Technology foresight for growth and productivity: the design and implementation of a new foresight approach for UK SMEs

Final report

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The aim of Business Basics funded projects
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is to build up the evidence base around what does and does not work in encouraging SMEs to adopt basic technologies and management practices.

Introduction

Technological change is a key challenge for organisations and particularly for small and medium sized enterprises (SMEs) that have limited resources for monitoring and developing emerging technologies, or for adopting technologies that already exist in other industries/sectors. However, technological change represents a huge opportunity for those organisations that are able to identify new technologies early and anticipate their future evolution, impact and response options.

Since the early 2000s, a significant number of corporate organisations successfully applied an innovative management approach to monitor new technologies and the systematic analysis of their future evolution and impact. Such approach is commonly named under the umbrella of "technology (or strategic) foresight". This includes techniques such as technology roadmapping and Delphi. Roadmapping consists of representations as interconnected nodes of major changes and events in the external environment, such as new technologies, products, and markets. Delphi involves a number of experts answering questions in two or more rounds. After each round, the experts are given a summary of average forecasts and the reasons for such forecasts, and are encouraged to revise their early answers in the light of this feedback.

Despite the growing popularity of technology foresight amongst large corporations, there is little evidence on its use in SMEs. However, foresight might be very beneficial to SMEs that are facing technological changes. This may enable them to pool their knowledge about new technologies and thus to set priorities and joint efforts, in a systematic way, for the optimal allocation of their resources.

Building upon the widespread experience of the primary investigator of this project in technology foresight, we aimed to develop and test a simple, effective and scalable foresight method specifically responding to the needs (and challenges) of SMEs in UK clusters. Precisely, this application gained support for designing and implementing a foresight exercise involving at least 15 SMEs in a Digital Health cluster. This was chosen on two main criteria: its impact on the UK economy and the potential/need for enhancing its current level of productivity.

Our foresight project consisted of three different main phases. The *first phase* focused on the identification of the SMEs to be involved in the project (target number: 15), the identification of the technology experts (target number: 5), the raising of awareness among the entrepreneurs and experts, the gathering of background information, and the identification of a preliminary list of technologies that are potentially relevant for future SMEs' productivity. The identification of the relevant technologies was based on techniques such as: a) an analysis of patenting activity by leading organisations (e.g., corporate firms and research centres) operating in the Digital Health sector, at an international level; b) a bibliometric analysis of publications; c) an analysis of project proposals funded by public bodies (e.g. the Horizon 2020 of the EU); and d) a survey (involving all the SMEs entrepreneurs and technology experts).

The *second phase* of the project consisted of a 3-round Delphi process enabling the evaluation of the preliminary list of technologies selected in the previous phase and the identification of the most relevant technologies for the target cluster of SMEs. The Delphi process involved all the technology experts and SMEs entrepreneurs.

The *third phase* consisted of two of workshops through which all the entrepreneurs and technology experts met and assessed the evolution, impact (e.g. new products and process), and response options available for adopting/developing the critical technologies identified in the previous phase. In particular, the two workshops explored the joint actions enabling the SMEs to overcome the limitations - e.g., expertise, financial – of each individual firm.

Altogether, these activities led to three main outputs. The *first output* from which SMEs benefited is a technology foresight methodology that is effective, scalable, and easy to use by UK SMEs, especially those operating in clusters. The *second output* is a list of critical technologies (e.g., data integration tools, data security protection) specifically related to the SMEs of the Digital Health cluster, i.e., those SMEs that will be directly involved in the implementation of the proposed foresight method. The *third output* is a list of key actions enabling these same firms to concretely develop/adopt the critical technologies identified through the foresight exercise. Furthermore, a valuable outcome of the project has been the creation of network among SMEs, universities, funding institutions, and public research laboratories.

At the end of the project, our findings showed that:

- the flexible foresight methodology we designed and experimented worked well: the SME managers could implement it successfully and smoothly. The SME managers who eventually took part in the project (14 out of 16) fully understood the methodology in relation to both the process (Delphi rounds, evaluation approach) and criteria (Attractiveness and Feasibility criteria);
- the foresight methodology we designed and implemented for this proof of concept led to results that were clear, tangible, and ready to use. At the end of the third Delphi round, four technologies stood out as the most attractive and feasible and therefore, as the priorities for future investments.

Although the project yielded extensive positive outcomes, we noticed the following drawbacks:

- a drop in feedback across the three different rounds of the Delphi;
- the recruitment of digital health SMEs was particularly challenging but the development of links with Digital Health UK proved very beneficial for all parties:
- the workshops were attended by five managers out of the 14 that took part in the Delphi. While it is generally difficult to engage SME managers in workshops, especially when they last a whole day, we believe that the time schedule of this proof of concept played a major role.

This report is structured as follows. First, we describe the first phase of the project and the companies involved in the project. Then we describe the main outputs of the project, i.e., the foresight methodology, the list of critical technologies, and the list of key actions for their transfer to SMEs. We conclude with a discussion of the opportunities for scaling up the proof of concept.

1. Identification of SMEs and technologies

The first phase of the project was conducted between November 2018 and January 2019.

1.1 SMEs and experts

A preliminary search of innovative digital health SMEs based in the London area pointed out that many of these companies were linked to the Digital Health London Accelerator (DHLA). We approached the managers of the DHLA and subsequently established a strong and effective collaboration. Together, we identified 15 companies that volunteered to take part in the project. One further company was enrolled after the suggestion of a technology expert. The manager of each company was interviewed by a member of our project team. During the interview meetings, we explained the methodology we were going to apply in the next Delphi process. After the interviews, two managers withdrew, due to other commitments or because they did not feel comfortable with the technology evaluation process. Altogether, 14 companies took part in the Delphi exercise.

Contextually, we identified six technology experts: three belonged to DHLA and three from the Computer Science Department, Kingston University. The experts were identified on the basis of their skills and current activities in the digital health sector.

1.2 Technology list

Based on both Google Scholar and IEEE Explore search engines, we selected almost 600 scientific publications covering the adoption of ICTs in the healthcare domain. Analyzing these papers (mainly published between 2013 and 2018) allowed the development of an up-to-date review of the scientific literature. This helped the identification of the main ICTs-based healthcare paradigms developed in the last few years, as well as the ICTs paradigms and the ICTs technology pillars that underpin them. At the same time, we carried out desk research (internet sources, business and media press) covering recent foresight exercises in the healthcare sector, at an international level, and future oriented publications depicting futures scenarios for digital health applications and technologies. Our desk research also covered the white papers of national governments in the EU, USA and Asia regarding the evolution of healthcare. This also included the UK Government's White Paper on "The future of healthcare:

our vision for digital, data and technology in health and care (published on October 17^{th} 2018). Finally, we monitored recent trends in related sectors including Home Automation, Digital Media, Digital Game and Self-Driving Cars, searching for new technologies that might be transferred to the Digital Health sector.

