This first joint position paper of Belgiums' two general academies KVAB and ARB makes a call for an accelerated digital transformation in Belgium. Indeed there are in Belgium several good initiatives by the regional and federal government and the societal actors, but there is room for a shift to a higher speed in 5 directions.

-The digital transition will only succeed in our country if the efforts for increased digital literacy with better digital skills and more insight in the digital world are accelerated for young and old. Collective actions and an awareness programme should be organised with media campaigns in order to stimulate the safe, responsible, ethical and sustainable use of all digital and ICT devices and services.

-Digital tools should constitute an integral part of education in all subjects and should facilitate more flexible learning processes that are close to the needs of the individual pupils or students.

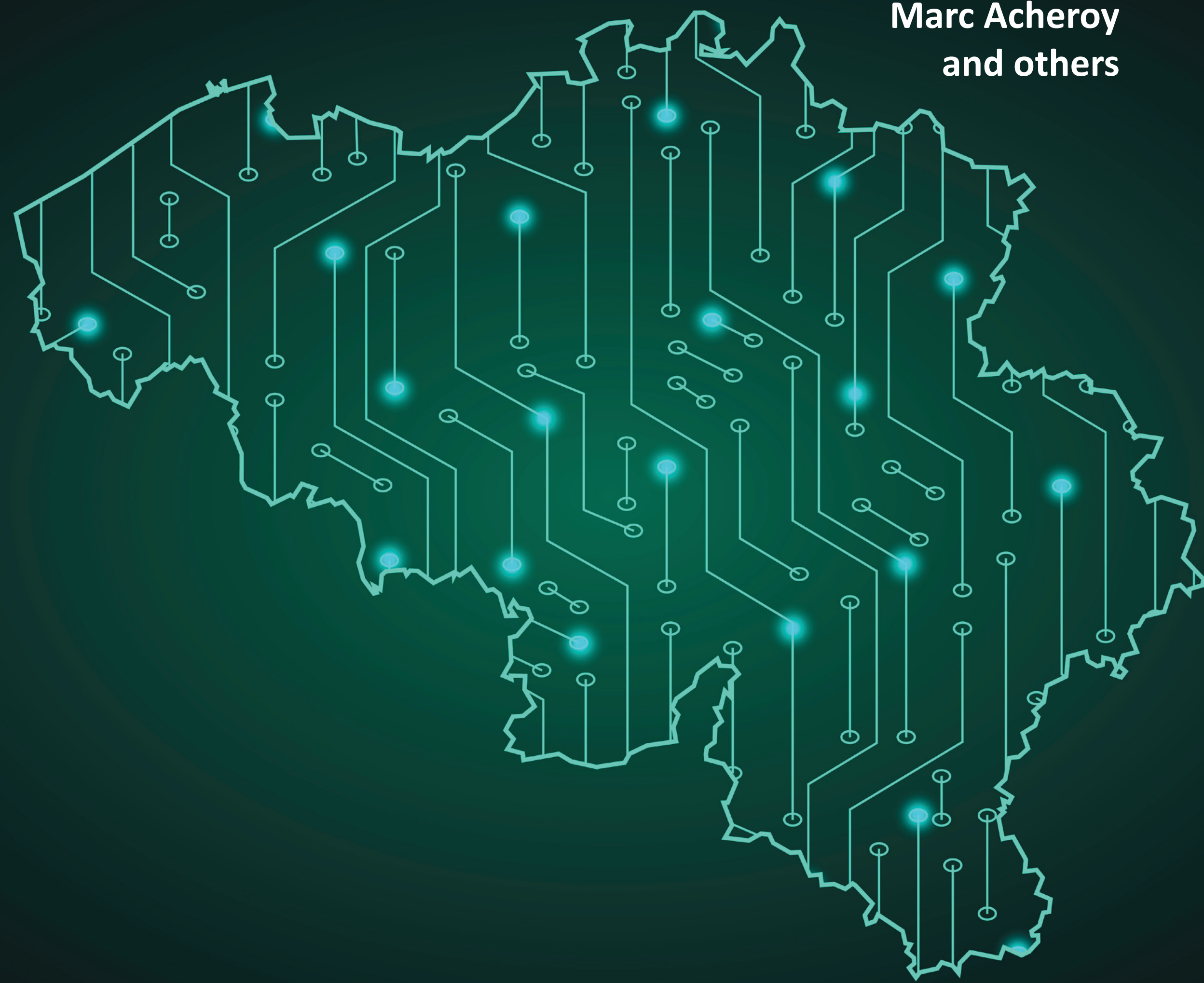
-Influential mass and social media have an important role to play in avoiding unjustified projections of digital transitions.

-In view of the growing needs in the labor market attracting more high school students to ICT studies as well as stimulating many professionals for lifelong learning (LLL) in ICT is crucial, bearing in mind that Belgium is lagging behind in LLL.

-In view of the growing need of electric energy for ICT, there should be a greater focus on a comprehensive strategy concerning energy consumption and the environmental impact of the digital transition.

A CALL FOR AN ACCELERATED DIGITAL TRANSFORMATION FOR BELGIUM

Joos Vandewalle
Marc Acheroy
and others



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A CALL FOR AN ACCELERATED DIGITAL TRANSFORMATION FOR BELGIUM

KVAB Press

ARB

KVAB POSITION PAPERS
77

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A CALL FOR AN ACCELERATED DIGITAL TRANSFORMATION FOR BELGIUM

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A call for an accelerated digital transformation for Belgium

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Guidance for the reader

This is quite an extensive position paper on an important societal process. Hence it is the intention of the Academies to make the document readable and useful for a large and diverse audience in Belgium. The expert reader and policy maker with limited time can jump to the last two sections with conclusions and recommendations and, additionally, they can read the appropriate sections using the table of contents. For the younger generations and teachers of secondary school or higher education and for the wider audience, a linear reading or a direct jump to the appropriate sections will expose them to the full content. For journalists, science communicators and opinion makers interested in misunderstandings or unjustified statements, a reading of 'the ingredients and limitations and the competing or complementary roles of human and machine' is advised. Social scientists and policy makers should also read the section on the impact of digital transformation on skills, education, research and jobs of the future as well as the societal challenges. Finally, specialists in different sectors can read the appropriate cases in Section 8.

Executive Summary

This is the first joint position paper by the two Belgian Academies ARB and KVAB. Hence it mainly addresses the Belgian components of an important process, namely the digital transition that is disrupting many societal mechanisms worldwide. It is still ongoing and is quite comprehensive and has been accelerated by the COVID-19 pandemic. It brings various opportunities for solving many of the challenges the next generation may face, as well as providing sustainable development goals, but there are many choices and design decisions that should be made in a synergetic interaction between ICT specialists, engineers, social scientists, and policy makers to avoid any misuse. Hence, it merits special attention from all Belgian stakeholders and educators.

A good understanding of this transition requests a deeper insight into the crucial ingredients that are underlying digitalisation, but that are often hidden or unknown to the public. First of all, we discuss chips that are the engine of digitalisation whether in a computer, a laptop, a tablet or a smartphone, and software which is essential for delivering good services on these devices; while underlying the software, the computers and the ICT networks, there are algorithms, artificial intelligence and machine learning systems, data security and cryptography, data fusion, and digital agents. A good insight into these ingredients and the opportunities and limitations of digital transformation can lead to a responsible use of digital instruments and services and can prevent unnecessary fear.

Along these lines we discuss the complementary role for humans and machines, and the impact of digital transformation on skills, education, research and future jobs. Next, we present the important societal challenges of digital transformation and important valuable actions at the EU, Belgian and regional level. This is followed by a section showcasing a number of case studies describing the impact of digitalisation on various sectors and services.

The future value of digitalisation for a society can only be realised by powering innovation and data across all disciplines. Idealistically, disruptive innovation must lead to a better personal experience and outcome for each individual and a lower cost for society. To realise this value, data must be connected, combined and shared in a safe, secure and sustainable infrastructure.

There are important recommendations for the relevant stakeholders, politicians and the general public in our country.

- The digital transition will only succeed in our country if the efforts for increased digital literacy with better digital skills and more insight in the digital world are accelerated for young and old.
- Digital tools should constitute an integral part of education in all subjects and should facilitate more flexible learning processes that are close to the needs

of the individual pupils or students. Moreover, the need for professionals in ICT is expected to grow and the motivation and appeal of such professional schooling should be addressed.
- Collective actions and an awareness programme should be organised with media campaigns in order to stimulate the safe, responsible, ethical and sustainable use of all digital and ICT devices and services.
- Influential mass and social media have an important role to play in avoiding unjustified projections of digital transition. Fake news and some science fiction movies often present an unrealistic world where superhumans or AI can enslave the masses. Rather, regulatory and technological instruments, that keep the individual in control, are already in place and should be broadcasted.
- Bearing in mind that Belgium is lagging behind in lifelong learning, we can see that the digital transition will bring about a labour shortage as it depends critically on the availability of skilled workers in the digital field.
- There should be a greater focus on a comprehensive strategy concerning energy consumption and the environmental impact of the digital transition.

There are also some specific recommendations related to the pandemic crisis.
- The leaders of the country, the regions and organisations should seize on the pandemic crisis to courageously bring forward bold and profound measures, like regaining efficiency in regulations and responsibilities, working from home, having online meetings and teaching online.
- During the crisis, a number of implicit and explicit behaviours were not permitted that were often based on unmentioned assumptions. After the crisis there is an opportunity to eliminate unnecessary rules and historical privileges.
- In the text, several examples are given on how we can learn from the failures that occurred during the pandemic, and how digital transition can contribute to solutions and remedies.

Résumé

Il s’agit de la première prise de position commune des deux académies belges ARB et KVAB. Elle aborde principalement les aspects belges d’un processus important, à savoir la transition numérique qui bouleverse de nombreux mécanismes sociétaux dans le monde. Elle est toujours en cours, très vaste et a été accélérée par la pandémie COVID-19. Elle offre diverses possibilités de résoudre bon nombre des défis auxquels la prochaine génération pourrait être confrontée et elle impacte plusieurs des objectifs de développement durable. De nombreux choix et décisions de conception devront être faits en synergie entre les spécialistes des technologies de l’information et la communication (TIC), les ingénieurs, les spécialistes des sciences sociales et les décideurs politiques afin d’éviter toute utilisation abusive. Par conséquent, elle mérite une attention particulière de la part de toutes les parties prenantes et en particulier de tous les éducateurs belges.

Une bonne perception de cette transition nécessite une compréhension plus approfondie des ingrédients cruciaux qui sous-tendent la numérisation, mais qui sont souvent cachés ou inconnus du public. Tout d’abord, nous discutons des puces qui sont le moteur de la numérisation, que ce soit dans un ordinateur, un portable, une tablette ou un smartphone, ainsi que des logiciels essentiels pour le bon fonctionnement de ces appareils. Sousjacents aux logiciels, aux ordinateurs et aux réseaux TIC, il y a des algorithmes, des systèmes d’intelligence artificielle, d’apprentissage automatique et des agents numériques, des exigences de sécurité des données et de la cryptographie, de la fusion de données. Une bonne connaissance de ces ingrédients et des opportunités et limites de la transformation numérique peut conduire à une utilisation responsable des instruments et services numériques et éviter des craintes inutiles.

Dans ce sens, nous discutons du rôle complémentaire des humains et des machines, et de l’impact de la transformation numérique sur les compétences, l’éducation, la recherche et les emplois futurs. Ensuite, nous présentons les défis sociétaux importants de la transformation numérique et d’importantes actions utiles aux niveaux européen, belge et régional. Suit une section présentant plusieurs études de cas qui décrivent l’impact de la numérisation sur divers secteurs et services.

La valeur future de la numérisation pour une société ne peut être réalisée qu’en alimentant l’innovation et l’utilisation des données dans toutes les disciplines. Idéalement, les innovations disruptives engendrées doivent conduire à faciliter la vie de chaque individu et à un coût moindre pour la société. Pour réaliser ces attentes, les données doivent être connectées, combinées et partagées dans une infrastructure sûre, sécurisée et durable.

Des recommandations importantes sont formulées pour les parties prenantes concernées, les décideurs politiques et le grand public de notre pays :

- La transition numérique ne réussira dans notre pays que si l'on accélère les efforts visant à accroître la culture numérique pour les jeunes et les moins jeunes, ce qui nécessite de développer les compétences dans ce domaine et une meilleure compréhension du monde numérique.
- Les outils numériques devraient faire partie intégrante de l'éducation dans toutes les matières et devraient faciliter des possibilités d'apprentissage plus flexibles et proches des besoins individuels des élèves ou des étudiants. En outre, le besoin de professionnels des TIC devrait augmenter et la motivation et l'attrait d'une telle formation professionnelle devraient être pris en compte.
- Des actions collectives et un programme de sensibilisation devraient être organisés avec des campagnes médiatiques pour stimuler l'utilisation sûre, responsable, éthique et durable de tous les appareils et services numériques.
- Les médias de masse et les médias sociaux influents ont un rôle important à jouer pour éviter les visions injustifiées des transitions numériques. Les infox (« fake news ») et certains films de science-fiction présentent souvent un monde irréaliste où les surhumains ou l'intelligence artificielle (IA) peuvent asservir les masses. Au contraire, des instruments réglementaires et technologiques, qui maintiennent le contrôle par l'individu, sont déjà en place et devraient être diffusés.
- Compte tenu du retard pris par la Belgique en matière d'apprentissage tout au long de la vie (« lifelong learning »), nous devons constater que la transition numérique entraînera une pénurie de main-d'œuvre, car elle dépend de manière critique de la disponibilité de travailleurs qualifiés dans le domaine numérique.
- Il convient aussi de mettre davantage l'accent sur une stratégie globale concernant la consommation d'énergie et l'impact environnemental de la transition numérique.

Certaines recommandations spécifiques sont liées à la crise pandémique :

- Les dirigeants du pays, des régions et des organisations devraient profiter de la crise pandémique pour proposer courageusement des mesures audacieuses et profondes, concernant l'efficience des réglementations et des responsabilités, le travail à domicile, les réunions et l'enseignement en ligne.
- Pendant la crise, plusieurs comportements implicites et explicites souvent fondés sur des hypothèses non mentionnées n'ont pas été autorisés. Après la crise, il est possible d'éliminer les règles inutiles et les privilèges historiques.
- Dans le texte, plusieurs exemples sont donnés sur la façon dont nous pouvons apprendre des échecs qui se sont produits pendant la pandémie, et comment la transition numérique peut contribuer à des solutions et des remèdes.

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Foreword

The Standpunten series

The Academy’s Standpunten (Position Papers) series contributes to a scientifically validated debate on current social and artistic topics. The authors, members and workgroups of the Academy write under their own name, independently and with complete intellectual freedom. The approval for publication by one or more Classes of the Academy is an assurance of quality. This Position Paper was accepted by the KTW class of Technical Sciences of KVAB on 14 September 2021 and by the CTS class of Technology and Society of ARB on 4 December 2021.

1. Statement of purpose

As the first position paper produced by the Belgian Academies ARB and KVAB we will first present its purpose and plans. It is an evidence-based consensus effort by a committee of experts who are its authors. Such reports typically include findings, conclusions, and recommendations based on information gathered by the committee and based on the committee's deliberations. It is not directed at providing comments regarding day-to-day policy decisions, nor is it meant to speculate about scenarios that might be projected more than 15 or 20 years into the future.

However, since problems have effects that are not immediately visible, it is important to consider consequences of choices and policies in a foreseeable period of maybe 10 years from now. Moreover, the goal is to consider comprehensive approaches that look at the whole system, rather than addressing individual parts that may neglect the impact on other parts.

Thus, this position paper tries to provide a scientific basis for an approach with scenarios, challenges, deeper causes, illustrative cases, critical issues, and recommendations for action. Indeed, many of the problems and issues need action in the near future and cannot be postponed by exhaustively long debates. It is a philosopher's role to debate, and to extend the debate by feeding it with new elements, while an engineer prefers to come to a comprehensive understanding within a context or situation, including its material constraints and consequences, so as to lead to action and impact within a short period of time.

Indeed, the authors of this position paper have contributed as scientists and experts without any prejudices, biases or conflicts of interest. They are autonomous, without links to politics or action groups. In the event that there may be a perception of a conflict of interest, it will be declared in advance. In most cases, the statements presented are the result of a consensus. However, if there is no consensus on an item, it will be presented with the pros and cons of each alternative view. Moreover, the findings are based on facts and evidence, and whenever there is some uncertainty on the findings, it will be declared. Thus, this position paper is not the result of a specific research project of the Academies, but of consensus building and debate about alternate views among experts with long-standing experience. Indeed, the quality of the position paper is further enhanced by comments, reviews and endorsement from the two classes of technical sciences, i.e. the KTW of KVAB and CTS of ARB.

2. General introduction

This is the first of two position papers dealing with the role of socially responsible technology in an accelerated transition to a post-COVID digitalised society flourishing in a sustainable world. The central themes are climate change, efficient energy use and decarbonation of the energy system, sustainable material use, personalised health care, data-processing services and the future of work and industry; all of these with respect to the human and individual condition.

Indeed, our human society lives and thrives in a shallow layer of a few kilometres around the globe with its limited resources in terms of materials and energy. In the post-COVID period, it would be wise to use the momentum gained by learning from our recent experiences, and avoid a return to sterile debates, or to the previous energy and climate situation that was leading humanity into serious problems. The recent flooding in our country, and many other extreme weather conditions around the world, just make this all the more urgent.

An important development during the pandemic was the accelerated digitalisation that became available to us for many important activities such as education, care, work, entertainment, and communication in general. This brings us to a triangle of resources that are central to this position paper: namely energy, matter and digital data. From an engineering standpoint, these three resources are closely connected.

When we collectively communicate, using the Internet or search engines, we make use of services that consume considerable amounts of energy. And when we move around in cars, trains or planes, we not only use energy but over the lifetime of these vehicles we consume valuable materials within them, as well as in the transportation infrastructure. Smart electricity grids can facilitate the transition of this very complex system into one that achieves greenhouse gas neutrality by optimising electricity consumption, production and storage, while smart supply chains can help save and recycle valuable materials, as well as save energy, and reduce our environmental impact.

