareness of the companies of the benefits of adopting an ecosystem view of business for medical technology and health services provision. Also, it has to be pointed out the large number of public-bodies found in the present study, which were not present in our previous review. This increase

Table 3 Total investment per programme

Programme	Investment	Projects ($N = 23$)
H2020	22.355.191,25€	7
AAL Programme	13.745.318,10€	8
2014–2020 INTERREG	9.475.704,16€	8

Table 4 Total investment per year

Year	Investment	Projects ($N = 23$)
2014	24.797.030,53 €	9
2015	10.210.757,89 €	5
2016	9.439.913€	8
2017	1.128.512,38€	1

is mainly attributable to the projects found within the different INTERREG project calls and also to the more recent H2020 projects. The above results indicate that health ecosystem developers are gaining awareness of the importance of incorporating public authorities in their proposals, as they have a fundamental role as the front line for delivery health services to most of the communities in the different countries.

The stakeholders considered in this work include not only those that correspond to the institutions that take part in the proposal, but also those that might benefit or be interested in the solutions developed in the projects. As such, included stakeholders are older persons, patients suffering different diseases, formal and informal carers and software providers and health device companies from the technological sector point of view. In terms of the particular scope of the calls, those related to the AAL program are clearly biased to senior users and formal and informal carers and include companies that develop assistive technologies. On the other hand, software related companies are mostly found in the H2020 and INTERREG projects, as they make extensively use of existing web platforms.

Results are highly correlated with the ones obtained in the previous study [7] in terms of the stakeholders type. However, it can be observed that the geographic scope of the proposed ecosystems has been broaden through the years, as the number of different countries has increased in the proposals, including even stakeholders from outside the European union. These results indicate that technological health ecosystems are gaining maturity, as they aim to involve stakeholders from many different distant countries despite the differences in care provision policies and regulations between those countries.

As for the application domain, the previous discussion regarding the scopes of the EU calls is also applicable. Call aims in turn lead to the different main domains the proposed solutions are framed in. Results show that healthcare provision services are the main domain of application of the technological ecosystems (11 projects), followed by independent living (8 projects), quality of life (4 projects) and assistive services (3 projects). Independent living and aging well are topics mainly addressed by the different AAL programs until the 2015 call, from which the healthcare domain begins to be introduced but always linked to the care provision for dependent people related domains that are specific to these initiatives. Healthcare oriented technological ecosystems are fundamentally developed under the calls found in H2020 and INTERREG, although those of H2020 also included services for facilitating independent living until the 2014 call. However, it must be taken into account that the domain of application of the ecosystems in the case of H2020 it is greatly marked by the call the projects belong to, since it is highly framed in these particular calls.

Despite of the above, it can be also observed that the projects generally combine more than one application domain, especially those projects with senior and dependent end users, which combine the healthcare domain with independent living and aging well main goals.

If compared with the results obtained in [7], there is an increase in the relative percentage of projects that belong to the healthcare application domain in comparison with application domains focused on the ageing-well or independent living. This outcome is in part a consequence of the greater number of INTERREG projects found dedicated to healthcare provision. However, it is also due to the fact that more recent AAL related projects consider healthcare as a main goal, incorporating healthcare provision into the ecosystem main service objectives. This indicates that there is increasing interest from stakeholders of different nature in the recent ecosystem proposals, which results in new ecosystem objectives and a broader range of aggregated services offered.

Finally, regarding the distribution of projects over time, the covered period of the studied projects ranges from 2015 to 2020, as the mapping study is focused on ongoing projects. It is remarkable, however, that despite the time period restriction the number of found projects (23) is higher than the one from the previous study (19 projects), which focused on finished projects ranging from 2003 to 2015.

It seems evident, therefore, that there is growing interest from the European initiatives in the development of technological ecosystems for health. However, it is also observed that the total investment has been reduced during the last calls when compared to the previous ones. In this regard it should be noted that these figures may have been affected by the lack of information provided by the projects under development, which entailed the discard of several projects that were labelled as eligible during the quality assessment stage.

Conclusions

This paper presents a systematic mapping review in the domain of European research projects focused on technological ecosystems in the health sector covering ongoing projects that started from 2015 to 2018. It extends the systematic mapping review previously developed by the authors that focused on closed projects ranging from 2003 to 2018. The comparison between the first mapping study focused on closed research projects, and the current study allows getting an overview of the evolution of technological ecosystems in the health sector.

The review was focused on seven mapping questions, and the main findings are:

- there is a maintained trend regarding the use of available web platforms as the core technology for the information exchange and actors' interaction in health ecosystems;

- results suggest that there is a higher level of standardization and regulatory compliance of the medical devices and sensors, and that previous monolithic offered services are evolving into aggregated services;
- percentage of large business companies has increased when compared to the rest of the involved project partners' categories;
- the geographic scope of the proposed ecosystems has been broadened through the years;
- there is an increase in the relative percentage of projects that have a healthcare application domain in comparison with application domains focused on the ageing-well or independent living;
- there exists a growing interest through the years from the European initiatives in the development of technological ecosystems related to the health sector.

Finally, although it is not a main conclusion from the study, is important to highlight that the mapping protocol defined to carry in this study can be used to carry out other mapping studies.

Compliance with ethical standards

Conflict of interest   The authors declare that they have no conflict of interest.

Ethical approval   All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent   Informed consent was obtained from all individual participants included in the study.

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