The results of this research was a preliminary list of 26 technologies that might affect the future evolution of the digital health sector and have an impact upon the future growth (or even the survival) of digital health companies, especially UK SMEs. We classified these 26 technologies in 4 main categories: 1. Communication; 2. Hardware; 3. Software; 4 Transversal technologies (technologies that involve 2 or more of the above domains or might be transferred from other industries).

These 26 technologies are:

1. Machine to machine communication
2. Internet of things
3. Cloud computing
4. Fog computing and Mobile Edge computing
5. Wireless body area networks communication protocols
6. Wireless body area networks
7. Wireless sensors (wearables)
8. Smart devices
9. Robotics
10. Smart e-health systems
11. 3D printing
12. Health Data Formats
13. Big data analytics
14. Artificial Intelligence
15. Image analysis and facial recognition
16. Speech recognition and chatbots
17. Social media
18. Security and privacy (cryptography)
19. Augmented reality and virtual reality
20. Biometrics
21. Blockchain
22. Micropayments
23. Technologies from self-driving cars
24. Automated Transport Systems (drones, autonomous ambulance)
25. New touch interfaces and displays
26. Human augmentation

We provide a full description of all the above technologies in Annex 1.

2. Technology Foresight for UK SMEs

The second phase of the project included a 3-round Delphi process for the evaluation of the list of digital health technologies identified in the previous phase. This took place between mid-January 2019 and mid-April 2019. The third phase involved organising a workshop to deliver the findings of the projects; hold interactive discussions between SME owner-managers, experts and researchers to analyse the impact and evolution trends of the key technologies; and generate the list of actions to enable SMEs to adopt new technologies. The workshop was held on April 29th 2019.

In this section we describe the methodology developed and applied in the evaluation process. The evaluation specifically focused on the digital health SMEs based in the London area, especially the SMEs of the Digital Health London Accelerator.

2.1. Delphi Round 1

Attractiveness evaluation

The attractiveness of a given technology refers to its capability to improve products (or services) and product features and thereby foster the competitiveness (and ultimately the sales and profits) of digital health companies. The Attractiveness of each technology was evaluated against the following criteria:

Economic impacts

Competition

Uncertainty

OVERALL attractiveness

Feasibility evaluation

Feasibility links a given technology with the concrete capability of digital Health SMEs to develop or adopt this technology. The Feasibility of each technology was evaluated against the following criteria:

Capabilities

Congruence

Technological investments

OVERALL feasibility

2.2. Delphi Round 2

At the end of the first Delphi round, participants were asked to comment on the overall scores received by each technology regarding the overall attractiveness and feasibility evaluation. More specifically:

- If a given technology achieved a very high score and the participants AGREE with such scores, they could write down their comments/arguments/information and thus explain the reasons why they agreed with such evaluation from the first Delphi Round.

- Alternatively, if they did NOT agree with the OVERALL evaluation received by a given technology (e.g., a technology that resulted particularly attractive or feasible WHILE they did not think so or, vice versa, a technology that resulted to be NOT particularly attractive or feasible WHILE they think it is) they were requested to write down their comments/arguments/information for this technology, so explaining the reasons why they disagreed with such evaluation from the first Delphi Round.

The participants were given a table to provide their opinions for any technology they wish to comment on. (The participants did not need to consider all the technologies in the table: they could just focus on a few technologies, i.e., those 3-4 technologies for which they particularly agreed or disagreed with the scores received in the previous Delphi round).

2. 3. Delphi – Round 3

Participants were asked to repeat their attractiveness and feasibility evaluation of each technology (as in Round 1 of the Delphi) in the light of the feedback received from the previous (second) round of the Delphi exercise. The criteria and procedure were exactly the same as in the first round of the Delphi. Participants had the option to either change or confirm their evaluations in the first round. In addition, they were asked to repeat the process only in relation to the criteria of Overall Attractiveness and Overall Feasibility.

In the next section of the report, we will discuss the findings of the technology evaluation process.

2. 4. Workshops

The objective of the first workshop was to explore further the evolution of the critical technologies for Digital Health SMEs identified in the Delphi and their impact on future products and services and, more generally, the future growth of Digital Health SMEs. We also presented the aggregated results of the preliminary interviews we conducted with all the company managers, in relation to the main barriers and enablers of technology innovation in Digital Health SMEs.

The objective of the second workshop was to explore the options available to SMEs for adopting/developing the new technologies (especially joint actions enabling SMEs to overcome the limitations - e.g., expertise, financial – of each individual firm).

3. Critical (priority) technologies for the Digital Health SMEs

The key *output* of the Delphi process was a set of critical technologies that were both Attractive and Feasible based on the original 26 identified from the literature. These represent the priorities for the future investments of the London based SMEs, especially those of the Digital Health London Accelerator.

3.1 Delphi first round results

Four key technologies (i.e. the most attractive and feasible technologies for London–based digital health SMEs) from the first Delphi Round