Our energy and material resources are limited, unless we succeed in harnessing deep Earth or space technologies, which is not for tomorrow. On the other hand, the amount of digital data that has been harvested is still growing signficantly, and extracting knowledge or wisdom from it requires a substantial amount of energy and intellectual effort. Technology has an ever-growing impact on our daily life and the pandemic situation has made this dramatically clear. Hence, it plays an important role with regard to the sustainable development goals of the United Nations. Technology should be a force for good, and a contributor to society.

The theory of technological mediation offers a framework in which to consider the roles that technologies play in human existence and in society. Its central idea is that technologies help to shape the relationship between human beings and the world. This is different from the traditional viewpoint that it is the role of technology to deliver passive products and services to human beings, or to merely act as their extensions. Mediation theory is rooted in the 'post-phenomenological' approach in the philosophy of technology, which was founded by Don Ihde and advocated by Peter-Paul Verbeek[1]. Mediation theory can guide the practice of engineering design and social choice, because it enables designers to analyse, anticipate, and experiment with the relationships between humans and products, and with the impact of different technologies on human experiences and behaviour, and on their social practises.

To get the pandemic under control, public authorities of the EU, the state and the regions have succeeded in mobilising an enormous number of resources in record time, while it has – so far – been impossible to make a comparable financial effort to tackle climate change or to make innovations in health care affordable and accessible worldwide. Yet the threats of climate change and the increase in existing inequalities require more attention, though their urgency is perceived to be less significant because of their subtler visibility and different time scale. Faced with such a situation, which is critical both for today and the future, the Academies cannot remain passive. Their role in preserving and promoting scientific knowledge, contributing to the progress, prosperity and well-being of the society to which they belong makes them important players in this difficult period in which the population and those in power need informed and evidence-based position which are independent of individual, narrowly parochial, political or economic interest.

From the outset, this approach has been supported by the European academic associations, of which our Academies are members and our intention is to cover all areas of interest. We also work in close collaboration with the Academies of Medicine.

As an example, the European Academies Science Advisory Council (EASAC) has published a complete position paper[2], with our approval, emphasising the need to base all actions and decisions on scientific knowledge, and it underlines the absolute necessity of achieving economic recovery and the urgency of addressing health inequalities and climate changes.

1 https://ppverbeek.org/mediation-theory/
2 https://easac.eu/fileadmin/PDF_s/Covid-19/EASAC_Covid19Recovery_Web_29_May.pdf

The European Recovery Plan, based on the Green Deal, must be the guiding benchmark[3]. Only coherent and ambitious measures at the level of the EU and its leadership can achieve the necessary goals, not only for the EU itself but also on a world scale. Many of the recommendations of the IPCC (GIEC) on climate change and the 17 UN Sustainable Development Goals give specific goals.

Indeed, the challenges we face are so vast and complex that all sciences, the humanities, the social and the exact sciences, must do their part in diagnosing problems, defining goals and identifying solutions. Even though the diagnoses and objectives are already relatively clear and are being refined, the practical implementation of the solutions poses a particularly significant challenge where existing and emerging technologies must play a major role. The difficult choice of technologies and the scenarios for their implementation must be made in a strictly scientific manner without any ideological considerations. This is precisely what the joint working group focuses most of its approach on. The working group has the support of the European Council of Applied Science and Engineering (Euro-CASE), which has put together a position paper[4] on this topic that is fully consistent with the proposed approach.

Euro-CASE has played an important role in the past and has continued to do so in the Scientific Advisory Mechanism (SAM) for the European Commission. We mention in particular the actions and recommendations of Euro-CASE on two very important issues: the transition to carbon-free energy and the digital society. The energy transition is probably the most complex global problem that needs to be solved in the time available to achieve the goals that have been set. Apart from the sheer technological complexity, the need to finance the energy transition, and the ability to implement technologies, nothing can happen if one cannot count on the support of the public at large to make difficult decisions that will profoundly affect our way of life. If one does not include the social and cultural consequences of our objectives and policies, and if social equity, solidarity and the values to which the population is attached are not taken care of, any highly needed decision will inevitably be doomed to failure. The role of the Academies, with their many multidisciplinary and interdisciplinary ramifications, which extend well beyond the exact sciences and technologies, is all the more important.

In terms of the two main challenges identified, Belgium is still far from being the best student in the class of the EU. Despite its relatively modest size, however,

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[3] Session keynote of U. von der Leyen at the US National Academy of Medicine 50th anniversary, Oct 19 2020. *Responding to global crises: Future directions in science and policymaking to address complex threats to society*. https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_20_1952

[4] https://www.euro-case.org/wp-content/uploads/Eurocase/PDF/covid19/EuroCASE_Position-Paper-Economy-Recovery-09102020.pdf

the quality and quantity of skills available to Belgium, and its tradition of social cohesion, should enable our country to position itself among the reference countries, both in these areas and in all others.

Our two Academies are joining forces and are available to our society in order to contribute to the achievement of the objectives set in the framework of the European Green Deal. But they cannot do this on their own. Strengthened by their links with the scientific, cultural, economic, industrial and political spheres, they solemnly appeal to the Public Authorities, to all actors of the civil society and in particular to business and industry associations from all areas, to rise to the challenge by resolutely embarking on the road to sustainable development, despite all the difficulties that may lie ahead.

3. The Context of the digital transformation

Human civilisations have produced several innovations in the communication mechanisms that have had a strong impact on the organisation of society and the life of its individuals. The invention of '*writing*', generally attributed to the Sumerians around 3200 BC, permitted humans to transmit messages that are not simultaneous and in direct physical contact with the speaker, thereby transmitting messages over generations and geographic distances. The invention of the '*printing press*' by Johannes Gutenberg in the 15th century enabled the mass production of books and the rapid dissemination of knowledge throughout Europe. The '*digital transformation*' that we are witnessing now, permits the combination of most types of human communication like speech, text, images, video, sound, music, film, and also metadata (the data about data like location, time, duration, channel, sender, receiver, Internet Protocol IP address, etc.) into the same format of bits (i.e. the units of digital information, 0 or 1). Moreover, these bits can be transmitted over superfast networks around the world and processed in even more powerful computers and various handheld devices like smartphones and tablets. In general, computers offer continuous digital services, transmit data over the Internet and provide access to massive amounts of data and information. Sensors and cameras can record and transmit all important variables. Not only can humans be connected by the Internet, but equipment, (household) devices, sensors and vehicles can also be connected by the Internet of Things (IoT). So, the amount of data is growing exponentially, with a current estimate of 74 zettabytes, i.e. a number of bytes formed by 74 followed by 21 zeros, and a byte is 8 bits. This data set is often called 'big data' because of the three Vs: volume, velocity, and variety. Valuable user experiences on computers and smartphones from this data require considerable efforts in software development. This software is built with methods from the digital era: algorithms, machine learning, artificial intelligence, and software engineering. Every aspect of our lives and our society is affected by this digital transformation: industrial activity, labour conditions, education in all its forms from kindergarten to permanent education, healthcare, shopping, logistics, family and friendship relations, leisure, travel, government, the organisation of a city, legislation, law enforcement, etc.

Technology facilitates access to information and decision-making, and in that way makes many of our actions more efficient. The ease with which technologies and services enter our daily lives, however, may obfuscate the many problems or implicit choices they bring. With such a deep impact on society, it is clear that the design of services, devices and instruments should be done with good interaction with society by involving citizens. That should start rather early in the conception of these services. This has been recognised in a number of reports by many organisations in recent years. Let us mention here two that have been active in our country. Firstly, the Friday Group of creative young Belgian professionals (aged 25-35) who published a report[5], in 2019, that centres around the following questions: 'In which digital society do we want to live? What are the goals and which collective project do these serve? What are the priorities, conditions, and limits?' It advocates a deliberate and responsible choice away from blind fascination and irrational fear of digital technology. The second report was produced by the KVAB Academy in its Thinkers Programme in 2019: "Societal values in digital innovation: who, what and how?". Three complementary international experts; Jan Rabaey, Peter-Paul Verbeek and Rinie van Est, each with their own extensive experience in engineering design, technology ethics and assessment within the Netherlands, Silicon Valley and international organisations, debated with Flemish stakeholders and formed their independent assessment and guidance for good practices[6]. In a similar spirit, Wallonia's digital strategy strives to be ambitious, innovative and inclusive. Digital Wallonia is a comprehensive project designed to transform the region, the economy and society to boost its appeal, its competitiveness and the wellbeing of all, based on values including a cross-disciplinary approach, transparency, coherence, openness and flexibility[7].

Since these reports were published, the pandemic has struck. It started in March 2020 and forced strict distancing rules for many sectors of our daily lives. Fortunately, digitalisation succeeded in avoiding a complete standstill by introducing online teaching, teleworking, online meetings and conferences, and online leisure activities. In other words, COVID-19 has accelerated a forced digital transformation, and in many sectors. However, many limitations and constraints on forced digitalisation have become apparent. These are reasons enough for a debate and concerted action plan for a digital transformation that is respectful to our society as a whole as well as to individuals, young and old, in order to tackle the upcoming challenges.

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5 The Friday Group, 'The Digital Era: Time for a Debate' 2019 and https://www.alternumeris.org/nl/home-main-nl/

6 Jan Rabaey, Peter-Paul Verbeek, Rinie van Est and Joos Vandewalle "Societal values in digital innovation: who, what and how?", KVAB position paper 2020.

7 https://www.digitalwallonia.be/en/posts/digital-wallonia-2019-2024

4. Key ingredients and limitations

Digitalisation is like a jigsaw puzzle where many pieces come together in order to bring value to its users and to society. Therefore, a deeper understanding of the key ingredients of digitalisation is essential in order to grasp its possibilities, limitations, impact on energy and material resources, and in order to avoid unjustified fear and blind fascination. It is also important to see where these ingredients have advanced in the process from research to innovation and broad utilisation.

4.1 Chips

The central workhorses of digitalisation are the small physical silicon devices, called '*chips*' or *integrated circuits ICs*. They are quite small and usually hidden from the user, but are essential and ubiquitous in all kinds of devices like computers, smartphones, smart sensors, smart TVs, vehicles, Internet of Things, routers, supercomputers, and in digital data storage devices. The basic operations they perform on bits are very simple logic operations like 'AND', 'OR' and 'NOT'. In doing so they consume tiny amounts of energy, and hence dissipate heat. Progress in silicon technology, measured in the number of transistors per chip, has doubled every 18 months over the past 50 years, as expressed in Moore's law. The current state-of-the-art high performance chip contains about 16 billion transistors, works at a clock rate of around 4 GHz and consumes around 60 to 100W of electric power. It is impressive if one realises that such a layout has to be 'written' and printed on a wafer-thin piece of silicon. This process requires extremely high precision in the positioning of the transistors on the chip with interconnections a few nanometres wide. The Dutch company ASML is the world's leading manufacturer of chip-making machines at a nanometre level, while the Flemish research centre, imec, is world renowned in nano-electronics. However, the mass production of chips is currently concentrated in only a few companies mostly located in Taiwan, Korea and Silicon Valley. The designing of chips is a central theme for many Belgian companies, spin-offs and research groups, and involves not only computing devices but also many smart sensors, components for telecommunication, electric cars, smart energy systems and medical and health care devices. The analogue interface circuits deal with communication over the air, wireline or optical cables. They allow wireless transmission of huge amounts of digital data, via internet or optical cables entering homes. In order to keep up with the ever-increasing number of transistors, increasing data volumes and faster communication requirements, careful interface circuits and power management circuits would certainly be a key part in these digitalisation efforts.

4.2 Software

The second crucial ingredient is '*software*' because without software most chips and processors can only perform very basic operations and would therefore be useless. So, a whole software industry has grown over the past 50 years that designs and distributes software products, app's and services to the user. This software industry is less concentrated geographically and more mobile than chip technology. Software and computer programs are also digital in nature and can be directly communicated between computers without any human intervention. Consequently, software can be transmitted via the Internet, and copied indefinitely. In order for users to trust the software, a crucial element would be that it performs the task correctly and precisely and does not deviate from its initial goal. This brings us to a similar situation in the biological world where humans and animals are built with a hierarchy of DNA, cells, organs and a body and are vulnerable to viruses and bacteria. So, inside the software there may be unwanted pieces of hidden code that are malicious like viruses, worms, or Trojan horses. This calls for maximal transparency of software and open source. There is a momentum towards this open software that definitely merits more support.

4.3 Algorithms

A third crucial ingredient is the *'algorithm'*. This is a recipe, a finite sequence of well-defined computer-implementable instructions for solving a class of specific problems or performing a computation. Software development and software engineering depend strongly on the design of high-performance algorithms. Over the years, civilisations have built a body of mathematics that is an ever-growing tree of mathematical wisdom. This tree contains basic calculations, theorems, properties, and logic that are widely used by the general public, craftsmen, and in education. It is also a foundation and language for many sciences as well as engineering. Computer software also needs powerful algorithms in order to deal efficiently and effectively with data and to design useful services. Many ICT breakthroughs are based on high-performance algorithms but with the popular and inspiring books by the historian Yuval Harari and the use of artificial intelligence, the word 'algorithm' is now surrounded by several misconceptions in popular literature. Algorithms and the entire tree of mathematics cannot and will not take over our world or have inherent biases. They are just confirmed results of human intelligence and provide a rich source for designing applications.

4.4 Artificial Intelligence and machine learning

A fourth ingredient that has recently received worldwide attention in companies and the government and even in the popular press, is '*artificial intelligence*'. In studies on human intelligence, this concept is often split up into reasoning (fluid intelligence) and acquired knowledge (crystallised intelligence). While human intelligence is often seen as a combination of problem-solving skills, deductive reasoning skills, social conscience and the ability to give advice or show wisdom, artificial intelligence is the artificial counterpart of computers and software that can perform some of these tasks. In other words,[8] artificial intelligence (AI) is a scientific and engineering discipline that seeks to find methods and technologies to build systems that perform functions like the human brain; for example, sensory perception, pattern recognition, planning and control of complex systems, production and processing of language, learning regularities, making predictions, structuring knowledge, etc. AI does not necessarily need to realistically mimic human intelligence or simulate the operation of the human brain, though, in some cases, it is neuro-inspired, e.g. computational networks of vision. It tries to solve problems that require some form of intelligence, in the perception of humans. One can distinguish[8] two rather different types of artificial intelligence: the knowledge-based and the data-based approach. The knowledge-based approach tries to represent, as accurately as possible, the human expert by observing and conversing with them, and it then converts these representations into rules and search strategies that can be implemented into the software so that it approximates the expert's behaviour. This approach is still mainly in the research phase, i.e. a phase of reflection, exploration, and experimentation; however, it is very promising and has the advantage of giving a clear explanation for the decision that it makes. The data-based approach, also called machine learning, uses observed or collected expert input-output data for each individual problem in order to optimise a system of software or hardware during a training phase, to approximate the desired input-output behaviour of the expert. Unseen expert input-output data can then be used to test the system. When the test results reach approximately the same accuracy as that of the training data, one can say that the system is generalising, and so can reliably use the system in practice. This generalisation capacity is often considered as human intelligence, or something magical, but for machine learning this is purely the result of mathematics. Moreover, the quality of the performance depends strongly on the quality of the expert input-output data. Many of the machine learning systems use an artificial neural network (ANN) as an input-output map. These ANNs are just mathematical constructions that roughly mimic the human brain. They consist of several layers of neurons, where each neuron is connected with weights to the neurons of the previous layer. So, an artificial neuron is just a mathematical formula, and an ANN is just a network of interconnected neurons; so there is nothing magical about neurons or ANNs. Moreover, it is not an accurate representation of the mechanism of the neurons in the brain. Many of the recent record achievements for object recognition and face recognition in images and many other tasks have been obtained with Deep Neural Networks (DNN). These DNN are ANNs that consist of a very large number of layers, some of which have a special structure and form a representation with features of the inputs.

[8] L. Steels, "Artificiële intelligentie, Naar een vierde industriële revolutie?, KVAB Standpunt 53, 2017.

Although this has created an unrealistic euphoria as well as a fear for loss of human control, there is a growing consensus that AI in general and machine learning especially is of the utmost importance for the economy of the future and can contribute to a better functioning society with new or better products, improved production processes, better administrative procedures and improved access to massive amounts of digital data and information. An important inconvenience of the machine learning methods is that they are black boxes, in the sense that they do not provide an explanation for their decisions. Another important drawback is that these methods create enormous expectations of an individual’s best option for a problem, while this may still be too complex for the method. The value of the solution will heavily depend on the variety and richness of the data the model has been trained with and does not automatically justify it because there might be inherent data biases.

4.5 Data security and cryptography

The intense use of digital services and communications and the many security incidents have rendered this ingredient very important. It is well known that ‘secret writing’ has been prominently present in the realm of governance, diplomacy, and the military since the early ages of writing and history is full of fantastic stories about the use of cryptography and code-breaking such as the Enigma during the Second World War. The use of cryptography by the public has, however, gained serious momentum and is in wide use in the digital transition. Clearly, diplomacy and military methods of keeping the algorithm as well as the key secret are not compatible with full transparency and the need for standardisation and public availability of the algorithm. The security of the algorithm should come solely from the secret key (Kerckhoffs’s principle). It is estimated that more than 50% of all data worldwide use the Advanced Encryption Standard, AES,[9] designed by two young Belgian cryptographers in 1999. This algorithm is implemented in many applications like social media such as WhatsApp and many online banking systems and online services. It has to be mentioned here that the security of practical cryptographic algorithms like AES and all other practical algorithms cannot be mathematically proven. Hence the users have to live with the fact that progress in public mathematical research uncovers new weaknesses in some of these cryptographic schemes. An even more serious situation is that unreliable designers usually build a hidden trapdoor in their algorithm, so that they can break in for criminal purposes. So, it is crucial that the algorithms are made public and are subject to public scrutiny. In this way the public can have trust in them and are quickly informed when a weakness is discovered. In fact, this public evaluation of cryptographic algorithms is very important since many of the newly designed algorithms are broken by competing researchers. One can state, though, that since the 1980’s there has been a steady global progress of open cryptographic

9 https://en.wikipedia.org/wiki/Advanced_Encryption_Standard

research that has produced many interesting results like public key cryptography, RSA, zero-knowledge protocols, digital signatures, secure protocols such as the SSL certificate, digital currencies like bitcoin, blockchain and online voting.