1. Artificial intelligence
2. Big data Analytics
3. Internet of things
4. Smart devices

Figure 1. Results of the first round of the Delphi

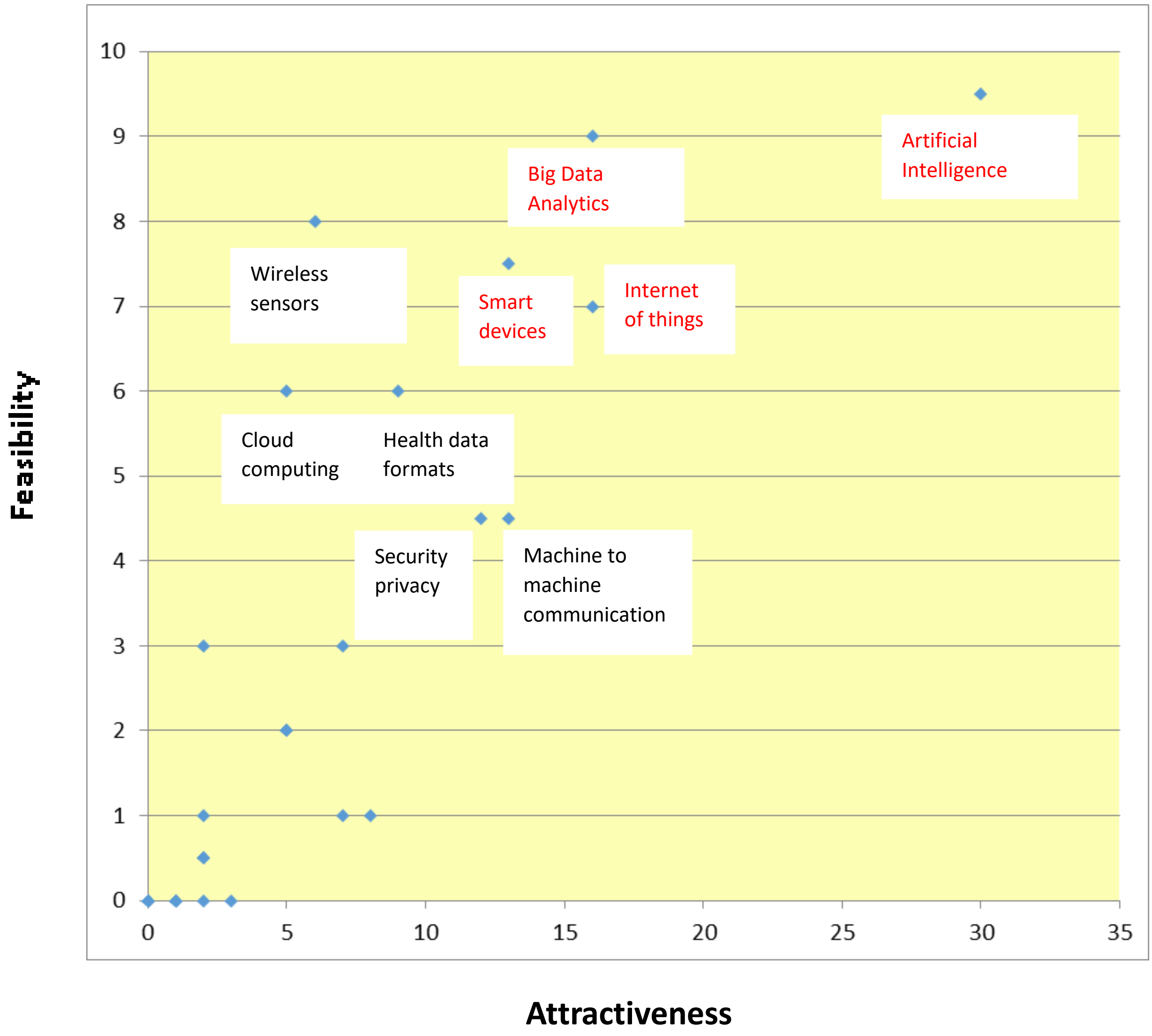


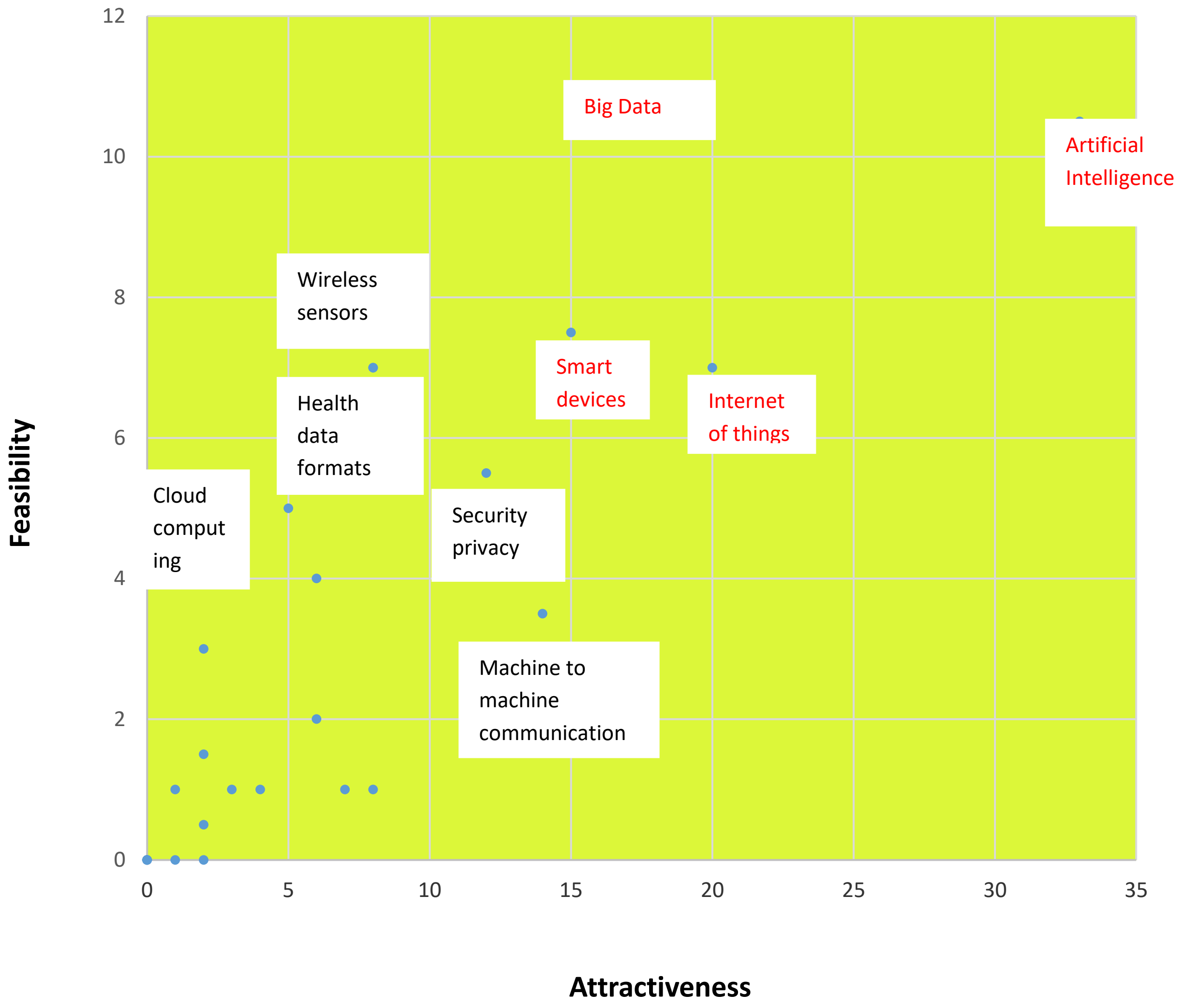
Figure 1 maps these technologies according to their feasibility and attractiveness. The figure shows that AI is regarded as being the most feasible and attractive technology.

3.2 Delphi Third (Final) Round

The results of the third round of the Delphi process confirmed the results of the first round, by actually increasing the overall scores and relative prominence of the four key technologies identified in the first phase. These are illustrated in Figure 2.

Four technologies clearly stood out in terms of both Attractiveness and Feasibility according to the experts and SME managers. This is quite unusual (generally the technologies that are the most attractive are not the most feasible) but very encouraging.

Figure 2. Result of the third Delphi round



4. List of key actions

A workshop held on 29 April 2019 was attended by five SME managers and all the six technology experts. The Workshop led to the identification of a set of actions for fostering the development and transfer of the relevant technologies identified in the Delphi process (especially Artificial Intelligence and Big Data Analytics) to the London based digital health SMEs.

1. *Data access* to NHS records is considered to be an essential enabler of new Artificial Intelligence based products and services, by helping SMEs to understand patients' needs and problems and the role of new digital technologies in addressing these problems. Digital Healthcare start-ups often experience difficulties in accessing data due to their limited resources and networking.

2. *Collaboration* with hospitals and medical centres. SMEs should team up with hospitals and clinical research team to enhance knowledge sharing, data access, funding, and build a vision for the future of digital healthcare. Such collaboration should involve as well universities, research centres, and stakeholders who can provide early feedback, accelerate knowledge transfer and information exchange.

3. *Education* is necessary since early stages (e.g., primary school) foster the development of a favourable environment, enhancing mutual understanding and nurturing a wide range of capabilities in both service providers and final users, such as problem-solving, idea generation, analytical skills, networking and relational skills. These capabilities in turn would be beneficial to enhance the adoption of digital technologies and services.

4. *Definition of lead projects and products.* SMEs need to focus on a selection of priorities in terms of products and services. Traditional NHS procurement practices often favour large corporations, by promoting large-scale projects (and procedures) that are too large for SMEs to bid for. By focusing on a few projects and products, SMEs can develop 'state-of the art' skills that might ultimately enable them to partner with leading, large corporations.

5. *Funding*. Innovative approaches to fundraising were discussed during the workshop. Such approaches include crowdfunding, private venture capital and private equity. A relevant new trend in fund raising is Initial Coin Offering (ICO), which recently proved successful in enabling healthcare start-ups to raise money in a considerably short period of time (e.g. MedicalChain, Docademic). ICO involves the initial offering of a digital cryptographically secure piece of data (a digital token) created on a blockchain as part of a decentralised software protocol.

5. Impact and dissemination plan

This project has led to three main outputs designed to helping UK SMEs boost their future growth and productivity. The *first output* is a technology foresight methodology that is effective, scalable, and easy to use by UK SMEs; and especially for those operating in clusters. The *second output* is a list of critical technologies (Artificial Intelligence, Big Data Analytics, Internet of Things, Smart Devices) specifically related to the SMEs of the London Digital Health Accelerator, i.e., the SMEs that have been directly involved in the implementation of the proposed foresight method. The *third output* is a list of priorities for action enabling these firms to concretely develop/adopt the critical technologies identified through the foresight exercise. Furthermore, a valuable outcome of the project has been the creation of networks, with the establishment of partnerships among SMEs, universities, funding institutions, and public research laboratories.

After the conclusion of the foresight exercise (31st of May), the project approach and outcomes will be disseminated through various ways. These include publications in academic journals; networking events and workshops with government agencies and other associated organisations; conferences; and industry and sector based events. Online reports will be made available so that UK firms, universities, technology research centres, government agencies and public policy-makers can register and access the findings of the foresight exercise (methodology, list of critical technologies for Digital Health). In particular, we will present the results of our project at the Digi Health UK Conference (Manchester, October 2019) and at the ISBE Conference (Newcastle, November 2019). We will also submit two papers to primary international academic journals (like Technological Forecasting and Social Change and Small Business Management. Target deadline for submission: June 2020).

Overall, the success of this Delphi exercise lies with the SMEs managers and their future efforts to adopt at least one of the critical technologies identified in the project. In this regard, the Workshop on the 29 April generated useful feedback from the SME managers. One of them has already communicated their intention to start an artificial intelligence project and potentially involve one of the technology experts met during the workshop. Another manager pointed out that it would be very interesting to replicate the technology foresight project in other digital health clusters in the UK, e.g., Manchester or Nottingham, and compare the results – especially in relation to the feasibility of the key technologies.

6. Lessons learnt: SMEs' experiences and benefits (positive and negative findings)

Our proof of concept project invited feedback regarding the experiences of the SMEs and the benefits they accrued from participating in the project. This feedback was provided by the SME managers themselves during the Delphi process and through an evaluation questionnaire they filled in at the final workshop. Furthermore, an online survey was carried out in late September 2019, which collected, in a systematic way, the opinions of the SME managers regarding the clarity of the Delphi exercise (Attractiveness and Feasibility criteria, overall methodology); the actual use of the results of the project for informing technology investment decisions; and the overall benefits of participating in the project.

In the remainder of this section, we sum up the key lessons we learnt regarding the benefits and limitations (advantages and opportunities for improvement) of this proof of concept.

Positive findings

First, the flexible foresight methodology we designed and experimented worked well: the SME managers could implement it successfully and smoothly. The SME managers who eventually took part in the project (14 out of 16) fully understood the methodology in relation to both the process (Delphi rounds, evaluation approach) and criteria (Attractiveness and Feasibility criteria).

Second, the foresight methodology we designed and implemented for this proof of concept led to results that were clear, tangible, and ready to use. At the end of the third Delphi round, four technologies stood out as the most attractive and feasible and therefore, as the priorities for future investments.

Challenges

Although the project yielded extensive positive outcomes, at the end of the project some clear lessons emerged regarding what we could improve. First of all, we noticed a drop in feedback across the three different rounds of the Delphi: while 14 managers sent their scores by the end of the first round, 9 managers sent their comments by the end of the second round and 4 managers changed their scores by the end of the third round (all the other managers confirmed the initial scores they had given in the first round).

Second, the recruitment of digital health SMEs was particularly challenging but the development of links with Digital Health UK proved very beneficial for all parties. However, if there had been more time and resources for a UK wide technology foresight project, we could have been more selective in relation to the companies participating in the project, especially in relation to their stage of life cycle, size, and capability to grow.

Third, the workshops were attended by five managers out of the 14 that took part in the Delphi. While it is generally difficult to engage SME managers in workshops, especially when they last a whole day, we believe that the time schedule of this proof of concept played a major role.