4.6 Global view of data and data fusion

An important ingredient in this digital transformation is the global and systemic view of data and its processing. Large companies and governments have been setting up data centres and have provided cloud services, and national health care systems have been bringing together data from different platforms while universities and research centres have been networking their platforms of reports and publications, often in open access. In this way a process of '*data fusion*' has been obtained whereby the whole system can be monitored and analysed, in order to improve system reliability, decision making, output quality, robustness, etc. Data fusion is part of Big Data. It is a process of integrating multiple data sources to produce more consistent, accurate, and useful information than that provided by any individual data source.

Overall, such systems have many analogies in the physical and human world. The human beings, for instance, have a multi-sensor system allowing them to drive a car. Vision (frontal, lateral, back mirror), hearing (brake, horn, blinking, engine noise), touch (pedals, steering wheel), balancing capacity (acceleration, turn), reflexes (urgent stopping), knowledge (driving rules, journey, maps, relationships vision-sound-touch-balance, weather conditions, other users, …), objectives (moving the car from one place to another) and constraints (security, speed limit, time limit, energy limit) all produce data and information they can use and fuse to perform their driving activity.

Many applications, which are often part of the Green Deal, can benefit from data fusion: medical diagnoses, remote sensing, traffic statuses, disaster relief operations, intelligent transport systems, climate change, resilience building, prevention and preparedness, digitalisation of the European energy market, distance monitoring of air and water pollution, intelligent analysis of Big Data, ocean surveillance, wireless sensor networks, soil mapping (qualifying soil types and properties), intelligence (strategic warning and defence – battlefield intelligence – surveillance and target acquisition), monitoring of equipment and robotics.

4.7 Digital agents and multi-agent systems

Other important elements are *digital agents* and *multi-agent systems*. Software and technological systems have exhibited an ever-increasing complexity. Systems can be simple (a bicycle), complicated (a car), complex (a manufacturing plant or a hospital). The behaviour of simple and complicated systems can be inferred from the constituting components (agents) and their interactions with each other and with the environment, but this is no longer true in complex systems. The behaviour of complex systems cannot be predicted from the knowledge of their components only, but also from the way these components interact. Complex systems can show so-called *emergent behaviour* where complex adaptive systems even go one step further than their component and their behaviour changes over time. They can show *self-organising behaviour*.

The components of complex systems are commonly called *agents* in software systems, or *holons* in technological systems where hardware is involved. Agents or holons are flexible, autonomous entities, connected to their neighbours and to the environment through sensors and actuators, and working together to achieve a global system goal. Examples of agents are: a machine tool in a manufacturing plant, a patient in a hospital, a solar array in a smart residential energy system. *Multi-agent systems* or holarchies are hierarchies of agents (holons) emulating the structure and behaviour of complex systems. In Industry 4.0 jargon they are called *digital twins*.

To cope with their increased complexity, complex (adaptive) systems call for distributed modelling and control methods. Indeed, in order to be robust, adaptive, scalable and reconfigurable, complex systems have to abandon the traditional and strictly hierarchical top-down control structure and adopt a more heterarchical distributed multi-agent control architecture[10]. The rigid rules of hierarchical systems have to be combined with the flexible strategies of heterarchical systems, resulting in agile systems able to cope autonomously with local disturbances. Again, ICT offers the necessary tools to implement such systems. Multi-agent control architectures form a solid basis for controlling complex systems in many disciplines, such as factories, hospitals, robot swarms (e.g. fleets of wheelchairs in nursing homes, distribution of meals and drugs in hospitals), open-air engineering systems (harvesting, road construction, open-air mining), smart power grids, traffic control, health care systems, airports and holiday reservation systems.

5. Complementary or competing role for human and machine?

Data is not wisdom. The different levels in the pyramid (see Figure 1), from data to wisdom are beautifully described by R. Ackoff[11], and referred to among other things as the DIKW hierarchy pyramid. Data are typically bits that are sensed or measured or collected about properties of people, objects and events or data produced by humans or machines. They are stored in computers, smartphones, data warehouses, RAID systems (Redundant Array of Independent Disks) or the cloud. The amount of data being stored has increased enormously (see Figure 2).

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[10] P. Valckenaers, H. Van Brussel (2016), Design of the unexpected. From holonic manufacturing systems towards a humane mechatronics society, Butterworth-Heinemann, Elsevier.
[11] R.L. Ackoff, From data to wisdom, Journal of applied systems analysis, 1989.

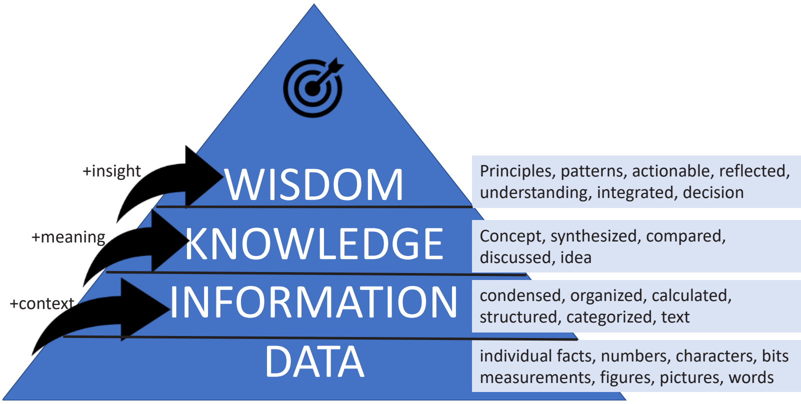

Figure 1. The Data, Information, Knowledge, Wisdom (DIKW)pyramid.

By processing the data in computers or humans, one introduces structure and context, condenses the data and obtains information that is more useful than raw or unstructured data. In 1948, the brilliant mathematician, electrical engineer and cryptographer, Claude Shannon drew the foundation of information theory, a mathematical theory for the compression, protection and encryption of data.

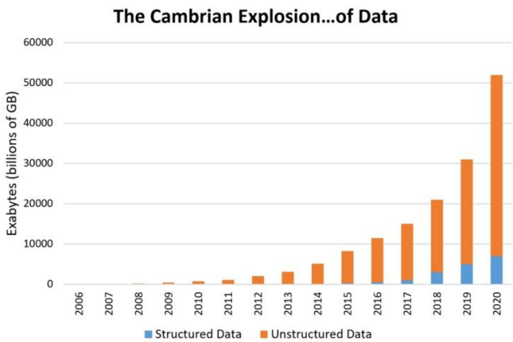

Figure 2. Explosion of data (see LinkedIn Patrick Cheesman).

Information theory bridges the gap between probabilities and information and provides building blocks for various types of coding. Nowadays computers and smartphones use compression software for texts, images or videos in order to reduce the number of bits to be transmitted. Information can give answers to questions like who, what, when, where, and how many. Knowledge on the other hand is conveyed by instructions and answers to how-to questions and provides information with meaning. Wisdom adds insight to knowledge. It is the ability to think and act using knowledge, experience, understanding, common sense and insight and to foresee the consequences of actions. Wisdom is associated with values such as unbiased judgement, compassion, experiential self-knowledge, self-transcendence, and virtues such as ethics and benevolence.

It is clear that both human beings and chip-computer-software-AI-robot systems can work or try to work at these different levels and process information between these levels. In order to understand their performance and limitations, it is useful to compare their respective complexities, speed and power consumptions.

Human brain:

- Higher complexity: the human brain typically has 100,000,000,000 neurons, which is much more than the number of artificial neurons used in AI nowadays and will not be beaten within the coming few decades.
- Much higher interconnectivity and parallelism: 1000 synapses(weights)/ neuron = computing in memory. Very different from traditional Von Neumann computing.
- Lower processing speed: the reaction time of a biologic neuron and the neural network is only 1 to 2 millisecond.
- Better energetic efficiency: biological neural networks are much better than chips. Typically, they consume about 10**-16 Joule per basic operation. Overall the brain consumes about 20 Watt.

Artificial brain/ chips-computer-software-AI systems

- Lower complexity: in electronic hardware, one VLSI chip implements only a few thousand neurons. Using simulations on computers, and dedicated CPU's and GPU's, one can implement neural networks of several millions of neurons.
- Superior processing speed: several hundreds of billions of basic operations per second can be performed on a chip or computer. Today's top CPUs or GPUs reach a trillion operations/second (a trillion = a million million).
- Vastly lower energetic efficiency: the best Von Neumann computers and chips consume 10**-9 Joule per basic operation. One of the most performant chips, the NVIDIA GPU consumes 250 Watt.
- However, many new computer architectures are emerging that imitate analogue computing in memory: lower power, much higher performance/ watt.

One can conclude that the design of artificial brains should not be based on the human brain or on biological neural networks. AI is not magic, but it is based on solid mathematics and statistics. At the same time, this comparison proves that artificial brains can perform tasks in a different way than humans. While it is still less complex and needs much more energy than human brains, it can profit from a much higher speed than humans.

Looking at these figures one can only admire the beauty and power of a human brain. We should not try to copy it blindly but use the artificial brains we make for the tasks they are good at, such as their high processing speeds and handling large data sets. An artificial brain that challenges the performance of the human brain is not for tomorrow.

There are, however, influential authors claiming that, in the near future, AI will be superintelligent and will overpower the human race as projected by science fiction stories and movies. Techno-futurist Ray Kurzweil, for example, overestimates the capabilities of computers and robots when he predicts the Singularity Point, the point in time when computers become more intelligent than man, to be reached by 2045. The crucial unknown in these predictions is the precise definition of the concept 'intelligence'. Kurzweil reduces intelligence to computing power; the bigger and faster the computers become, the more intelligent they are. First of all, computing power is a poor measure of intelligence. More relevant are elements like interconnectivity, parallelism, memory capacity and in memory computing. Research is ongoing for designing such new computer architectures. Even if these are successful, the deployment of such methods will take a great deal of time. Second, he does not mention the skills and the higher levels of the DIKW pyramid needed for the computers to interact with the world. Big questions, such as how human intelligence and learning processes emerge in children, are not resolved. Similarly, Jennifer Pan, the Stanford professor of communication and political and social science has described in her book[12] how political censorship, propaganda, and information manipulation work in the digital age. At the same time, Harari[13] clarifies in one of the 21 lessons for the 21st century, that science fiction movies do not give a scientifically sound picture of the future. They influence opinions and have a great responsibility towards the general public; hence they should be more scientific and less speculative in the way they represent future realities. Some more of the other societal AI challenges of Harari are discussed in the next section.

In the past 10 years, machine learning and deep learning methods of AI have led to spectacular results, and they are now widely used in applications such as Big Data analytics, medical diagnostics, language translation, speech processing, face recognition, and various games like Alpha Go in which they often defeat world champions. Typically, the strength is that the artificial methods can handle larger data sets than humans and perform the step from data to information much faster. So, we can expect many more applications in which they can beat humans in the coming decades. However, they are specialised and specific for one task and may generalise well for that task while remaining useless in other tasks. Hence, their generic value in solving many problems at the same time is limited. Moreover, for many of these tasks the combination of the human expert

[12] Jennifer Pan, "Welfare for Autocrats: How Social Assistance in China Cares for its Rulers", ISBN-13: 978-0190087432

[13] Y. Harari, "21 lessons for the 21st century," Pinguin Random House, 2018.

and the trained AI system can outperform each one individually. So, the final use of the information delivered by the AI system can and should still be made by the human expert considering the particular contexts. Moreover, the term ‘Artificial Intelligence’ creates the wrong impression among the broader public because it is not really intelligence but rather computer optimisation and machine learning.

For the higher levels of the DIKW pyramid, one can raise some questions on the abilities of man-made artificial systems. According to J.-C. Baillie[14], for a machine/robot to be able to reach the general intelligence level, there are a few conditions that need to be satisfied: (i) consciousness of itself and its place in the world, (ii) meaningness to everything encountered, said or done – this is known as the ‘grounding problem’. A machine that is steered by an AI algorithm does not know what is going on and it has a very narrow field of expertise.

The solution to the grounding problem requires four questions to be answered: (i) How does the AI-robot structure the information it gets from the world? (ii) How does it create meaning from this structure? (iii) How does it create sensible communication with the world? (iv) Why does an AI-robot do something, rather than nothing? While many efforts in the knowledge-based approach of AI are geared towards these questions, they are far from being implemented and are not widely deployed in services.

Strictly speaking, deep learning realises, in an impressive way, the transformation from data into information. The automatic reduction of huge amounts of data (Big Data) into a limited number of classes is a valuable step that allows human specialists to be able to take appropriate actions, e.g. in medical diagnosis. Human intervention is still needed to convert the information into knowledge, thus to give meaning to the information.

Moravec’s paradox states that ‘what are trivial tasks for humans are difficult for robots and vice versa’. A child can, with some training, easily tie its shoe laces – which is much more difficult for a robot – while a computer’s Deep Blue and AlphaGo defeated Kasparov and the Korean world champion respectively. The dexterity, flexibility and insights of plumbers, carpenters, toolmakers and farmers are very difficult to automate, while routine white-collar tasks in the service sector are easily automated, e.g. bank tellers. It remains astonishing that mere walking, throwing and catching a ball, needle work, folding a T-shirt, are so difficult for robots to perform.

Notwithstanding the impressive results obtained by deep learning, there is a wide consensus that more is needed to make machines generally intelligent; machines

[14] J.-C. Baillie, “Why AlphaGo is not AI”, IEEE Spectrum posted 17 March 2016. http://spectrum.ieee.org/automaton/robotics/artificial-intelligence/whyalphago-is-not-ai https://en.wikipedia.org/wiki/Jean-Christophe_Baillie

that learn to live in the world, interact naturally with people and understand the complexity of their emotions and culture. Solving unique cognitive problems, requiring intuition, lateral thinking and creativity are not yet reserved for computers and robots, let alone their expression of emotions, affection and love. Complementarity is the keyword: let humans work together with robots instead of letting the robots take over their jobs[15]. As long as there is no solution for 'the hard problem'[16] – how the objective physical processes that take place in the human brain can give rise to subjective processes and feelings (consciousness, imagination, ethical and moral feelings, emotion, madness) – there is no hope of machines or robots rising to wisdom level.

6. Impact of the digital transformation on the skills, education, research and jobs of the future

6.1 Impact on digital skills and literacy

In the coming decades, this complementary role of humans and machines will significantly affect the digital skills needed in our daily life and in our jobs. Many of the jobs and activities that are at the bottom of the DIKW pyramid will (partially or entirely) be taken over by machines, and there will be more emphasis on the higher-level skills and competences of humans. Education should therefore reduce the present attention to memorisation of loosely-connected facts and place more emphasis on the memorisation of structured ones; it should work on bringing in context, meaning and insight. After all, these will bring more joy and happiness to life, and a feeling of understanding and control. Harari [8] devotes an interesting chapter to Education: "People need the ability to make sense of information, to tell the difference between what is important and what is uninteresting and above all to combine many bits of information into a broad picture of the world". Many pedagogical experts argue that schools and universities should devote more attention to the four Cs: critical thinking, communication, collaboration, and creativity. A very nice example of the four Cs is Wikipedia, which is a big step forward with respect to the previous print-based encyclopaedia produced by the French revolution and the enlightenment. Wikipedia is a free online encyclopaedia written and maintained by a community of volunteer contributors through a model of open collaboration, using a web-based editing system. The encyclopaedia contributes to all levels of the knowledge pyramid and has reached high standards of correctness and objectivity. Even the Encyclopaedia Britannica has been beaten in correctness by the collective and creative efforts of the digital Wikipedia. However, it will be important to experience at a young age the ability to deal with change, to learn new things and to preserve mental balance in unfamiliar situations.

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[15] https://www.wrr.nl/publicaties/verkenningen/2015/12/08/de-robot-de-baas

[16] D. Chalmers, "The Conscious Mind," Oxford University Press, 1996

6.2 Impact on formal education

The COVID-19 pandemic has already exposed our society to unusual circumstances that are likely to occur in a similar form, but not necessarily as a pandemic, in the coming decades. Education is usually about the future of society, and it builds on the past. It is typically slow in making transitions, yet it made a quick shift to online teaching during the pandemic. Preliminary findings on the role of online teaching in elementary and secondary education have however shown that online teaching works well for memorisation but turns out to be more difficult for deeper insight. Hence, there is an important task for education experts together with domain experts to improve the digital mechanisms of education and training. Some steps have been proposed for teaching with MOOCs (Massive Open Online Courses), and blended learning[17] and learning analytics[18]. There is a need to stimulate digital literacy, STEM (Science, Technology, Engineering and Mathematics) knowledge and skills in basic and secondary education. The new high school end terms for Flanders are in line with the recommendations of the KVAB position paper[19]. In Wallonia, the digital skills of citizens are a major issue; they need to play an active role in the digital transformation by acquiring technology skills and adopting entrepreneurial habits, which are essential for economic and social development. There are a number of initiatives in place, run by Digital Wallonia, focusing on this area[20].