Fourth, our sample of firms was quite heterogeneous, ranging from micro companies with 2-5 employees to small companies with up to 30 employees. Overall, we noticed that the firms that were relatively bigger were generally more prepared to take part in the foresight project.

7. Opportunities for scaling up the proof of concept

Based on the feedback from the workshop on the 29 April 2019 and a critical reflection over the lessons learnt from our pilot foresight exercise, we conclude this Report with some preliminary thoughts on how this proof of concept may be scaled-up:

- The core activity of the Technology Foresight project was a 3-round Delphi process enabling a sample of selected digital health SMEs (based in the London area) to identify the most relevant technologies for their future growth and productivity. In order to identify such technologies, we used four criteria of attractiveness and four criteria of feasibility. The Delphi also involved a group of six technology experts. In order to scale up this project and improve the *reliability and comprehensiveness* of the results and outcomes, it would be helpful to: a) increase the number of SME managers and technology experts involved in the process; b) e*xpand the time horizon* of the project to allow both the SME managers and experts more time for collecting and elaborating data.
- The pilot project involved 15 SMEs from the Digital Health London Accelerator (DHLA). With the managers of DHLA we have already considered the opportunity to scale up the project and involve all the 85 companies associated with DHLA. In order to scale up the project and enhance its results and outcomes, it would be helpful to run the foresight process and apply our innovative methodology in two or three different clusters of digital health SMEs, e.g., the London cluster and the Nottingham cluster. This would allow to compare the results and to look for similarities and synergies between these different territories.
- Furthermore, we aim to increase the number of criteria (both attractiveness and feasibility) used to assess the future evolution and impact of the emerging digital health technologies, in relation in particular to their likely applications (innovative products and services). In particular, we aim to explore the use of public procurement (i.e., public measures which attempt to pull through innovations and the diffusion of innovations) for stimulating the design and provision of innovative products/services (based on emerging technologies) from digital health SMEs.

- Finally, it would be useful to apply our innovative foresight methodology to other technology intensive sectors e.g., the digital game industry or the autonomous (self-driving) car sector. In this way, we can improve/expand the methodology itself and test/adapt it to different contexts, by pointing out potential technological synergies and opportunities for collaboration among the SMEs of different (but related) sectors.

Annex 1.

A.1.1. Communication technologies[1]

Machine to machine communication

Machine-to-machine communication (M2M) technologies envision billions to trillions of everyday objects and the surrounding environment to be connected and managed through a range of devices, communication networks, and (cloud-based) servers. To implement the M2M vision, the availability of devices, ultra-scalable connectivity and infrastructures for centralized decision-making are required. M2M communication for healthcare also relies on sensors to form a body area network (BAN).

Healthcare is expected to rely on medical devices and systems (i.e., organizing machines) that are networked to ubiquitously match the need of patients in any circumstances. Such healthcare systems enable intelligent hospitals and allow to implement seamless control of medical and biological treatments and guided surgery and therapy. Leveraging reliable high-speed connectivity such as that guaranteed 4G/5G cellular networks, one of the primary services potentially enabled by M2M in healthcare is remote patient monitoring and care.

Internet of things

The Internet of Things (IoT) can be considered as the interconnection of uniquely identifiable smart objects and devices (things) with advanced connectivity that goes beyond M2M scenarios within the current Internet infrastructure. Indeed, IoT is considered a civil disruptive technology, because of its potential widespread in everyday life and variety of application fields. Starting from the basic IoT paradigm, a number of variations specific to healthcare have been envisioned.

The first, i.e., the Internet of Medical Things (IoMT) refers to applications enabled by a personal healthcare system and consist of implantable and wearable sensors and devices connected to a personal health hub (e.g., a smartphone or smartwatch) that is connected in turn to the Internet.

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[1] This appendix particularly benefited from the following paper: Aceto G., Persico V., Pescapè A. The role of Information and Communication Technologies in Healthcare: Taxonomies, Perspectives, and Challenges, Journal of Network and Computer Applications. 2018.

The second, i.e., the Internet of Nano Things (IoNT) refers to the application of IoT in nano medicine, that is expected to enhance human health in novel ways (preventive health, proactive monitoring, follow-up care, and chronic care disease management). IoNT-powered e-health systems will make health monitoring, diagnostics, and treatment more personalized, timely, and convenient.

The third, i.e., the Wearable Internet of Things (WIoT) aims at creating an ecosystem for automated telehealth interventions. WIoT connects body-worn sensors to the medical infrastructure such that physicians can remotely perform longitudinal assessment of their patients. WIoT enables monitoring human factors including health, wellness, behaviors, and other data useful in enhancing individuals' everyday quality of life.

The fourth, i.e., the Internet of m-health Things (m-IoT) envisions a connectivity model between low-power personal-area networks (leveraging e.g.,6LoWPAN) and evolving 4G networks, emphasizing the existing specific features intrinsic to the global mobility of participating entities.

The fifth, i.e., the Internet of Health Things (IoHT) results from the combination of mobile apps, wearables, and other connected devices. It is based on context-aware professional-grade sensor medical devices that are always on. These smart devices are capable to learn, leveraging sophisticated cloud-based analytics.

Cloud computing

Cloud computing is a paradigm that enables the leasing of computing resources (such as computational, storage, and networking resources) in real time and with no upfront commitment by customers. It guarantees pay-per-use billing on a short-term basis, simplifies operation, and increases (computing and networking) resource utilization via virtualization, so allowing implementing economies of scale. Cloud computing can significantly contribute to containing healthcare integration costs and optimizing resources. Economics, simplification, and convenience of the way computing-related services are delivered are among the main drivers of cloud computing. Indeed, cloud computing offers a promising approach to satisfy the information technology needs of the healthcare sector in a favourable way, by simplifying health processes. The need for computation, storage, and networking resources are common drivers to the adoption of cloud technologies for general applications leveraging the IoT paradigm.

Cloud computing is expected to play a big role in changing the face of health information technology. This will be of benefit for healthcare research, improving healthcare services (enhancing their quality and outcomes for patients), and helping to manage the current trend of growth in digital data and anywhere-and-anytime availability of medical services.

Fog computing and Mobile Edge computing

The proliferation of pervasive mobile devices generating big amounts of data to be stored and processed, together with virtualisation and programmability technologies promoting the softwarised deployment of network functions, present major challenges for the cloud. Indeed, in several contexts the cloud cannot meet all the requirements of healthcare applications and a new architecture is needed. Fog computing and mobile edge computing (MEC) may come into play to mitigate these issues.