Forced distance learning at universities during the COVID-19 pandemic revealed that it is more effective in theoretical parts of courses with recorded lectures, and video clips or online lectures, and less suited to laboratory sessions and exercises that are better implemented with face-to-face learning. Students appreciate that they can work at their own pace. Didactical teams gain efficiency in travel, but the remote lectures and sessions are much more time consuming even though they are reusable and can be shared in many locations. Both didactical teams and students do not like very long periods behind a screen and miss the contact with colleagues. They also have a need for feedback and communication. Distance education is very likely to remain post-COVID-19 since students are more open to distance education than before the pandemic. Half of students are open to blended learning with more than 20% in favour of distance education. Since distance

[17] G. Van der Perre, and J. Van Campenhout, (eds), "Higher education in the digital era, a thinking exercise", KVAB position paper, 2015. https://www.kvab.be/sites/default/rest/blobs/77/tw_blended-learning_en.pdf

[18] T. De Laet, e.a. "Learning Analytics in het Vlaams hoger onderwijs", Standpunt KVAB, 2018. https://www.kvab.be/nl/standpunten/%E2%80%9Clearning-analytics%E2%80%9D-het-vlaams-hoger-onderwijs

[19] G. Samaey, J. Van Remortel, e.a. "Informaticawetenschappen in het leerplichtonderwijs", Standpunt KVAB, 2014. https://www.kvab.be/sites/default/rest/blobs/81/tw-ja_informatica wetenschappen.pdf

[20] https://www.digitalwallonia.be/en/posts/digital-skills-in-wallonia

learning had to be developed so quickly during the pandemic, one can expect an even better quality of sustainable blended learning material post-COVID. It has to be mentioned that didactical teams have a more positive view on distance education than students.

The whole chain of ingredients of the digital revolution – chips, computers, smartphones, software, algorithms, AI, robotics, cryptography, data fusion and agents – will see an increasing need for skilled workers. And on top of that, skilled workers are needed to create novel and attractive products and services using these ingredients. Before COVID-19 there was already a chronic shortage of computer scientists, engineers and scientists in Belgium and an accelerated digital transformation will enhance this need. Since thorough IT knowledge and competence in scientific disciplines are prerequisites for mastering AI, it follows that there is an even more significant shortage of AI engineers. In general, all graduates from STEM master programs will be in high demand in the job market. For example, the AI service developers will use mathematical, algorithmic and software extensively, as well as data science skills. Also, digital transformation will certainly enhance the need for digital humanities, which is a relatively new field of education and research focused on the use of computational techniques to support research in the humanities, social and behavioural sciences. Digital AI technology will change the behaviour of students and the science of learning, which will in turn affect the curriculum. An example is the basic programme[21] on data science for all first-year students at UC Berkeley with several thousands of students.

In addition, there is too little knowledge of what AI can do or cannot do among broader layers of the population, including business leaders and administrators. This leads to excessively high and unrealistic expectations or misplaced fear. So, there is a need for science communication on digital transformation and AI for the general public.

6.3 Impact on future research and innovation

Research is also witnessing an important transition due to digital transformation. Digital data, tools, platforms and networks transform the whole research cycle from hypothesis to publication and communication worldwide. As with education, the goal is to make it more open, global, collaborative, creative and closer to society[22] (Figure 3). Open Science is about the way research is carried out, disseminated, deployed and transformed by digital tools and networks. It relies on the combined effects of technological development and cultural change towards collaboration, openness and better service to society. By providing unlimited, barrier free,

[21] https://data.berkeley.edu/
[22] https://ec.europa.eu/digital-single-market/en/open-science

open access to research outputs, Open Science makes scientific processes more efficient, transparent and responsive to societal challenges. It offers new tools for scientific collaboration, experiments and analysis and makes scientific knowledge more easily accessible. Open Science has many interesting contributions like pre-registration, replication research, sharing data and research tools, open peer-review, publishing open access, uploading preprints and (meta) research about scientific methods, transformations of the publishing cycle, research data management and, copyright retention. COVID-19 has shown how important it is to share scientific evidence on a novel virus to enhance detection, monitoring, vaccine development, and investigate its impact. The massive, open scientific collaborative search for vaccines was unprecedented, and delivered deployable and effective vaccines in less than a year. There is however also a word of caution with respect to uploading unreviewed preprints, which are taken up in the lay press and social media.

A recent European Scoreboard[23] positions Belgium as an innovation leader and ranks it in fourth position after three Scandinavian countries. It is important that our country consolidates this position after the COVD-19 pandemic and all the way through the green and digital transition.

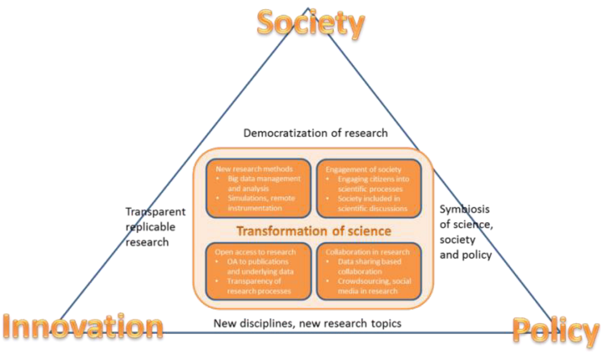

Figure 3. The digital transformation of research[24]

6.4 Impact on future work

The COVID-19 pandemic has dramatically disrupted the labour markets[24]. The short-term consequences were widespread with millions of people losing their jobs, at least temporarily. Those who kept their jobs had to adjust their working conditions, e.g. by suddenly being forced to work from home. Other workers whose physical presence was essential, for example personnel in medical and

[23] https://ec.europa.eu/docsroom/documents/45943 June 21, 2021.
[24] McKinsey Global Institute, The future of work after COVID-19, Feb 18, 2021, Report.

care facilities, supermarkets and department stores, manufacturing companies, garbage collecting, public transport, had to adapt their working conditions drastically to reduce the spread of the coronavirus. These suddenly changing working conditions and the shifts in labour demand and workforce skills will undoubtedly have a lasting impact in the post-pandemic society.

Before COVID-19, job polarisation (shifts in employment) was already visible[25]. To analyse this phenomenon, five types of tasks can be defined: (i) manual routine tasks (e.g. assembly line), (ii) manual complex tasks (e.g. plumbing), (iii) cognitive routine tasks (e.g. travel agencies, administration), (iv) processing of new information (e.g. troubleshooting), (v) solving unstructured problems (e.g. product design). As a consequence of Moravec's paradox: 'Manual (i) and cognitive routine tasks (iii) are easy to automate while tasks requiring manipulative skills (ii) are much more difficult to automate'. Tasks requiring general intelligence ((iv) and (v)) are still impossible to automate. As a consequence, employment shrinkage was observed in the first place in industry, and to a lesser extent in finances, insurances, agriculture, forestry, mining and real estate. Employment increases took place in domains like electricity, gas, water, sewage, recycling, construction, science and technology, transportation, storage, hotel, catering, ICT, wholesale, retail, repair and the public sector. In all European countries the number of middle-paying jobs decreases[26] while the number of low-paying and high-paying jobs increases, and in Belgium this effect is particularly strong.

Measures are being taken for jobs involving close physical proximity to alleviate COVID-19 risks that are likely to be (partially) continued in post-COVID-19 times because of other positive effects they bring with them, e.g. telemedicine. Robotics and automation will play an increasingly important role in the future to further improve these. On-site maintenance services will be increasingly automated by widespread use of sensors and will be augmented by virtual reality, enabling remote diagnostics. Production facilities requiring close worker proximity, e.g. automotive assembly lines, are being reformatted and/or robotised to satisfy COVID-19 regulations, e.g. social distancing, and this trend will continue in post-COVID-19 times, albeit for other reasons, like ergonomics, productivity and quality.

The effects of COVID-19 as described above will necessarily affect and eventually reshape the workforce and the work content. COVID-19 has revealed the positive and negative effects of remote work and virtual meetings. It is difficult to predict their effect on the economy (travel, hotels, restaurants, office space, traffic congestion and public transport), work efficiency and well-being of the workforce

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[25] H. Van Brussel, J. De Schutter, et al. (2016), Naar een inclusieve robotsamenleving, Standpunten 46, KVAB https://www.kvab.be/sites/default/rest/blobs/682/tw_robotisering.pdf

[26] M. Goos, A. Manning, A. Salomons, Explaining Job Polarisation: Routine-Biased Technological Change and Offshoring, American Economic Review 2014, 104(8): 2509-2526.

(lack of social contact), but there is no doubt that remote work and virtual meetings are here to stay. The same is true for e-commerce, which has grown up to five times faster than before the pandemic. Other digital transactions like online banking and streaming entertainment have taken off as well and are not expected to disappear after the pandemic.

A different job polarisation pattern may emerge in the post-pandemic world, showing little job growth in low-paying jobs. The biggest negative impact of the pandemic is expected for workers in the food and customer sales and service sectors, and in the less-skilled office support roles. Jobs in warehousing and transportation will increase because of the booming e-commerce and delivery economy, but not enough to offset the disruption of many low-paying jobs. Demand for health care workers may grow to maintain high-quality care for an ageing population. STEM-related jobs remain very popular in line with an increasing demand for people who can innovate, create, deploy and maintain new-technology systems. And so the Government of Flanders has developed a STEM action plan[27] with an agenda for 2030. The integration of 'Art' in the Action Plan 'STEM' has been advised and is accordingly abbreviated to 'STEAM'. Art in its various forms and dimensions is a cornerstone of humanity. It represents a symbiosis in society; a historical interactive link between humanity and culture, supported by specific human talents, and is actually linked to digital AI technology. In response to the increasing number of jobs in the field of sciences, technology, engineering and mathematics, the government of Wallonia and the Wallonia-Brussels Federation have created a reference STEM Centre[28].

While, before the pandemic, job losses were concentrated in the middle-paying jobs like those in manufacturing and some office work, reflecting automation, the number of low- and high-paying jobs continued to grow. Nearly all low-paid workers who lost their jobs could move to other low-paying jobs, but because of the pandemic's impact on low-paying jobs as well, more than half of the displaced low-paid workers may need to shift to jobs in the higher wage brackets, requiring different skills so as to remain employed. A study in eight countries around the world, representing 60% of the world population, showed that, given the job growth in high-paid salary jobs and declines in low-paid jobs, about 25% of the current workforce will have to find a different occupation by 2030[29].

There is clearly a need to reskill the workforce. The transition brought about by the pandemic urges companies and policymakers to provide for additional training and education programmes for workers at different levels. These programmes should

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[27] STEM-AGENDA 2030, STEM-competenties voor een toekomst- en missiegericht beleid. https://assets.vlaanderen.be/image/upload/v1624978438/STEM_agenda_2030_pjxpnw.pdf

[28] https://www.digitalwallonia.be/fr/publications/centre-stem

[29] https://resources.oxfordeconomics.com/how-robots-change-the-world?source=recent-releases

preferably be based on the skills they need rather than on school or academic degrees. This requires a redesign of the job content and of the way jobs are to be executed. The result can be hybrid remote working strategies enabling workers to take on skills adapted to the subtasks, to increase worker satisfaction and to reduce working place costs. Remote work may offer the possibility of keeping valuable people who are unable to relocate to the place they are needed, and increased digitalisation of the infrastructure and data handling will be key elements for success. Companies and policy-makers should collaborate to support workers migrating between occupations. Let us now consider the situation in Belgium; a study by Eurostat shows that, in Belgium, only 7.4 % of the people aged between 25 and 64 took an education or training in July 2021. That is under the European average of 9.2% and way below the nearly 30% in Scandinavian countries. Only with lifelong learning will Belgium be able to solve the mismatch and the shortage in the job market.

A recent study by the European Investment Bank[30] shows that Belgian firms are outperforming the EU average in the adoption of digital technologies in all sectors: manufacturing, construction, services, and infrastructure.

6.5 Related actions

Let us mention some actions around this theme. The preparedness of all generations for this transformation is addressed in the EU actions on the digital skills, education and work[31] with a *Digital Education Action Plan* to boost digital literacy and competences at all levels of education, a *reinforced Skills Agenda* to strengthen digital skills throughout society, and a reinforced Youth Guarantee to put a strong focus on digital skills in early career transitions as well as an initiative to *improve labour conditions for* platform workers.

Also, on the Flemish level, SERV has published an interesting vision note[32] on these issues.

The 'Ecole Numérique' project, set up by Digital Wallonia, covers several areas designed to provide primary and secondary schools with good quality equipment and connections to promote the use of digital technology, to acquire specific digital skills and to support other ways of learning[33].

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30 Digitalisation in Europe 2020-2021, Evidence from the EIB Investment Survey. https://www.eib.org/en/publications-research/economics/surveys-data/eibis-digitalisation-report.htm

31 https://digital-strategy.ec.europa.eu/en/policies/digital-skills-and-jobs

32 Visienota De transitie naar een digitale samenleving: aanzet voor een integrale beleidsagenda, Brussel, 17 januari 2018

33 https://www.digitalwallonia.be/en/posts/digital-skills-in-wallonia

7. Societal challenges of digital transformation and related actions at the EU and Belgian level

7.1 Broad perspective on the societal challenges

It is important to discuss the realistic societal challenges of digital transformation and how to deal with these while avoiding the unrealistic science fiction projections and fantasies that were briefly described in Section 5. We also refer the reader to EU and national reports for the technological developments in infrastructure that should be deployed and supported by EU post-COVID-19 budgets. Yet it is one of the important elements of this position paper to discuss several important and realistic societal challenges and how to deal with these. Let us first discuss the actions at the EU and Belgian level. Commissioner Margrethe Vestager, Executive Vice President of the European Commission for 'A Europe Fit for the Digital Age' addressed the issues of the digital transformation in The Hague on 3 February, 2020[34] and in the EU communication[35]: "Digital technologies, as advanced as they may be, are just a tool. They cannot solve all of our problems. Yet they are making things possible which were unthinkable a generation ago. The success of Europe's digital strategy will be measured in how well we are able to *put these tools to work in delivering public goods to European citizens*. The *data-agile economy and its enormous transformative potential will affect all of us* and Europe stands ready to make full use of the advantages it will bring. Yet for this digital transformation to be fully successful, we will need to *create the right frameworks to ensure trustworthy technology and to give businesses the confidence, competences and means to digitalise.* Coordination of efforts between the EU, Member States, regions, civil society and the private sector is key to achieving this and strengthening European digital leadership. Europe can own this *digital transformation and set the global standards when it comes to technological development*. More importantly still, it can do so while ensuring the *inclusion and respect of every single human being*. Digital transformation can only work if it works for all and not for only a few. It will be a truly European project – a digital society based on European values and European rules – that can truly inspire the rest of the world."

Five of the 14 Megatrends in EU[36] are closely related to digitalisation: accelerating technological change and hyperconnectivity, changing the security paradigm, increasing the influence of governing systems, changing the nature of work, and diversifying education and learning. The last two have already been discussed in

[34] M. Vestager, "Shaping a digital future for Europe", Symposium on Digitalisation, The Hague, 3 February 2020.
[35] https://ec.europa.eu/info/sites/default/files/communication-shaping-europes-digital-future-feb2020_en_4.pdf
[36] https://knowledge4policy.ec.europa.eu/foresight/tool/megatrends-hub_en

the previous section. The Eurobarometer on digitalisation in our daily lives[37] dates back to March 2020, and hence has no COVID-19-related questions. Almost seven out of ten people think they are sufficiently skilled to use the digital devices that are part of their daily lives. Almost eight out of ten would like manufacturers to be forced to make devices easier to repair. But the proportion drops to four out of ten if this is tied to higher prices. On personal data, over 40% of participants are willing to share their data to improve medical research and care – if it is by a secure means – and some 30% are willing to do so in emergencies (e.g. natural disasters, terrorist attacks). Just over 60% said they would find it useful to have a single digital ID for all online services.

Specific societal values and related ethical issues caused by the digital transformation have received a more specific meaning in Table 1.

Table 1. Societal and ethical issues relating to digitalisation (source: Kool et al.[38] 2017)

Topic	**Societal and ethical issues**
Privacy	Data protection, privacy, digital inviolability, mental privacy, surveillance, function creep
Security	Information security, identity fraud, physical security
Autonomy	Freedom of choice, freedom of expression, manipulation (dissemination of disinformation, micro-targeting), protection of democracy, paternalism, skills, limits of self-sufficiency
Control over technology	Control over and understanding of AI technology, responsibility, predictability
Human dignity	Dehumanisation, instrumentalisation, de-skilling, de-socialisation, unemployment
Justice	Discrimination, exclusion, equal treatment, stigmatisation
Power structures	Unfair competition, exploitation, consumer-business relations, business-platform relations

In this context there is a regional barometer of the public digital trends in Flanders measured by a broad public enquiry called 'the Digimeter'[39]. There is definitely a digital acceleration due to COVID-19, but there are also some challenges since a quarter of respondents were not prepared for living exclusively online, with 5% lacking screens and 11% buying a new device or screen:

- Videocalling (monthly) 50% (25% increase in the pandemic)
- Watching Live TV (daily) 56% (9% increase)

[37] https://europa.eu/eurobarometer/surveys/detail/2228

[38] Kool, L., J. Timmer, L. Royakkers & R. van Est "Opwaarderen: Borgen van publieke waarden in de digitale samenleving". Den Haag: Rathenau Instituut, 2017.

[39] https://www.imec-int.com/en/imecdigimeter-2020#report

- Online shopping (monthly or more) 65% (10% increase)
- Paying contactless with smartphone (weekly) 26% (12% increase)
- Paying cash (weekly) 43% (18% reduction)
- Sharing economy – AirBnB 16% (5% reduction)
- Search for news through search engines (monthly) 71% (14% increase)
- News apps (monthly) 52% (14% increase)
- Paying streaming services (monthly) 46% (7% increase)
- I bought a new device or screen during the lockdown 11%

The recent Flemish report advocates an accelerated digital economy and no return to the pre-Corona age[40]. These figures, also roughly applicable to Wallonia, show the importance of digital education as the main way for the population to be better informed about the potential benefits, the pitfalls and, above all, the skills needed to make the most of these technologies, both for personal development and to participate in economic and social life[41].

It is also worth mentioning the Flemish reflections on the 2030 Digital Compass: the European way for the Digital Decade[42].

1. Flemish stakeholders welcome the European Commission's idea of accelerating digital transformation.
2. Attention to cybersecurity and the security of the digital economy and society in the context of digital sovereignty.
3. Flemish stakeholders call for special attention to be paid to the link between the circular economy and digitalisation and ask that solid objectives be drawn up for this as well. The best way to make the link here is between the European strategic objectives for digitalisation and the Green Deal.
4. The term 'ICT Specialists' needs to be clarified. In addition, the objective regarding skills should also focus on experts in other fields who can use advanced technologies.
5. Flanders supports the objective concerning 5G but asks that European Research Centres and companies be involved in its rollout.
6. The KPI on 'Edge Nodes' should not be limited to small data centres. The focus should be on AI in the equipment itself.
7. Flanders asks to include a KPI that focuses on the amount of venture capital available in Europe.
8. Flanders supports the rights-based approach to digitalisation, but points out the importance of integrating ethics into the workings of organisations.

[40] Vlaanderen welvarender, weerbaarder en wervender rapport https://publicaties.vlaanderen.be/view-file/37584

[41] https://content.digitalwallonia.be/post/20210916135353/2021-09-Baromètre-Citoyens-2021-Complet.pdf

[42] https://www.ewi-vlaanderen.be/sites/default/files/bestanden/reflectiepaper_digital_compass_2030.pdf

9. Finally, Flanders asks that monitoring the proposed objectives be made possible at regional level. This will benefit the charting of the effects of regional digital policy.

In response to the 2030 Digital Compass, on 6 December 2018, the Walloon Government approved the updated Digital Wallonia strategy for 2019-2024. It establishes the framework defining the approaches that Wallonia needs to adopt in order to grasp the socio-economic opportunities presented by the digital transformation over a 5-year period. Wallonia's digital strategy is designed to transform the region, the economy, and society to boost its appeal, its competitiveness and the well-being of everyone, based on values including a cross-disciplinary approach, transparency, coherence, openness and flexibility. Digital Wallonia 2019-2024 is structured around 8 cross-disciplinary challenges that form its structured framework and its key elements for all the decisions made and the measures taken within five themes: digital sector, digital business, digital administration, digital territory, digital skills[43].

1. *For strong, coherent, cross-disciplinary digital governance.* Digital Wallonia's ambition involves an approach to governance that is specific to digital policies in order to manage the speed at which this field evolves and make sure all sectors of Wallonia reap the rewards.
2. *Digital Society. For an inclusive, responsible, self-determining society.* The digital transformation must be guided and supervised to support the major social disruption that it involves.
3. *For strong digital ecosystems.* Wallonia needs to choose its areas of digital expertise and concentrate public and private resources on clearly identified ecosystems.
4. *Giga Region. Super-fast broadband for everyone as the bedrock of digital initiatives.* The region's connectivity forms the foundations of all the initiatives involved in the digital transformation, both for businesses and the public sector, not to mention individual citizens.
5. *For digital skills for everyone.* In our modern societies, where digital technology is omnipresent, it becomes hard to live and work if we do not understand the language and codes.
6. *For data at the heart of actions and following up those actions.* Data must be seen as an "essential infrastructure" for the Region similar to other tangible and intangible assets.
7. *For a comprehensive platform for Digital Wallonia.* On the basis of a global value change and coherent ecosystems, the digitalwallonia.be platform needs to make it possible to identify, stimulate and showcase everyone involved in the digital transformation.

43 https://www.digitalwallonia.be/en/posts/digital-wallonia-2019-2024

8. *A strong, attractive brand to embody digital Wallonia.* Wallonia needs to assert its digital existence and its vocation thanks to a unique, strong brand that still respects or incorporates the identity of those that it encompasses.

7.2 Challenges of fair and competitive businesses and economy

The EU wants a frictionless single market, where companies of all sizes and in any sector can compete on equal terms, and can develop, market and use digital technologies, products and services at a scale that boosts their productivity and global competitiveness, and consumers can be confident that their rights are respected. After all, Europe's 25 million small and medium-sized businesses account for more than half our GDP, and two-thirds of our business jobs. Digitalisation can bring challenges for them, since only one in six SMEs in Europe is highly digitalised. But it also has enormous opportunities to offer. And the task for the EU governance is to make sure that Europe designs its policies in a way that allows SMEs to grasp those opportunities. As discussed in the previous section, this also brings other issues on the job market and requires digital skills and education.

A deeper level of discussion is related to the business model of the internet. Via the internet companies design attractive 'free' services that collect personal data which are then sold to advertisers. The key of the business model is to make money by creating an addiction among users, generating social problems, provoking conflicts which generate more reactions on social media, creating a huge societal problem, etc. This detrimental business, threatening our society model, is only looking for profit, without empowering the users. Don't we need to reinvent it completely? In November 2019 Tim Berners Lee, the inventor of the web, unveiled a global plan[44] to save his brainchild. It identifies a set of 'principles', laying out the basic rules for each of the stakeholders (governments, companies and citizens) and invites these stakeholders to endorse it. A more extensive discussion is given in our previous KVAB position paper (Rabaey e.a. page 52, 53).

7.3 Challenges of an open, democratic and sustainable society

When schematised one can say that there are worldwide roughly three approaches to digitalisation. The US has a system that is dominated by big tech companies like GAFA (Google, Apple, Facebook, Amazon). In this market-driven approach, the US companies collect all types of information about customers in order to profile the user and deliver more targeted ads, which in return provide them with additional income. This approach is based on the commercial and advertising value of all customer data it can harvest, and delivers in return interesting attractive services to these customers worldwide. It also supports the US government.

[44] Tim Berners Lee, 2019 "Contract for the Web", https:// contractfortheweb.org

Clearly the privacy of customers worldwide and the interests of non-US countries and companies are under threat. Moreover, these companies evade taxes on a massive scale, and history has taught us that many of their systems suffer from data breaches, ransom attacks or denial-of-service attacks. It is only recently that they have paid more attention to better security for their customers. A second approach is the Chinese system where data are controlled by the government, and mass surveillance is widely practised by the government and used with the potential for human rights' violations (e.g. ethnic face recognition systems, DNA profiling studies[45]). A system is being deployed whereby a social score for citizens is centrally collected and then decreases when rules are not followed, for instance going through a red light. A higher social score entitles the user to receive benefits or priorities. Europe aims at being an open, democratic and sustainable society: a trustworthy environment in which citizens are empowered in how they act and interact, and have some control over the data they provide both online and offline. A European approach to digital transformation is one that enhances our democratic values, respects our fundamental rights, and contributes to a sustainable, climate-neutral and resource-efficient economy. This is a human and respectful approach with attention to the SMEs and markets. It is the intention to deepen the Internal Market for Digital Services, by increasing and harmonising the responsibilities of online platforms and information service providers, and to reinforce the oversight over platforms' content policies in the EU. There should be transparency on information that companies collect on citizens, and citizens should retain their rights, including the right to be forgotten. Along this line there is currently a Rights Retention Strategy[46] being advocated by Coalition S, whereby researchers would not have to relinquish the copyright when they submit their research papers to a journal.

7.4 Challenge of loss of privacy

It is the duty of government and business to make a fundamental assessment[47] for each big data solution as to whether the benefits outweigh the risks. This is important to protect personal data and society as a whole against the consequences of, for example, data leaks. The GDPR General Data Protection Regulation, launched in 2016, has given more respect to the privacy of personal data, and serious fines have forced all companies to revise their data procedures. It now serves as a role model for many non-EU countries and even for some states in the US, like California. The public is increasingly advocating the right to decide what is done with their personal data. Typically, the designers must consider whether or not the same objective could be accomplished using less data

[45] https://theintercept.com/2021/08/04/dna-profiling-forensic-genetics-journal-resignations-china/
[46] https://www.coalition-s.org/rights-retention-strategy/
[47] https://www.kvab.be/sites/default/rest/blobs/1501/tw_privacy_en.pdf

or less data aggregation. This ensues from the basic principles of EU legislation: data protection by design and data protection by default. In light of the plethora of leaks from data libraries, it is time for the Data Protection Authorities to invoke their new powers to impose effective solutions that feature data protection by design, with data remaining local as much as possible and stored centrally as little as possible. A nice example of the principle of minimal use of personal data is the design of the virus contact tracing app 'coronalert'[48] that is deployed in many EU countries and also in Belgium. Without using GPS location information and only using Bluetooth, it can still perform the contact tracing action completely anonymously.

7.5 Challenges of designing a digital world of fairness and trust and facing loss of control

The success of digital business may be built by combining clever technology and full attention to societal issues. But it also depends on the work of many people in the physical world. In order to win people's trust and acceptance, a proper ethical framework and design structure is needed, called value-driven innovation (Figure 4).

Digital technology should be secure and resilient so that consumers have exactly the same protection online as in the physical world. Citizens should not be subject to the pressure and seduction methods, with the enormous power that some platforms have. Moreover, IT service providers should be transparent about their methods and values.

Value-driven innovation is about the synergy between technical and social innovation. Five processes play a role here: assessing public values, experimenting, seizing opportunities, mitigating risks, and working and learning together (see Figure 4). 'Assessing public values' is about elucidating public values and objectives that people aim at. 'Experimenting' means making space for trying out new things. 'Seizing opportunities' means being open to the possibilities that digital technologies offer. The government should have the ambition to ensure that our society can profit as much as possible from the blessings of digitalisation. 'Mitigating risks' involves protecting citizens as far as possible from the risks of digitalisation. Steering digitalisation in the right direction is a joint challenge. It requires coordination and cooperation between various levels of government and between diverse authorities and knowledge institutions, companies and of course citizens. 'Working and learning together' is the fifth ideal. The involvement of relevant stakeholders is crucial, but not always straightforward. There may, for example, be 'stakeholders' who do not wish to be involved or who are 'elusive'. How do you ensure, for instance, that young people without an internet connection

[48] https://coronalert.be/en/

can still take part as a stakeholder in whatever way possible in the discussion about the digitalisation of education? Digitalisation no longer refers to a collection of gadgets but is now seen as a transition with opportunities and risks and many uncertainties. The transition perspective brings the question of the digital good life to the table and with it the key democratic question: What kind of digital society do we want to live in?[31] Both in Belgium and the Netherlands there is a growing awareness that digitalisation comes with numerous ethical, legal and societal challenges. For approaches like ethics by design, multidisciplinary teams, test facilities, experimentations and test facilities there is interuniversity cooperation in Flanders in the AI research program[49]. The Knowledge Centre Data and Society[50] was set up to boost the idea that those social and ethical issues should not be perceived as obstacles to digital innovation, but as important and enriching elements to take into account from the start. Similarly, five universities of the Wallonia-Brussels Federation and four research centres have joined forces

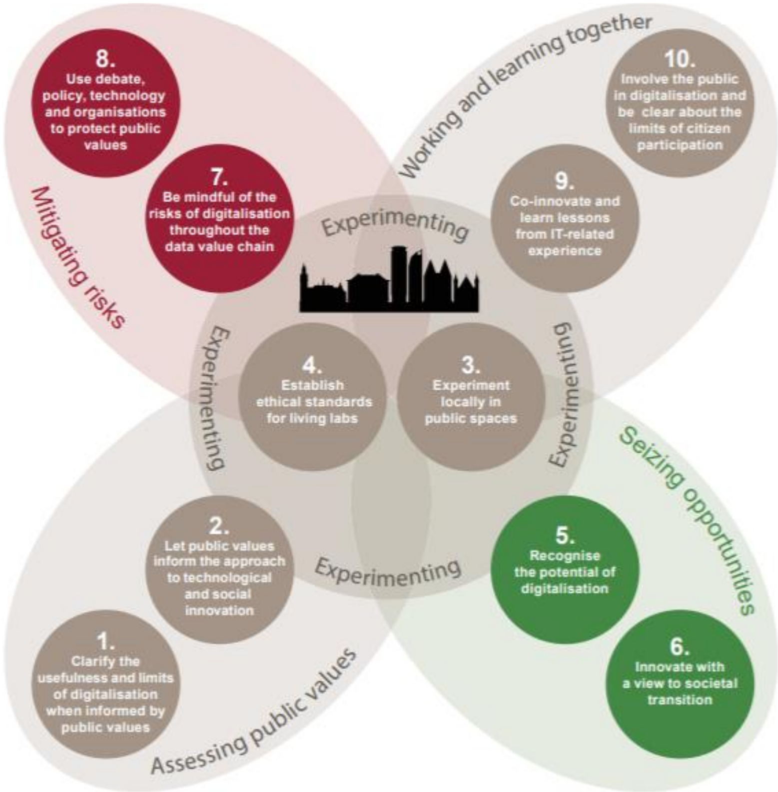

Figure 4. Value-driven innovation by means of five key innovation processes[10,31].

49 https://airesearchflanders.be/
50 https://data-en-maatschappij.ai/en/

to create the TRAIL Institute (Trusted AI Labs), dedicated to artificial intelligence: training, research, products and services[51].

7.6 Challenges of the IT security

As mentioned in section 4 about the ingredients of the digital transition, there may be malicious pieces of software hidden in the computers, smartphones, tablets and IoT such as computer viruses, worms, and Trojan horses. This calls for maximal transparency of software and open source and inspection and scrutiny. There is a momentum towards this open software that definitely merits more support. Also, improved digital literacy should make the general public vigilant about cyberattacks, but it should not lead to real fear or prohibit full use of digital services. At the level of governments and utility companies providing water, electricity, telecoms and Internet, and the nuclear energy and chemical companies, there should be an awareness of the vulnerability of critical infrastructure to cyberattacks.

A European cybersecurity strategy, including the establishment of a joint Cyber-security Unit, a Review of the Security of Network and Information Systems (NIS) Directive13, gives a boost to the single market for cybersecurity. A reinforced EU-wide inter-governmental interoperability strategy is needed to ensure coordination and common standards for secure and borderless public sector data flows and services.

7.7 Challenges on the lack of transparency, loss of control and bias of AI

AI systems and services often give the user a feeling of loss of control over technology. This is a perception that needs to be corrected. AI systems give the user the impression that AI makes the decision, whether good or bad. However, people – not computers – remain in charge of the design decisions that affect the quality and the service of an AI system. Humans design the algorithms, program it in software, and select the data to train the AI system. There is no intelligence in the system itself, only computation and optimisation; human beings bring together the elements for it to function properly. To be more specific the designers are the ones that are mostly in control and not the users. Hence, they should be transparent about the values, choices and methods they use, and should not take biased design options for data or algorithms; as much as possible they should also leave control and insight regarding the AI technology to the user. The designers therefore have a huge responsibility. As we have seen before, AI systems and in particular learning systems are often unable to explain why they make a certain decision. There is much research going on now to ensure that machine learning systems are not a “black box” but can give an explanation of their decisions, so that users can check and eventually challenge the answers they produce.

[51] https://www.uliege.be/cms/c_12324944/en/trail-institute-to-boost-artificial-intelligence

Several engineering and ICT institutions have drafted notes on 'ethically aligned design' and AI codes of conduct for sound applications of AI; in particular, there is the Barcelona Declaration[52] for the proper use and development of AI in Europe. This code of conduct emphasizes prudence, reliability, accountability, transparency, limits to autonomy and concern for the preservation of human knowledge. On 8 April 2019 the High-Level Expert Group on AI appointed by the European Union produced a White Paper on Artificial Intelligence[53] describing the key principles behind the deployment of ethical AI. It sets out options for a legislative framework and cryptographic technology for trustworthy AI and outlines seven key principles:

1) **Human agency and oversight**, including fundamental rights, human agency and human oversight.
2) **Technical robustness and safety,** including resilience to attack and security, fall back plan and general safety, accuracy, reliability and reproducibility.
3) **Privacy and data governance,** including respect for privacy, quality and integrity of data, and access to data.
4) **Transparency**, including traceability, explainability and communication.
5) **Diversity, non-discrimination and fairness,** including the avoidance of unfair bias, accessibility and universal design, and stakeholder participation.
6) **Societal and environmental well-being,** including sustainability and environmental friendliness, social impact, society and democracy.
7) **Accountability**, including auditability, minimisation and reporting of negative impact, trade-offs and redress.

Among these seven basic principles, some are clearly requiring the specific deployment of cryptographic tools and security architectures:

- Resilience to attack requires architectures including authentication and integrity of data, ciphering of communication, integrity of the AI models, and authentication of the parties involved in the training and the use of the models.
- Respect for privacy, includes new learning models, being either federated (the data are kept at the source, and the model travels to learn from data silo to data silo) or based on the use of Full Homomorphic Encryption which allows the models to be executed directly on encrypted data without any decryption phase.
- Traceability may require the authentication of the models (origin of the model and its integrity) and traceability of the model and data themselves. Emerging techniques of watermarking are suitable for such challenges.
- Finally, fairness and stakeholder participation can be achieved by blockchain technology.

[52] L. Steels, R. Lopez de Mantaras, "The Barcelona declaration for the proper development and usage of artificial intelligence in Europe", AI Communications, 2018 https://content.iospress.com/articles/ai-communications/aic180607
[53] https://digital-strategy.ec.europa.eu/en/library/ethics-guidelines-trustworthy-ai

Another challenge concerns a loss of control of the internet itself that could dangerously affect society. One of the most important infrastructures in the world has been built quite easily, without requiring public funding, nor extensive consultations between multiple parties. This huge infrastructure can be used free of charge, for a lot of applications at least. However, the collection of personal data sold to advertisers is the key to a profit-oriented business model that consists of making money by creating addictions, that could result in social problems and conflicts[54].

7.8 Production and innovation challenges

The digital transition is currently being slowed down by a shortage in the production of many vital chips needed for computers, tablets, electric cars, AI-based services and the green transition in general. An environmental concern regarding ICT that is seldom mentioned is the use of microchips, and of electric batteries containing a very broad spectrum (nearly two-thirds) of elements in the periodic table, many of which require substantial energy to mine, and which can be significant polluters when ICT equipment is decommissioned.