Fog computing (introduced by Cisco) deals with the transfer of cloud computing services to the edge network, possibly integrating them with other users' device resources, thus delivering them in a distributed way between end devices and traditional cloud computing data centers. Similarly, mobile edge computing provides IT and cloud-computing capabilities within the radio access network in close proximity to mobile subscribers.

The purpose of fog and mobile edge computing is to run heavy real-time applications at the network edge, directly taking advantage of the billions of connected mobile devices. The main advantage in adopting these paradigms is an improvement in the quality of service: delay-sensitive applications face the problem of large latency, especially when several smart devices and objects are involved in human life.

Wireless body area networks communication protocols

A Wireless Body Area Network (WBAN) consists of intelligent devices attached on or implanted in the body and are capable of establishing a wireless communication link. Communication protocols designed for wireless body area networks (WBANs) can span from communication between the sensors on the body to communication from a body node to a data centre connected to the Internet. Taxonomies proposed in the scientific literature introduce intra-BAN communications (tier-1), inter-BAN communications (tier-2), beyond-BAN communications (tier-3). The term intra-BAN communications is adopted in reference to radio communications of about 2 meters around the human body. Inter-BAN communications can be divided into two categories: ad hoc and infrastructure-based. Finally, beyond-BAN (tier-3) communication is intended for use in metropolitan areas. A number of different standards for WBANs exist (e.g., Bluetooth Low Energy, UWB, Bluetooth 3.0, and ZigBee) as well as open and proprietary technologies (e.g., Insteon, Z-Wave, ANT, RuBee, and RFID).

A.1.2. Hardware technologies

Wireless body area networks

A Wireless Body Area Network (WBAN) consists of intelligent devices attached on or implanted in the body, which are capable of establishing a wireless communication link. WBANs represent a paramount technological joining link, enabling wearable sensing technologies to be leveraged in pervasive monitoring activities. WBANs are composed by different types of devices: (i) sensor nodes (in charge of responding to physical stimuli and gathering data on them, possibly processing and reporting this information and (ii) actuators nodes (acting according to data obtained from the sensors or interaction with users). In addition, (iii) a body control unit (BCU), i.e. a personal device (typically a smart-phone or a personal digital assistant) also known as body gateway or sink may gather all the information acquired by the sensors and inform the user via an external gateway, an actuator, or simply a display or a led on the device.

Wireless sensors (wearables)

Wearables are electronic devices that can be worn on the body, either as an accessory or as part of material used in clothing. One of the major features of wearable technology is an ability to connect to the Internet, enabling data to be exchanged between a network and the device. Wearable sensors help form the basis to engage and encourage patients to lead a healthy lifestyle, where the treating clinician can continuously track both health and wellness in real-time.

In particular, nano- and micro-networks of sensors enable health monitoring and logging vital parameters of patients. Notable examples of the available sensors are: tri-axis accelerometers, to recognize and monitor body posture; gyroscopes, to measure or maintaining orientation; glucose sensors, to monitor the amount of glucose circulating in the blood (non-invasive glucose monitoring has been also investigated through infrared technology and optical sensing); blood-pressure sensors, to measure systolic and diastolic human blood pressure, utilizing the oscillometric technique; oxygen and carbon dioxide (CO_2) gas sensors, to monitor changes in CO_2 levels, as well as to monitor oxygen concentration during human respiration; ECG sensors, to obtain a graphic record of the electrical activity of the heart; EEG sensors, to measure the electrical activity within the brain (usually by attaching small electrodes to the humans scalp at multiple locations); EMG sensors, to measure electrical signals produced by muscles during contractions or at rest; temperature sensors, to measure the temperature of the human body; humidity sensors, to measure the humidity of the immediate environment around a person.

Emotion sensors are tipped to be next, with the potential to change the way devices, clinicians and the environment interacts with a patient based on their emotional state of mind.

Smart devices

Smart devices (smartphones, PDAs, smartwatches, or tablets) guaranteeing portability, constant internet connectivity, and enough computing power to run complex applications are key part of the e-health revolution that digitized the health sector. They have been an instrumental tool in the evolution of the healthcare-related paradigms, acting as the major catalyst for the transition of e-health to mobile health. Indeed, they are considered as service mobile platforms for health information delivery, access, and communication.

The tremendous potential for mobile communication to transform healthcare and clinical intervention in the community is clear. Several previous studies have evaluated the use of mobile phones to support healthcare and public health interventions (e.g., in support of the collection and the integration of data for healthcare research as well as medical education, clinical practice, telemedicine and remote healthcare, information delivery in rural areas).
With the advent of custom designed applications, the adoption of smartphones has rapidly expanded and a number of specialties are producing innovative specific applications (e.g., orthopaedic decision support applications, off-site radiology access, infectious disease tracking, storage of reference material). Smartphones have the potential to improve diagnostic skills and education of a surgeon. In the next decade pioneering advances and increasing

applications of smartphone-based devices and applications in the exponentially growing field of mobility health, are expected.

Robotics

Robotics for healthcare is an emerging field that is expected to grow due to population aging, health-care personnel shortages, and the need for higher quality care (e.g., high precision surgery). Indeed, robotics are envisioned as a key component in a number of healthcare scenarios. For instance, a mobile robotic nurse assistant is highly desired to enhance the efficacy and quality of care that nurses and paraprofessional staff can provide, both in a hospital ward and when providing assistance to old-aged people under direct and telepresence control by a nurse or physician.

A long-time and evolving application of ICTs to healthcare is the surgical robot (also in teleoperator set-ups). Surgical robots are an established tool for surgical operations that are minimally invasive and require extreme precision of movement that is hard to achieve with hand-operated tools. Being electronically mediated, the commands given to surgical robots can also be transmitted by a remote operator (and the visual and tactile feedback sent to the operator), allowing teleoperation when the surgeon cannot be physically present with the patient. Suitable telecommunication infrastructure is needed to guarantee the strict service requirements of the communication between the operator and the robot.

Smart e-health systems

The adoption of advanced medical and environmental sensors enables networked systems (sometimes defined smart e-health systems) to continuously monitor patients' physiological and physical conditions, and transmit sensed data in real time via either wired or wireless technology to a centralized location where the data can be monitored and processed by trained medical personnel. Often, state-of-the-art-solutions leverage cloud computing as it can provide a powerful and scalable storage and processing infrastructure to perform both online and offline analysis and mining of sensor data streams, also lowering management costs.