The deployment of the 5G network in Europe offers enormous opportunities for more and better services and connection with unprecedented gigabit operating speeds. Its innovative architecture generates a large diversity of comprehensive processes and proactive cloud performances. This interactive technology encompasses a substantial level of applicability and versatility for IoT, machine learning, smart factories, devices for emergency interventions and critical missions such as healthcare surgery and automotive control. However, in society there are some concerns about the safety of this 5G technology. Medical radiation specialists and electromagnetic engineers recommend a precautionary principle, that is followed for the deployment in most countries.

7.9 Challenges regarding the energy consumption of ICT

Contrary to our expectations, energy consumption by ICT is a controversial subject where experts of different organizations express divergent views[55]. A reason for the controversies about ICT's energy consumption is the relative lack of systematic measurement data. Indeed, although it is technically possible to globally monitor ICT energy consumption, it requires industry to take an active role in the measurement and monitoring of its energy consumption when it provides and operates ICT devices such as computers, laptops, home entertainment and game consoles, mobile devices, network forwarders, routers, copper and fibre

[54] https://www.ohchr.org/Documents/Issues/Business/B-Tech/B_Tech_Foundational_Paper.pdf
[55] H. Ferreboeuf et al. "Lean ICT: Towards Digital Sobriety,", The Shift Project, March 2019, https://theshiftproject.org/wp-content/uploads/2019/03/Lean-ICT-Report_The-Shift-Project_2019.pdf

connectors, wireless base stations and IoT devices. While this is done by data centre operators and by most network operators, it remains difficult to do so for the billions of devices that are installed, and constantly produced and utilised.

Obviously, experts from the computer industry will tend to extol the increasing efficiency of digital equipment and its value in reducing energy consumption and CO_2 impact for important societal needs such as heating and transportation; while those that are concerned with sustainability will stress the projected increase of energy consumption by ICT, as well as the increasing use of rare and polluting materials for the manufacture of devices and computer chips. ICT is often presented as the means to obtain energy consumption savings, and the resulting reduction of CO_2 emissions, whereas in fact over the last decade ICT has substantially increased its overall share of electricity consumption, going from 4-5% a decade ago, to perhaps currently 8-10% of total electricity production, and an overall 2% share of carbon emissions, similar to the whole of air travel[56]. Of course, carbon emissions per kWh of electricity vary widely from one country to another, based on the primary sources of energy that are used, and countries such as Belgium and France that generate most of their electricity via nuclear plants have very low average CO_2 emissions, well under 100g per kWh of electricity.

In a world that consumed close to 25,000 TWh (tera-watt hours) of electricity in the year 2019, ICT amounted to roughly two thousand TWh, of which it is estimated that 50% was related to the manufacturing of new ICT equipment. Indeed, the manufacturing of ICT devices represents as much electricity consumption in one year as the total annual electricity consumption to run the devices. Other important figures for the year 2019 are the 200 TWh consumed by data centres, 250 TWh by communication networks, while 550 TWh were consumed by end-users, customer premises servers and network equipment, and laptops and mobile devices[57]. In the latter amount, we also need to include Blockchain and crypto-currencies which are estimated to consume as much electricity as a small but advanced country such as the Netherlands.

GSMA, the organisation that represents the interests of mobile operators world-wide, indicates that 20-40% of the operating expenses of network operators are currently for electricity, and that 5G will initially cause a substantial increase (in the order of 300%) of energy consumption by the wireless component of communication networks, before further design efforts possibly reduce consumption in newer generations of wireless communication systems to levels which will nevertheless be 100% higher than in previous generations of networks (i.e. 3G-

[56] E. Gelenbe and Y. Caseau "The impact of information technology on energy consumption and carbon emissions," Ubiquity Vol. 15, Issue June, Article 1, pp. 1-15, https://doi.org/10.1145/2755977
[57] G. Kamiya "Data Centres and Data Transmission Networks," International Energy Agency, Paris, June 2020, https://www.iea.org/reports/data-centres-and-data-transmission-networks

4G)[58]. Thus methods[59] that are being sought to achieve energy savings include the smart use of slower operation or 'sleep' cycles for equipment when system workloads are lower, as well as optimum equipment replacement policies that take the best advantage of new equipment with lower power consumption, to offset the additional energy consumption due to manufacturing of new equipment, and the decommissioning of old equipment. Another way forward would be to adaptively control via machine learning important system properties such as network paths and computer loads, so as to minimise objective functions that combine energy consumption and quality of service. Certain ICT industry sectors also choose to purchase energy from renewable sources to improve their emissions; although this encourages electric power companies to increase their renewable energy supplies, it also pushes non-renewable energy sources to other sectors of the economy that cannot negotiate or afford large energy contracts or premium prices.

8. Cases of accelerated digital transformation in certain sectors

Digital transformation affects all types of human activities and the COVID-19 pandemic has accelerated this transformation, with many elements that are expected to last[60]. Here we present a number of concrete professional activities that are of particular value to Belgian society and that have opportunities for accelerated transformation.

8.1 Manufacturing in the post-covid society

Manufacturing continues to be important in and after the digital and green transition.

Manufacturing, one of the key industrial sectors to ascertain and improve the living standards of the world's population, has experienced unprecedented disruption due to COVID-19. It now has to reinvent itself by finding innovative solutions to guarantee workforce safety and well-being, and to develop reliable and predictable supply chains of critical goods, and by introducing reliable, high-quality, sustainable, affordable products – all this to be achieved by adopting innovative technologies (Industry 4.0, the Internet of Things) and business

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[58] GSMA "Energy Efficiency", https://www.gsma.com/futurenetworks/wiki/energy-efficiency-2/

[59] E. Gelenbe, "Energy Consumption by ICT and Cybersecurity at the Time of COP26", Blog 9-11-2021, https://iotac.eu/energy-consumption-by-ict-and-cybersecurity-at-the-time-of-cop26/

[60] McKinsey&Company, A new survey finds that responses to COVID-19 have speeded the adoption of digital technologies by several years—and that many of these changes could be here for the long haul, Oct.2020. https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/how-covid-19-has-pushed-companies-over-the-technology-tipping-point-and-transformed-business-forever

models[61]. Robustness, resilience, agility, scalability, reconfigurability, sustainability and autonomy of manufacturing systems and products are to be taken into consideration as key performance indicators (KPIs). The concept of quality has to be redefined in the post-COVID era.

The pandemic has forced the world community to face some harsh facts: Is the world ready to find a way out of the pandemic? It is clear that the manufacturing world will have to play a key role in the evolution towards the 'new normal'. So, the question is whether manufacturing companies are ready to face the challenge. Technology watchers in US have called it 'Unmade in America: Decades of decline left the US's industrial commons[62] incapacitated in the face of the pandemic'[63]. The newly emerging technologies, such as Industry 4.0, were already transforming some, but by far not all, manufacturers' operations before the pandemic. Coping with the challenges will be reserved for the technology-haves or for those who are willing to adopt technology. The same goes for the European manufacturing industry.

From 'making things' to 'value creation'.

Manufacturing companies should focus not only on 'making things', but on 'creating value'. This requires an integrated vision of manufacturing by simultaneously merging innovation, design, production, (customer) services during the genesis of a product, as the four vertices of the value chain tetrahedron, where the top vertex (innovation) fertilises the other three vertices[64]. This requires the application of concurrent (or simultaneous) engineering methods, and the integrative mechatronic design methodology. The term Design-for-X – where X stands for design, production, assembly, use, packaging, maintenance, disassembly, recycling, transport, cost, customer satisfaction, ecological footprint – elegantly expresses the integration idea. It also underscores the need to redefine the concept of 'quality'. Quality should permeate every aspect of the value cycle. An impressive example of integrated value creation, of phenomenal complexity, is the production, packaging and worldwide distribution of COVID-19 vaccines.

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[61] https://www.digitalwallonia.be/en/posts/iot-ecosystem

[62] The 'commons' are a general term for shared resources in which each stakeholder has an equal interest. https://en.wikipedia.org/wiki/Commons The industrial commons are the publicly available technological knowledge and skills of a country that should serve as indispensable ingredients to support innovation.

[63] https://www.technologyreview.com/2020/08/14/1006428/unmade-in-america/

[64] H. Van Brussel,et al., "De maakindustrie: motor van welvaart in Vlaanderen," KVAB Standpunt #17, 2013

Some definitions

Robustness reflects the system's ability to withstand external disturbances. Resilience refers to the system's ability to keep itself in good shape (homeostasis) under external or internal disturbances. Agility reflects the ease of adaptation of the system to changing working conditions. A scalable system is easily extendable. Reconfigurability refers to the ability of the system to adapt its shape for another application. An autonomous system takes care of itself in difficult situations.

Impact of Industry 4.0 and the COVID pandemic on future manufacturing

While the previous industrial revolutions took many years to develop, with the unfolding Fourth Industrial Revolution (FIR) we now see exceedingly rapid changes in the way we live and are forced to live. The COVID pandemic has accelerated this evolution in an unprecedented way. All organisational societal structures, including industry, are deeply affected. It is no exaggeration to state that the digitalisation of society in all its aspects, brought about by the Internet, is one of the main motors of this (r)evolution. The pandemic has disrupted the world in all walks of life, not least its industry. How can industry recover from this tragedy and put its capabilities at the world's service, helped by the newly emerging ICT technologies?

Several elements are essential to advance manufacturing so that it can cope with the aftermath of the COVID pandemic:

- The role of new and emerging technologies
- Data-driven manufacturing
- Robots in a post-pandemic society
- Changes in workforce practices and skills
- Rebuild the supply chain
- New business models
- Revised business strategies

The role of new and emerging technologies: Industry 4.0. (move to higher)

The Internet of Things (IoT) expresses the ultimate dream of 'connecting everything to everything'. The Industrial Internet of Things (IIoT) is the application of this idea to the industrial world. In Germany the term IIoT is better known by its broader term: 'Industry 4.0' (I4.0).

One way to define Industry 4.0 is the integration of cyber-physical systems (CPS: digitally controlled things), cloud and edge computing, high-performance computing, IoT and Internet of Services (IoS), their interoperability and interaction with humans in real time, to maximise value creation[65].

[65] https://www.imec.org/solutions-and-resources/technology/industry-4-0/

I4.0 is expected to turn manufacturing into a smart factory infrastructure characterised by agility, flexibility, automation, autonomy, reconfigurability and cost efficiency. Advanced manufacturing hinges on the seamless incorporation and coordination of next-generation wireless technology (e.g. 5G), the internet of things (IoT), advanced artificial intelligence (AI), high-performance computing (cloud and edge), big data and data analytics, and on its protection from cyber risks.

<u>The role of artificial Intelligence</u>

Artificial intelligence (AI) and machine learning (ML) have become everyday terms, although their potential is neither fully developed nor understood. On the one hand, there is some exuberance about evolving capabilities, e.g. by deep learning, that promise to advance business and manufacturing. On the other hand, there is confusion about unknown or possible unintended consequences. AI processes data through ML and deep learning neural networks by collecting data, analysing information, creating and training a model, and ultimately making decisions based on real-time events. It is expected that next-generation AI will not only create a model based on learning from continually generated meaningful new data, but will also advance that model through unsupervised learning to understand cause and effect[66]. For example, AI can identify manufacturing quality issues in real time and spot faults on the production floor faster than humans through monitoring and machine-to-machine and human-to-machine communication, thanks to speedy, low-latency, high-capacity communication technology, like 5G. All this, however, still has nothing to do with 'general intelligence' as observed in humans. We therefore keep calling it 'narrow intelligence', without ignoring but admiring the leaps of progress that have been made through deep learning, e.g. in face recognition and medical diagnosis. But in this latter case the final decision is still reserved for the physician.

The success of future IoT will depend on next-generation wireless technology, like 5G, to allow for higher levels of automation and autonomy required in complex, distributed manufacturing systems. If thousands of sensors and actuators have to work together at high bandwidths, 5G and beyond will be required. Large numbers of IoT sensors embedded in products and machines provide information about product performance during service life through data exchange between the production line and the product. They lead to more agility, flexibility, and autonomy of the manufacturing system.

The convergence of AI and IoT will create an intelligent network of devices that can gather and analyse voluminous data – from raw materials, production lines, finished products, warehouse activities, and customer complaints – remotely

[66] R. Toews, "What Artificial Intelligence Still Can't Do", Forbes, June1, 2021.

in real time, and translate the data into intelligent actions locally through in-situ computers (edge computing). The IoT can also capture data on energy use, maintenance records, workers' safety, and other operational parameters. In addition, connected, intelligent machines can trigger maintenance processes autonomously. Data analytics can facilitate the detection of process inefficiencies and thus reduce production costs and enhance product quality. It is also possible to monitor how customers use the products, helping companies with customer service, warranty management, and product design. Last but not least, the data collected and processed about the working conditions of the factory workers directly contributes to their safety.

Data driven methods for new manufacturing processes

Not only is ICT profoundly influencing the technological society in general, and manufacturing in particular, the processes generating the products are also undergoing a revolution. A textbook example of innovative manufacturing process technology developed thanks to ICT is additive manufacturing (AM), popularly called 3D printing. AM is an additive production process – in contrast to subtractive processes, like milling, where material is removed – whereby a product is built up layer by layer, by the selective melting with a laser of a layer of metal or plastic. This process has some unique advantages, in that no special (cutting) tools or clamping fixtures are required – the product grows from the bottom up – and it allows quasi-unlimited freedom to choose the shape of the final product. In its original form, stereolithography, 3D printing was only suitable for prototyping, hence the term *rapid prototyping*. Mass customisation, 'lot size one' production at mass production prices, is facilitated a lot by rapid prototyping. Mass production is the next challenge for 3D printing. Connectivity via cloud computing, Manufacturing Execution Systems (MES), and robotised production is accelerating its development.

Multi-agent manufacturing execution systems

In order to be robust, adaptive, scalable and reconfigurable, next-generation manufacturing systems have to abandon the traditional strictly hierarchical structure and adopt a more heterarchical distributed multi-agent control architecture. The rigid rules of hierarchical systems are combined with the flexible strategies of heterarchical systems, resulting in agile systems able to cope autonomously with local disturbances. Again, ICT offers the necessary tools to implement such systems. Multi-agent control architectures developed for manufacturing can be used for controlling complex systems in other disciplines, such as robot swarms (e.g. fleets of wheel chairs in nursing homes, distribution of meals and drugs in hospitals), open-air engineering systems (harvesting, road construction, open-air mining), power grids, traffic control, and health care systems.

Digital twins

A digital twin is a digital version of a physical entity (product, manufacturing system, patient, etc.). A comprehensive digital twin describes in digital form the full life cycle of a product or production system: design, production, quality control, supply chain, use, recycling. It serves to accelerate and optimise the product design and the production cycle. It is the basis of the integrative mechatronic design approach. It also optimises the control of complete manufacturing plants, including supply and distribution chains.

8.2 Robots in the post-pandemic society

Robots are here to stay

Robots have invaded the industrial world over the last 50 years, for spot welding in the automotive industry and for material handling in all kinds of industrial and non-industrial (e.g. hospitals) activities. Now, they are gradually becoming accepted in non-industrial settings. Robot vacuum cleaners are proliferating in our households. And companion robots are making inroads in retirement homes. Rehabilitation robots help victims of accidents to recover. Intelligent wheelchairs have the potential to autonomously transport patients in hospitals or residents of nursing homes. Surgical robots controlled in a master/slave setup – where the surgeon is still the master – are increasingly used in the operating theatre.

Robots everywhere

Prevailing problems hampering the smooth transition of robot technology to the service and medical world are twofold: hardware technology and human/robot communication. Robots have, with the present drive technologies, a small load-carrying capacity versus own weight ratio, compared to humans. This makes them too bulky to serve as an 'iron nurse' for lifting bed-ridden patients in and out of their bed. Surgical laparoscopic robots need extremely miniaturised tools that can enter the body through a small incision, carrying, besides cutting and stitching tools, miniature force or tactile sensors to give a haptic perception to the hands of the surgeon, who operates the slave robot via a master console. Impressive progress is being made in university labs on these issues, giving a bright outlook to quick adoption in the operating theatre.

Human/robot communication. Cobots

As regards human/robot communication, humans and robots are starting to come together, in industrial as well as in medical settings. What is fundamental here is that the communication language should be as natural as possible. In industry, until recently, humans had to be physically separated from robots by putting the robot behind a fence. As a result of the increasing reliability of hard- and software, this rule has been gradually relaxed so that robots can now be placed, as a cobot, next to a human worker on an assembly line. This allows the worker, for instance, to take the robot by the hand and physically demonstrate the path the robot tool (e.g. a spray gun) has to follow in order to execute the task. The robot then plays back that trajectory, thereby avoiding collisions with obstacles. In intelligent wheelchairs, the control is shared between the wheelchair driver and the control computer. The computer tries to infer the driver's intention from the (inaccurate) signals he/she exerts on the joystick and plans a trajectory towards the goal. The driver might try to correct this trajectory, implying that the path imposed by the computer is not the one intended by the driver, whereupon the computer plans a new trajectory. This gives the driver the impression that he/she has everything under control. In surgical laparoscopic robots the surgeon controls the laparoscopes through a set of master joysticks, thereby guided by a picture on a monitor obtained from a camera inside the body held by another robot and positioned by the surgeon, e.g. by foot or voice control. Exoskeletons, to help paraplegic persons to walk again, are controlled through electro-myographic signals captured from remaining active muscles, from which the user's intention can be inferred and used to energise the right actuators to produce a 'normal' gait.

Robots and the pandemic

Robots and humans could become companions on a broader scale in a post-pandemic world. The COVID-19 pandemic has created dangerous situations for care personnel. From ensuring social distancing to disinfecting rooms and delivering medicine as well as automating the production of personal protective equipment, we have seen the emergence of mobile and autonomous service robots in hospitals, workspaces, and in factories during the coronavirus pandemic outbreak. Laboratories where vaccines are developed are completely robotised to protect the personnel against viral infection.

Sterilising hospital areas quickly, efficiently, and reliably has always been a challenge, but during the coronavirus pandemic it became, in some cases, a matter of life and death. Because the SARS-CoV-2 virus is highly infectious, rooms where patients are intubated (put on ventilators) or treated must be sanitised perfectly to prevent infection from spreading to other patients and hospital staff. A Danish company, UVD Robots, developed a robot that solves the very important and pressing problem of disinfecting hospital rooms and various items inside them. Instead of sprays and soaps it uses ultraviolet light to kill germs, thereby killing 99.999 percent of all viruses and bacteria in a very short time. The company started with intensive care units, but quickly realised that the robots could disinfect other places, e.g. shopping malls, supermarkets, train stations, offices, assisted living and nursing homes, fitness centres, schools, and prisons.

Robots beyond the pandemic

There are several other areas where robotics can make a difference. Besides sterilising and decontaminating spaces and equipment, they could take over the disposal of contaminated waste. Doctors, nurses and engineers are now dreaming of adopting autonomous robots to operate within coronavirus wards, taking temperature and other vital signs or perhaps even examining the patients by following doctors' commands remotely. They dream of a telepresence robot enabling them to virtually 'walk' between the rooms and talk to the patients, look at the monitors, and know what is happening. Several research labs are developing such devices; RoboTiCan at Ben-Gurion University's Robotics Lab, Israel, is a well-advanced example. These devices can act as an 'iron nurse' to lift bed-ridden patients in and out of bed or change their position to prevent bed sores. Mobile robots can be used in hospitals and nursing homes to distribute meals and medicines to the patients and residents, to distribute and remove bedlinen to and from the rooms. Robots can step in to help outside hospitals, too. When a large percentage of the population has to stay home, robots can perform vital tasks that cannot be done remotely, including operating power plants, waste treatment facilities, and other services. They can also autonomously operate warehouse docks and stock supermarket shelves. As more produce is grown in-side greenhouses, robots could help tend plants or harvest crops while workers practise social distancing. They can also deliver meals and medicines to those quarantined in their homes to reduce human contact.

8.3 Changes in workforce practice and skills

Re-engineering the work space is becoming of paramount importance (remote workforce, remote site visits, ergonomic considerations (ventilation, heat control, safe distances), co-working with robots, human/machine interaction, …).

Remote work

Companies are suddenly having to deal with remote working on a large scale, as well as new concerns about protecting their remaining on-site employees, and have had to adapt their workforce organisation. On the shop floor, such measures include: (i) keeping teams at a maximum of five to ten people, (ii) decoupling the start and end times of shifts, (iii) reorganising the workplace layout to allow for a distance of more than 1.5 metres between employees, (iv) conducting shift handovers remotely. IoT tools can play an important role in ensuring a seamless transition through these changes.

Remote employee collaboration

In general, the more digitalised a company's processes are, the simpler it is to collaborate remotely. Off-the-shelf IoT tools support the continuation of operations with fewer employees on site, since they facilitate remote work in direct and indirect functions. One solution can be to use a manufacturing execution system (MES) to optimise production and increase transparency. Even though many managers are no longer on site, the MES outputs provide the information they need to have valuable discussions during videoconferences. Similar solutions are available for the shop floor, e.g. digital team boards to coordinate jobs, measure production levels, and improve performance gaps across shifts. Other IoT tools, such as digital 'heat maps' from IoT sensors, can support root-cause analyses for various problems, such as machine breakdowns.

Workforce tracking

When facilities remain open, workforce-tracking solutions can help enforce essential physical-distancing measures. Employees can wear positioning devices for fencing purposes that show where they are moving within a facility. This information gets fed into intelligent algorithms that help managers optimise workflows.

Vision-based control systems

As with remote-collaboration tools, vision-based control systems can play an increasingly important role during the current crisis. For instance, systems that analyse video feeds can be combined with infrared imaging to detect fevers. Together, these tools can assist with the identification of infected or infectious employees, monitor physical distancing, and ensure that sick employees remain at home.

Remote facilities control

IoT can allow companies to maintain operations when public-health interventions forbid or limit on-site work by monitoring and controlling equipment remotely. To implement such services, companies must connect critical facilities to cloud-based control software.

8.4 Rebuilding the supply chain

The COVID-19 pandemic has dramatically influenced industrial activity, leading to drastically reduced production and even the shut-down of some production plants. As a consequence, supply chains have been affected by shortage of products, goods and services. Hospitals and medical providers have had to deal with a shortage of critical medical devices and personal protection equipment. When China quickly filled the gap, the vulnerability of the global supply chain became embarrassingly exposed. The discussion about the pros and cons of the globalisation of industry is flaring up. The COVID-19 vaccine development has not only left us in admiration for the virologists who in record time came up with completely innovative vaccine designs, but it also showed the enormous complexity of producing, distributing and administering the vaccines. This wake-up call is forcing manufacturers to diversify their supply chains, by moving their production to cheaper areas, or even by reshoring part of their production closer to home. Diversifying the supply chain by means of regionalisation seems to be a logical step to make it more resilient.

The popular idea of lean manufacturing that works on just-in-time delivery and low stocks has hurt many manufacturing companies in times of unavailability of raw materials and components. This has changed the minds of many companies. They have had to reconsider the way in which they produce their products, and how and where they select their suppliers. Automation along the I4.0 paradigm and the consistent use of digital twins covering the complete manufacturing and supply cycle is of paramount importance to keep complete control over the product quality and reliability of delivery.

8.5 New business models

The supply chain problems that were exposed by the COVID-19 pandemic are only one reason why the industrial world has been pondering alternative ways of doing business.

Servitisation

Several alternative business models have been proposed and applied in the recent past. One is the introduction of a new definition of what a product is. Some companies now sell so-called 'extended products'. A manufacturer of compressors no longer just sells compressors, but guarantees a certain amount of compressed air under the right pressure at the right amounts and at the right time. A weaving loom manufacturer no longer just sells weaving looms, but guarantees a certain amount of woven cloth. This new business model is called 'servitisation'.

Urban factories

Supply chain problems have also led to alternative forms of factories. Urban factories or microfactories are just one example. Urban factories are production systems located in an urban environment that make use of the unique resources and characteristics of their surroundings to create products locally with a potentially high degree of customer involvement. Examples in Germany include the production of eyewear, small electric vehicles, medical products (surgical instruments), furniture, and food. It is clear that urban factories can be part of the solution to create resilient supply chains[67].

[67] Ch. Herrmann, et al., Urban production: State of the art and future trends for urban factories, CIRP Annals-Manufacturing Technology, 765-784, 2020.

Urban factories can offer the technology needed for mass customisation or even mass individualisation. The individual taste of the consumer requires the delivery of individualised products in small lot sizes at mass production prices. Processes like 3D printing are extremely well suited to this kind of production. Examples of individualised products in the health sector are orthotics (arch supports) and prosthetic devices. Individualised car interiors are a non-medical product example produced by an urban factory.

8.6 The future of medicine: how artificial intelligence can complement medical expertise

Technological advances have radically altered the way we practise medicine over the last decade. Electronic health care records and new imaging methods such as MRI have become mainstream and have impacted the organisation of our healthcare for the better. In our everyday lives, artificial intelligence methods are increasingly adopted to facilitate and speed up common activities (e.g. by suggesting upcoming words when writing a text) or even to ensure our safety (e.g. pedestrian detection incorporated in recent vehicles). Artificial intelligence (AI) techniques, such as machine learning, have been studied for the purpose of empowering physicians for over a decade and are slowly being introduced in clinical practice. Here are some of the foreseeable changes which AI will bring to the clinic[68].

Since neural networks are capable of recognising real-life images with the accuracy of a human observer, it is not unreasonable to study their potential to identify pathological CT or MRI scans.

The first academic studies using brain MRIs were performed over a decade ago, for instance in the prediction of dementia, and they proved quite promising. However, AI methods are still not widely used in clinical practice (with some notable exceptions such as acute stroke imaging). This paradox, of an impressive number of studies on successful AI methods in medicine, contrasting with a slow adoption of AI methods in clinical practice, is often referred to as the "AI chasm". Often at the origin of this paradox there is a lack of optimal training data. Indeed, this currently slows down the development of reliable and validated AI tools in many fields. Inherent to machine learning is that a pattern is learned from a training dataset. The method assumes that all labels or diagnoses in the training dataset are correct. Even though for many conditions, pathological confirmation is the gold standard, there is often no confirmation for some cases or controls in the training dataset. A good training set should also be as large as possible because it needs to offer a representative sample of the possible phenotypes

[68] Eric Topol, "Deep Medicine: How Artificial Intelligence Can Make Healthcare Human Again", 2019, Basic Books (US), ISBN: 9781541644632

and the normal variability. Clearly, large samples are difficult to obtain for rare diseases and are also necessary to capture the large heterogeneity among common complex diseases, making it hard to feed and train an algorithm to reliably diagnose such conditions. A final consideration is that, nowadays, ethnic minorities are underrepresented in most study samples, and it is imperative that future training data becomes representative for all ethnic groups. Therefore, AI may exacerbate historical discrimination if ethical considerations are not seriously taken into account.

Another challenge which currently hampers the introduction of AI methods in clinical practice is the lack of transparency. Even if an AI software tool were able to perfectly diagnose diseases in a human patient, few physicians and patients would be comfortable accepting this outcome if the AI tool were not able to pinpoint the reasons behind a certain diagnosis. Many of the current machine-learning methods are not able to explain their outcome as they are essentially 'black boxes'. In the first publications on diagnostic AI tools, accuracy scores may have been high, but readers were left in the dark about the elements leading to a certain outcome. The field is evolving towards acknowledging that we need to know more about the key features leading to an AI diagnostic, so physicians can interpret and validate the results. In this regard, it is important to note that AI may surpass a physician's capacity to combine information across a very high number of variables, but AI is not capable of understanding which variables are directly (e.g. a blood clot blocking a vessel) or indirectly (e.g. prior history of cardiac disease or risk factors) related to a diagnosis. Ideally, the features driving the diagnostic labelling should be meaningful biomarkers that are directly related to an underlying disease process.

From the current state of the field, it is clear that pattern recognition of medical images is an emerging technique that will most likely find its way to clinical practice in many specialties in the first part of the twenty-first century. Classification of medical images has a huge potential in many domains, and (mostly in experimental studies) has already been implemented for the identification of abnormalities using MRI, CT and PET images, ECG signals, endoscopic or fundoscopic images or digitised tissue samples across a wide range of specialties (cardiology, pneumology, neurology[69], ophthalmology, dermatology, gynaecology, etc.). However, it is clear that AI tools can by no means function as independent agents in the immediate future. An appealing approach is that image classification techniques could be introduced as a triage tool, which may highlight potential abnormalities. In a real-world test setting, such an approach proved useful in significantly reducing the time to diagnosis of intracranial bleeding on CT scans, by allowing the AI algorithm to label CTs with suspected haemorrhage as 'high priority'.

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[69] R. Bruffaerts, "Machine learning in neurology: what neurologists can learn from machines and vice versa", 2018, Journal of Neurology, 265(11):2745-2748. doi: 10.1007/s00415-018-8990-9

Besides these developments related to medical imaging, AI could facilitate the physician's job by alleviating the administrative burden. Automated information extraction techniques of 'data mining' could be adopted to generate a medical history from prior records, to track relevant biochemical changes across long periods of time, to schedule follow-up examinations or to automate billing procedures. From a scientific perspective, data mining of health records may yield new discoveries such as associations between conditions or new risk factors. An interesting prospect is that such data-mining tools may be integrated with vast databases of medical knowledge or with wearables recording the patients' biometrical data. Needless to say, the use of such AI tools necessitates taking into account many regulatory issues regarding privacy and data sharing. This will require updates to the legal framework to keep up with these new technologies, and clarity about the accountability of AI tools in the event that they provide incorrect information.

While popular media sometimes claim that robots may outperform and replace physicians in the foreseeable future, this overview of the current status of the AI applications in clinical practice clearly shows that this reality is still very limited. However, machine-learning methods are powerful because they are sensitive to patterns that are hard to discern by a human observer. In the coming decades, the use of AI in clinical practice will probably increase and AI tools may enable clinicians to work more efficiently, by signalling potential abnormalities and reducing the administrative burden. Ideally, the addition of AI tools to clinical practice will free up some of the clinician's time, which could then be invested in diagnosing complex medical cases as well as communicating with patients. As such, AI tools would positively impact the quality of care and physician well-being. The future of medicine includes AI tools, not as a substitute for physicians but as their empowering digital assistants.

8.7 MedTech is the driver towards a more sustainable healthcare

Health is a state of complete physical, mental and social well-being. Healthcare is thus only a minor component for the health of an individual. In 2010, the European Commission defined the primary goal of healthcare policy as that of maximising the health of the population within the limits of the available resources, and within an ethical framework built on equity and solidarity principles. This goal encompasses three pillars of major importance: to maximise health, with limited resources, in an ethical framework. Over the last decade the goal to maximise health has not changed, however the limitations and the framework surrounding this goal have altered significantly, including the call for more social responsibility and sustainability, the fear of the impact of climate change and COVID-19, among other things.

Achieving this original ambition in a sustainable manner requires strong leadership and everything starts with the vision from a focus on the patient. It is medical technology (MedTech) with medical devices ranging from preventive diagnostic in vitro testing to digital applications that drives this digital transformation towards a value-based, connected and finally integrated care around a patient.

<u>Covid 19 is the game changer for the healthcare transformation and the breakthrough of health technology</u>

COVID-19 has changed the world. We are still all adapting our way of living (online customer and retail service), our way of working, way of care provision and cure by accelerating new ((bio)engineering & technology. "Necessity is the mother of invention" said Plato, and this is how we view nowadays the fourth industrial revolution: the acceleration towards a bio-revolution (biopharma, biomolecules, biosystems, bio-machines, bioengineering, biocomputing). In healthcare we have become open to a new generation of 'health conscious' consumers and 'tech-fan' healthcare providers.

Health technology (Health Tech) is defined according to the World Health Organization[70] as the "application of organized knowledge and skills in the form of devices, medicines, vaccines, procedures and systems developed to solve a health problem and improve quality of lives". In our opinion it can be divided into three categories: BioTech, Digital Health and MedTech:

1. BioTech is the use of living systems (cells, biomolecular processes) to develop technologies and products to help and heal people.
2. Digital Health means the use of information and communication technologies to help address the health problems and challenges faced by patients. The European Patient Forum defines it as healthcare practices supported by electronic processes and communication.
3. MedTech includes:
   - Medical devices, including surgical tools, implants, active devices and active implantable technology
   - In-vitro diagnostics including self-test, bedside and laboratory equipment
   - Embedded or stand-alone software

Within health technology, the MedTech is subject to strict European quality and safety rules (EU Medical Device Regulation). However, its use still often depends on the experience of the healthcare provider, the quality of the hospital, and the knowledge of the user.

<u>A three-shift model in our society</u>

This parallel evolution of striving for more sustainability and social responsibility, the tsunami of introducing new (medical) technology and the pandemic, and

[70] WHO (2018) What are integrated people-centred health services?, World health organisation

the corresponding economic and mental crisis, are leading to three fundamental shifts[71].

The first shift goes from *the concept of hospital to the concept of community*. This allows patients to receive good and appropriate care within their own community and thus closer to home. This does not mean that hospitals become redundant, but that they organise care close to or in the comfort of the patient's home. This could include telemedicine, chronic care management, patient remote monitoring, patient self-management with or without coaching, etc. This is not only more comfortable for the patient and more affordable for the system, it is also essential in areas where people do not have easy access to advanced medicine and hospital care.

The second shift is *from healthcare to health*, meaning caregivers would not simply act in the healthcare process but in fact intervene in the prevention and pre-care process to enable better and healthier living conditions for their previous, current and future patients. This health continuum describes how clinicians should not only focus on diagnosis and treatment but also get involved across the patient care spectrum, in healthier living, prevention and home care. This starts from the idea that citizens are in a continuous loop. When citizens are treated and receive home care, they are treated as patients. Once they are fully recovered, they go back to being citizens. However, the chances are high that if no change in their way of life is initiated, they will quickly return to being patients in the diagnosis phase. As citizens are either future or past patients, it is logical that healthcare practitioners are connected to both citizens and patients.

The third shift is to go *from quality to value*, and to offer every patient the best possible value he or she can get. Quality means that the delivered care is safe (i.e. it does not harm patients), effective (i.e. consistent with best professional knowledge), patient-centred, and meets the needs of the patients. This revolution towards value, i.e. quality over cost, will be discussed in the next paragraph.

Towards value-based connected and integrated care

Within these frameworks, three healthcare concepts play an important role: value-based, connected[72] and integrated healthcare. All three are interconnected. The idea of *value-based healthcare* is that the goal and purpose of healthcare in general is to improve the value for patients. Value is the product of the patient's personal experience with his or her outcome divided by the cost to achieve this outcome.

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[71] G. Stevens, K. De Bosschere, and P. Verdonck. Is healthcare ready for a digital future? In M. Duranton et al., editors, HiPEAC Vision 2021, pages 198-205, Jan 2021.
[72] K. Colorafi (2016) Connected health: a review of the literature, Vol 2. No 4 April, mHealth.

Value= (patient's experience*patient's outcome)/(cost to achieve patient's outcome)

But this definition also includes value for the caregivers, the health system, the relatives of the patient, etc. As M. E. Porter[73] said, the only way to unite the interests of all participants in the healthcare ecosystem is by using value as a goal. Value is created by caring for a patient's medical condition over the full cycle of care. The improvements of the outcomes are the most powerful single lever in order to reduce costs and improve value.

The second concept is *integrated care*. Integrated care brings together inputs, delivery, management and organisation of services related to diagnosis, treatment, care, rehabilitation and health promotion. Nowadays, a hospital or an individual healthcare professional can no longer operate in isolation. All of these individuals are integrated into one or more healthcare networks. Once a patient consults a healthcare worker of a certain network, he or she automatically becomes part of this network, with of course the liberty to leave or change as he/she pleases.