Three Dimensional (3D) printing

3D printing can be defined as the process of creating three-dimensional solid objects from digital files using a computer-aided design (CAD) programme. 3D printing allows the rapid and inexpensive production of small parts for laboratory work. 3D printing technology generates a number of different opportunities in the health domain, as 3D printing structures are popular and used as key components of products. The rapid prototyping capability offered by 3D printing is also considered advantageous for commercial applications. As patients' understanding of their medical condition and treatment satisfaction has gained increasing attention in medicine, 3D printing may play a role in patient education, e.g., to facilitate patients' pre-surgical understanding of their surgery.

Robotic 3D bio-printers, consisting in multiple print heads (e.g., for human cells and hydrogel) and managing bio-ink to create layers of cells to build tissues are also becoming commercially available. In this context, monitoring health of 3D structures is particularly important (e.g., through sensors embedded inside a 3D structure itself).

A.1.3. Software technologies

Health Data Formats

Health data formats include electronic medical record (EMR), electronic health/healthcare record (HER), and personal health record (PHR). Electronic medical record (EMR) is a real-time patient health record with access to evidence-based decision support tools that can be used to aid clinicians in decision-making. EMR is used by healthcare practitioners to document, monitor, and manage healthcare delivery within a care delivery organization. In general terms, EMRs are clinician-focused in that they enhance or augment the workflow of clinicians or administrators.

An electronic health/healthcare record (EHR) is a repository of information regarding the health status of a subject of care, in computer processable form. More specifically, an EHR is a longitudinal electronic record of patient health information generated by one or more encounters in any care delivery setting, and reporting episodes of care across multiple care delivery organizations within a community, region, or state.

A personal health record (PHR) is a layperson-comprehensible, lifelong tool for managing relevant health information, promoting health maintenance and assisting with chronic disease management. It is controlled and managed by the citizens (or their legal proxy). By definition, it is not a legal record unless so defined and is subjected to various legal limitations.

Big data analytics

Large amounts of heterogeneous medical information have become available in various healthcare organizations. Smart and connected healthcare devices are increasingly adopted and contribute to generating streams of structured and unstructured data. In particular, three main data sources can be identified: (i) traditional medical data originated from the legacy health system; (ii) omics data, which refer to large-scale datasets in the biological and molecular fields (e.g., genomics, microbiomics, proteomics, metabolomics, etc.); (iii) data from social media, essentially consisting of signs and behaviors of how individuals and groups of individuals use the Internet, mobile applications, sensor devices, wearable computing devices, or other technological and non-technological tools to better inform and enhance their health.

Thus, today healthcare practitioners are commonly facing difficulties related to managing and capitalizing this data to their advantage. The implementation of big-data analytics in the healthcare field is the process of examining these large data sets to uncover hidden patterns, unknown correlations, and other useful information. Big data analytics is more and more attracting the interest of the scientific community, as this data would become useless without proper data analytics methods.

Advances in big-data analytics help naturally transform research questions from being descriptive (e.g., what has happened?) to predictive (e.g., what could happen?) and prescriptive (e.g., what should we do then?). For instance, big-data analytics in healthcare can contribute to evidence-based medicine, genomic analysis, pre-adjudication fraud analysis, device remote monitoring, and patient-profile analyses. Big-data analytics can effectively reduce healthcare concerns, such as the selection of appropriate treatment paths and the improvement of healthcare systems. More in general, big data technologies will reduce waste and inefficiency in clinical operations, public health, research and development.

Big-data analytics include data mining algorithms, which are classified into two main categories: descriptive (or unsupervised learning) and predictive (or supervised learning). Existing machine-learning algorithms (for e.g., data filtering, classification, clustering, association, and combination) can be adopted.

Artificial Intelligence

Artificial Intelligence (AI) is the simulation of human intelligence processes by computer systems. These processes include learning, (i.e. the acquisition of information and rules for using the information), reasoning (i.e. using the rules to reach approximate or definite conclusions), and self-correction. At the forefront of the techniques of AI rapidly advancing in healthcare scenarios are natural-language processing, pattern recognition, and machine learning, that can be applied to many specific fields, such as biomedicine and life sciences.
Artificial intelligence can lead to the development of tools to assist clinicians and potentially improve patient outcomes.

AI technologies include soft computing cognitive computing. Soft computing is the collection of problem-solving technologies that can adapt to the problem domain, such as probabilistic reasoning, fuzzy logic, neural networks, and genetic algorithms that provide promising solutions and better results in comparison to traditional approaches.

Cognitive computing is the evolution in computing that mimics some aspects of human thought processes on a larger scale. Cognitive computing tries to fill the growing gap between the huge amount of data available and the fraction being effectively integrated, understood, and analysed. Cognitive computing algorithms address data challenges by applying multiple technologies, to enable comprehension of disparate data sources.

Image analysis and facial recognition

Artificial intelligence solutions strongly support image analysis as well as voice and speech recognition, thus enabling a variety of applications. For instance, the elaboration over speech and face images allows to detect a patient' state.

In particular, image analysis technologies include 3D scanning and facial recognition technologies. These technologies, which are becoming more and more used in the digital game industry, allow game players to actually create their likeness in the gaming world or to inventively transfer their own expressions to other digital creations. For example, a few grimaces at the game screen means the system would dial down the game's difficulty instantly. Other technologies that might be transferred from the game industry into healthcare applications include gesture control technologies. These allow game players to simply interact with game devices with just a few waves of the hand. Using a 3D camera that tracks separate points in the hands, gesture control allows users to connect with their gaming experience by using the natural movements of the body.

Speech recognition and chatbots

Thanks to speech recognition, man-machine dialogue can be implemented by expanding the application scope of purposely designed robots. Services for building conversational interfaces into applications using voice and text (such as Amazon Lex) provide advanced deep-learning functionalities of automatic speech recognition for converting speech to text, and natural language understanding to recognize the intent of the text. These services enable health companies to quickly make voice or text-based chat interfaces for their apps, making them interactive.

Progress in speech recognition also leads to the implementation of chatbots (also known as a smartbots, Conversational interface or Artificial Conversational Entity) allowing users to type a question into messaging apps any time and receive free responses from doctors. A chatbot is a computer programme which conducts a conversation via auditory or textual methods. Thanks to chatbots and related apps, users are also able to see responses from doctors to questions that are similar to their own.

Social media

Social media (also social networking services) are online platforms that are used by people to build social networks with other people who share similar interests, activities, backgrounds, or real-life connections.

Although slower to adapt to changing trends, healthcare is starting to embrace social media, thus allowing medical providers to communicate with patients in ways they never could before. Social media implemented through web-based, mobile, and cloud applications and providing real-time access are changing the way health-care practitioners review medical records and share medical information. Social media frameworks enable healthcare practitioners and professionals who look after patients to easily collaborate both in and out of the hospitals. Social media are likely to change the nature of health-related interactions. For instance, social media might influence patients' choice of hospital, medical facility, or doctor. More in general, social media technologies are changing the practice of medicine.

Security and privacy (cryptography)

Problems of security and privacy are being constantly raised, as social media services have been increasingly provided by healthcare providers all over the world. For instance, if used inappropriately social network sites can have great implications for healthcare professionals, as they are changing the way information is shared and an increase in the number of users. The most common challenge is related to the breaches of privacy or confidentiality against patients. Other issues can arise as well: lateral violence against colleagues; boundary violation (when the professional relationship of doctor-patient or caregiver-patient starts blurring into personal relationship); employer use of social media against employees (including prevention of career advancement or hiring due to social media content deemed inappropriate); fake news misleading readers. Besides the misguided use of social media, technical issues arise regarding security and privacy of service usage (exploitable by malicious third parties). In this context, the recent general data protection regulation (GDPR) was enacted after several years of discussion on how new protections should be updated to reflect the emerging digital landscape of data processing and data controlling. This includes data concerning health, genetic data and biometric data.

In order to solve these problems, secure and privacy-preserving key management schemes resilient to mobile and Internet attacks have been proposed, e.g., leveraging the cooperation of the mobile patients in the same social group for both hierarchical and distributed environment. Technologies for security and privacy include cybersecurity, adaptive security, intelligence detection, remediation and adaptation techniques, and cryptography.

Augmented reality and virtual reality

Augmented Reality (AR) and Virtual Reality (VR) are being used across multiple points in the healthcare industry, including training, patient education and treatment. These technologies provide a safe environment to simulate realistic scenarios with little or no risk. The potential benefits are significant – improved training, patient outcomes and reduced costs. The value of VR/AR in healthcare is likely to continue to grow – particularly as integration with AI and sensors becomes more sophisticated.

In particular, VR can be used with clinicians to assist with training, by performing ‘hands on’ procedures in a safe and controlled setting, and to interact with a virtual patient and learn practical skills. VR can also be used with patients to aid in the explanation of diseases, for example by educating patients about positive lifestyle choices, such as stopping smoking. VR can be used as well to connect consumers to medical expertise through apps. Other bespoke treatment applications include using VR for social cognition training in patients with autism, and in pain management for burn victims.

AR can be used to aid surgery and medical incisions e.g. nurses use this to support the identification of veins. It can also be used as a form of exposure therapy e.g. phobia treatment where the sufferer is able to learn skills and build confidence in a virtual environment.

A.1.4. Transversal technologies

Biometrics

Biometrics covers a variety of technologies in which unique identifiable attributes of people are used for identification and authentication. These include (but are not limited to) a person's fingerprint, iris print, hand, face, voice, gait or signature, that can be used to validate the identity of individuals seeking to control access to computers, airlines, databases and other areas which may need to be restricted.

Specifically, biometrics in healthcare might be used as applications regulating access to doctors' offices, hospitals, and databases, or for use in monitoring patients. Such applications can include access control, identification, workforce management or patient record storage.

Blockchain

Blockchain is a distributed system recording and storing transaction records. More precisely, blockchain is a shared, immutable record of peer-to-peer transactions built from linked transaction blocks and stored in a digital ledger. Blockchain relies on established cryptographic techniques to allow each participant in a network to interact (e.g. store, exchange, and view information), without preexisting trust between the parties.

The promise of blockchain has widespread implications for stakeholders in the health care ecosystem. This technology has the potential to increase the security, privacy, and interoperability of health data. This technology could provide a new model for health information exchanges by making electronic medical records more efficient, disintermediated, and secure, and by creating unique opportunities to reduce complexity, enable trustless collaboration, and create secure and immutable information. In the long term, a nationwide blockchain network for electronic medical records may improve efficiencies and support better health outcomes for patients.

Micropayments

Micropayments - or micro-transactions - are a popular business structure for spreading posted content and providing access to it for a small amount of money. These technologies may be transferred to the healthcare sector for underpinning small transactions involving basic services. For that purpose, micropayments in cryptocurrency might be very promising. Blockchain could work as a large, decentralized audit book in which every transaction can be recorded carefully so that the user can keep track of all viewed pages, the duration of viewing and the amount of micropayments for a given service.

Technologies from self-driving cars

Technologies originally applied and developed for self-driving car might be profitably transferred and used in the healthcare sector. These technologies include path planning, car control, car navigation, and environment perception. In particular, AI applications might be transferred from self-driving cars, robotics and video analytics to the more sophisticated neural networks for healthcare and medical applications—from real-time medical condition assessment to point-of-care interventions to predictive analytics for clinical decision-making.

Automated Transport Systems (drones, autonomous ambulance)

Automated Transport Systems (including autonomous guided vehicles) are used in healthcare organisations to efficiently manage medications and material transport to improve workflow, streamline costs and enhance the patient experience.

In particular, drones are unmanned vehicles that are already used for delivering medicine, blood and even organs to rural communities and remote areas around the world.

Similarly, autonomous ambulance can improve outcomes during medical emergencies. Self-driving ambulances can improve care by allowing both paramedics to help a patient rather than having one required to drive. Alternatively the second paramedic could be redeployed to absorb growing demand, improve performance, or to new models of care. Ambulances already have the ability to change traffic signals in many countries, and using this in combination with route optimisation and the reduction of human error can significantly decrease the time for patients to reach emergency rooms.

New touch interfaces and displays

New touch interface technologies include touch screens, haptics, 3D touch. In particular, OLED (organic light-emitting diode) displays can be twisted, bent or folded to interact with the computing system within. Such flexible user interfaces enable users to naturally interact with smart devices even in the case of gloved fingers or when fingers are too big to reach the right buttons.

Human augmentation

In recent years there has been significant advancement in sensory and mobility aids to help people with disabilities live fuller lives. Currently there is a shift towards using human augmentation for enhancing human abilities, e.g., using optical aids to gain 'hawk eye' vision and exoskeletons to increase human strength. These fields might gain traction and expand beyond sensory and mobility aids – for example, combating cognitive impairment, enhancing metabolic rates.

Human augmentation technologies set foundations for a potential future where we could see cybernetic features worn as an aesthetic accessory and increased capabilities of users without underlying medical problems. Critical technologies for human augmentation include brain computer interface, telescopic or microscopic vision, hearing enhancement, and implantable (i.e., medical devices manufactured to replace a missing biological structure, support a damaged biological structure, or enhance an existing biological structure).