The last concept is *connected care*. We are increasingly confronted with smart environments. Wearables, smart cameras, ambient technology, connected equipment, etc. are embedded in a world where the Internet of (medical) Things is growing exponentially and everything and everyone is becoming connected. This connection can be seen at different scales, going from on-body to in-home to community, in-clinic or in-hospital settings. When a patient is treated with a certain device or undergoes a certain examination, digital data will be generated, stored and used by other devices, people, institutions or environments in order to improve the value for the patient.

Towards a health data framework turning data into value

Value, integration and connection are based on data. Without data that measures a patient's outcomes and costs, the value of optimising the healthcare process cannot be calculated. Without efficient data exchange, the healthcare networks described above cannot operate and healthcare staff would once again work on their own isolated islands, leading to redundant examinations and consultations.

The healthcare of the future will generate massive volumes of data. Connected devices, healthcare workers and patients will create and use data lakes. Sensors will perform the data collection from health, activity, location, emotions, parameters, etc. They will be the well of the data lake. One should not only think

[73] M. E. Porter (2006) The next wave of healthcare innovation: The evolution of ecosystems, Harvard Business Review Press.

of wearables or insideables, that monitor parameters of the patient, but also the external ambient sensors that measure humidity, temperature, weather, pollution, etc. Measuring the living environment of a patient is something that is already done with a technique called ambient intelligence. Ambient intelligence creates a digital environment that is aware of the individual's presence and context, and is sensitive, adaptive, and responsive to their needs, habits, gestures and emotions. Combining these measurements with the patient-specific data allows for a more patient-specific approach. This data, used as currency in the network, can take many forms, ranging from personal to population or environmental data and will be transferred between a variety of interested parties.

It is 'data science' that forms the important connection with the above ambition of value-based, connected and integrated care and the future of digital therapy as part of e-health, m-health and telemedicine.

Big Data can be defined as the capacity to search, aggregate and cross-reference large data sets. The 'Big Data' ecosystem[74] consists of five components: (1) data creation, (2) data collection and management, analysis and information extraction, (3) hypothesis and experiment and (4) decision-making and action. So Big Data is undeniably a process; let's call it data science. The Big Data ecosystem includes the application of advanced heuristics, statistical procedures, neural networks, machine learning algorithms, artificial intelligence techniques, ontology-based search strategies, inductive reasoning algorithms, pattern recognition, prediction algorithms, etc., with the aim of arriving at meaningful characteristics and patterns. Two key bottlenecks are still not completely solved for healthcare data: improving data quality and enriching available data. Hospitals with good data available for analysis are attractive partners for all kinds of research projects like 'discovery science' (in-depth understanding of the development of a disease), in 'clinical development' (use of data to improve the efficiency of clinical studies), and 'post-authorisation obligations' (continuous monitoring of patients on certain medications), etc.

Nowadays, data is typically spread over different entities. Central servers of hospitals, decentralised personal different communication protocols, can establish a connectivity (data transmission) between all those different parties in this integrated and connected care network: Wi-Fi, Bluetooth, cellular (3G, 4G, 5G), LoRa, etc. Of course, merely collecting and transporting data will not be enough. This continuous flow of data collection will outgrow the storage capabilities of modern-day healthcare infrastructures, and the IoMT and decentralised healthcare will only increase further the demand for storage space.

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[74] S. Singhal, B. Kayyali, R. Levin, and Z. Greenberg (2020) The next wave of healthcare innovation: The evolution of ecosystems, June. McKinsey & company.

Physical examinations will be partly substituted by a flow of digital information. Such a huge volume of data could easily overwhelm healthcare workers, leading to a situation in which value and patient outcomes no longer improve. The amount of non-processed data might lead to a decrease in efficiency and poor use of time, and thus also to a worsening of patient outcomes.

Therefore, next to collection, currency and transmission, intelligence needs to be introduced into the data framework. This intelligence, when introduced by computers, is called artificial intelligence (AI) and can be a great asset to healthcare teams. AI is able to analyse data in order to provide insights that can inform the actions of healthcare staff, decision-makers or the patients themselves. Signals that would otherwise go unnoticed or addressed too late can now be detected by the AI to trigger alarms directly to the responsible party. The use of this artificial intelligence in healthcare can be divided into three categories: knowledge-based decision support systems, data-driven clinical decision support systems and computer-aided diagnosis.

Last but not least, an important aspect of data is security. With the GDPR regulations of 2018, data protection has gained tremendous importance over the last two years. This, in combination with a huge volume of generated data, leads to the necessity to rethink the concept of data protection as a whole.

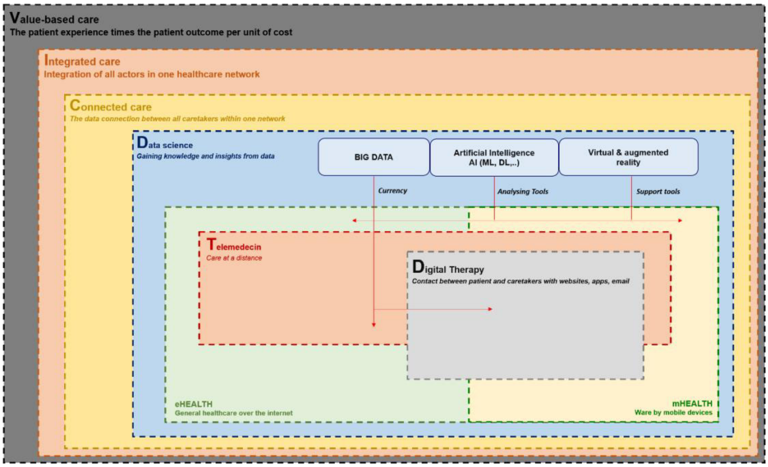
The possibility to use this data in a secure and effective way will lead to an increase in the future value of health care. Hence, without data, innovation will not create any value or vice versa.

Impact of medical technology on sustainable healthcare

The above-explained evolution can be summarised in one key figure. The vison is based on an evolution towards value-based, integrated and connected care where data science (including big data, artificial intelligence and augmented and virtual reality) is the hinge between the patient-centric approach and e-health, m-health, telemedicine towards digital diagnosis and therapy.

In conclusion[75] the focus should be on the patient in order to achieve the original ambition to maximise health, with limited resources, in an ethical framework in a sustainable manner. This means that healthcare is transformed, step by step to a value-based, connected healthcare leading finally towards integrated care around an individual. It is medical technology (MedTech) that drives this digital transformation connecting data science with digital diagnosis and therapy – thanks to sensors, data and algorithms.

[75] M. West, B. Collins, R. Eckert, R. Chowla (2017) Caring to change How compassionate leadership can stimulate innovation in health care, May. The King's fund.



8.8 The human in control of AI

Basic method for secure machine learning

In this case study we show how the basic tools of cryptography are suited for securing communication of the different steps in the deployment of a machine-learning system satisfying the criteria discussed in Section 7.6. For such systems, a first step consists of harvesting data to learn the model. The communications between the source of data and the learning model have to be secured *ad minima* by using classical cryptographic tools. The following steps can constitute an example:

1. The learning model broadcasts its public key through a certificate.
2. Each data source generates and provides a session key encrypted by the public key of the learning model.
3. The data batches provided by the sources are encrypted by their specific session key.
4. Each data batch is hashed for integrity check by the learning model.
5. Each batch hash is signed by the secret key of the data sources.
6. The computed model after learning can itself be hashed and signed for integrity and origin verification.

Such an approach can rely on exchanges at the http level and the use of Secure Socket Layer (https) and is straightforward to implement. The use of classical Advanced Encryption Standard (AES) ciphering, Secure Hashing Algorithms (SHA) for hashing and Elliptic Curves public key cryptography in SSL allows for a high level of confidence in each of these six steps. However, such an architecture does not provide additional features, which are demanded by the requirements for a Trustworthy AI.

Federated Learning, Federated Byzantine Agreements and the TCLearn model

In a classical security approach described above, all the stakeholders have to be trustworthy. If the party managing the learning model is not trusted, the learning must be distributed by means of secure federated learning, by which the model is learned by travelling across the data sources. This prevents the risk of a data leak, since only the model travels on the network while the data remains at their source.

Distributed, federated learning[76] has been proposed for multiple applications, including the medical field[77]. This approach facilitates cooperation through coalitions where each member keeps control of and responsibility for its own data (including accountability for privacy and consent of the data owners, such as patients). Batches of data are processed iteratively to feed a shared model locally. Parameters generated at each step are then sent to the other organisations to be validated as an acceptable global iteration for adjusting the model parameters. Thus, the coalition partners will optimise a shared model jointly by dividing the learning set into batches corresponding to the blocks of data provided by the members of this coalition.

The naive use of a Convolutional Neural Network in a distributed environment exposes it to the risk of corruption (whether intentional or not) during the training phase because of the lack of monitoring of the training increments and the difficulty of controlling the quality of the training data sets. The distributed learning could be monitored by a centralised certification authority that would be in charge of validating each iteration of the learning process. Alternatively, a blockchain could be used to store auditable records of each and every transaction on an immutable decentralised ledger. The blockchain approach would provide distributed learning with a more robust and equitable approach for the different stakeholders involved in the learning process, since all of them are involved in the certification process.

Classical cryptography is a technique for secure communication between multiple parties, where one party encrypts a message and sends it to another party, who then decrypts it. In machine learning on sensitive data, for example personal health data, this technique allows privacy to be guaranteed only if the parties are trustworthy and robust against attacks. If not, a data source which sends its data to the model for learning, even encrypted, must appear in clear in the AI algorithm.

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[76] Li, T., Sahu, A. K., Talwalkar, A., & Smith, V. (2020). Federated learning: Challenges, methods, and future directions. IEEE Signal Processing Magazine, 37(3), 50-60.

[77] Rieke, Nicola, Jonny Hancox, Wenqi Li, Fausto Milletari, Holger R. Roth, Shadi Albarqouni, Spyridon Bakas et al. "The future of digital health with federated learning." NPJ digital medicine 3, no. 1 (2020): 1-7

Machine learning on encrypted data

The goal of homomorphic encryption is to make the required machine learning computations feasible directly on encrypted data. In very concrete terms, the data are encrypted by a public key and sent to a model. The model itself is encrypted with the same public key and if the encryption is homomorphic, the computation done by the encrypted model will produce an encrypted result, which is equivalent to a result that would have been encrypted by the public key. Only the data provider that owns the corresponding secret key will be able to decipher the result. The AI model can therefore appear as an online service, making predictions based directly on encrypted data and providing directly encrypted results, and ensuring the highest level of privacy.

An example for the screening of patients for neurodegenerative diseases

Recent advances in Full Homomorphic Encryption (FHE) create new prospects for using personal data for screening and diagnosis. In FHE, personal data are encrypted through a public key associated with an individual. The data are processed by a model enciphered with the individual's public key. The result is obtained in an encrypted mode and is accessible only to the owner of the private key associated with the public key that was used. This makes it possible to create a personal homomorphic vault containing data over a long period of time. The encrypted data will be processed by models that could be improved over time through machine learning.

An example that is explored at UCLouvain, Belgium, on the early detection of Alzheimer's disease from personal data is given in Figure 6. The model is trained 'in clear' by data coming from volunteers, while the tests for large-scale screening are achieved with a high level of privacy by using the FHE.

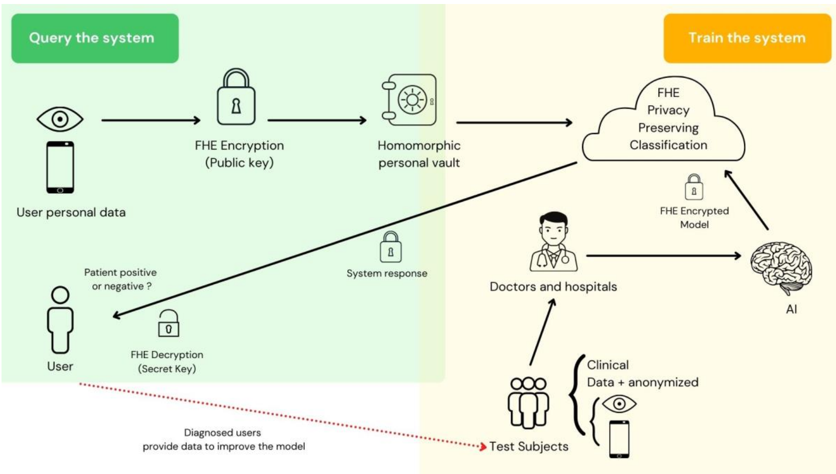
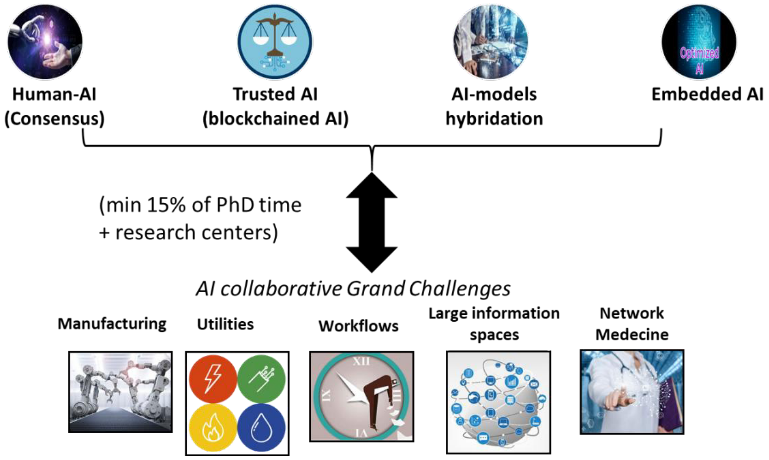


Figure 6 A privacy-preserving classification model. A user encrypts her private medical data and uploads it to a cloud computing service. Researchers encrypt their trained model parameters under the same public key and upload to the cloud, which performs the required computation for privacy-preserving classification. This result is then returned to the user, who decrypts it with his/her private key. Some of the patients agree to participate in clinical trials for which they give their complete data sets for AI training in an anonymised environment based on batching and federated learning.

Traceability of data and models through watermarking

The watermarking of data can be used for tracing a leak. Each batch of data can be slightly but robustly modified to contain a specific mark of the destination (for example, the learning model) in such a way that a leak at the destination point can be detected.

The research on cryptography for Trusted AI is supported in Wallonia in the framework of the TRAIL (Trusted AI Labs) Institute[78]. TRAIL is a virtual institute grouping the give French-Speaking universities in Belgium (UCLouvain, ULB, ULiège, U-Mons and U-Namur) as well as four research centres (Multitel, Cetic, Cenaero and Sirris). TRAIL will ensure the attraction, training and retention of talents in the Wallonia-Brussels Federation in order to allow the appropriation of AI by companies and public services. The TRAIL Institute will conduct cutting-edge research identified as strategic and will aim at connecting it with Flanders and at the highest international level. The research concerns both purely technological aspects and other questions fundamental to the appropriation of AI by the economic and social fabric (change management, AI law, data intelligibility, etc.).



[78] Trusted AI labs https://trail.ac/

Figure 7: TRAIL is developing, among other things, research programmes on Cryptography for Trusted AI in a framework that connects the research to industrial needs through Grand Challenges.

8.9 Supply Chain Management in COVID-enabled enterprises

<u>Is there a need for a change in the supply chain?</u>

Coronavirus has raised the question, among many others, about what is the appropriate response in order to protect and maintain, or possibly improve, the supply chain performance as it has evolved in recent years. This case study proposes immediate and longer-term actions that can be taken in response to business disruption and supply chain challenges from the global spread of COVID-19, including looking ahead to the longer-term solution of digital supply networks. As such, COVID-19 could be the catalyst that forces many companies, and entire industries, to rethink and transform their global supply chain model. One fact is beyond a doubt: the pandemic has already exposed the vulnerabilities of many organisations, especially those who have a high dependence on external partners to fulfil their need for raw materials or finished products. The supply chain has been shaken by recent events, but it has not been broken, thanks to many governmental, entrepreneurial and individual initiatives. The companies that continue to scale their infrastructure and place the customer at the core of their operations will be the ones to thrive as we emerge from this pandemic.

However, businesses can no longer avoid actions in digitalisation or risk management in favour of cost reduction. The visibility vacuum, coupled with an emphasis on just-in-time inventory management practices, has meant that many businesses have lacked the flexibility to tackle this crisis. With delivery slowdowns compounding upon an inability to source crucial products, the dependence upon just-in-time inventory management and global sourcing networks demonstrates a fundamental weakness. The necessity for a buffer and improved visibility has been made painfully evident.

Recent findings have shown that some companies are better prepared than others to mitigate the impact. These companies have developed and implemented supply chain risk management and business continuity strategies. They have also diversified their supply chains from a geographic perspective to reduce the supply-side risks from any one country or region. They have multi-sourced key commodities or strategic components to reduce their reliance on any one supplier, and they have considered an inventory strategy to buffer against supply chain disruption. These companies have built strong relationships with key suppliers and have put systems in place to provide visibility across the extended supply network in order to better understand their risks and drive specific actions based on their priorities. They developed agility within their production and distribution networks to quickly reconfigure and maintain supply to meet global demand, and they invested in supply chain planning and control tower solutions to better sense and respond, and even predict, supply chain issues.

Other companies are scrambling. These companies are overly reliant on a single geography or a single supplier for key products. They don't have enough visibility across the extended supply network to see their risks. They don't have the systems to understand their inventory status, to project stock-outs of direct materials and optimise production, or to project stock-outs of finished goods to optimise customer allocation, and they don't have flexible logistics networks to ensure the profitable flow of goods.

Demand for change in the global supply chain is not new. The ongoing trade war between the USA and China has already prompted businesses to diversify their supplier bases away from China. Other factors are driving change, including the desire to mitigate disruption risk generally, cost savings, greater output agility and closer proximity to centres of demand. COVID-19 has only served to further expose the fragility of global supply chains and turbocharge the demand for change. A recent ongoing survey of 50 chief financial officers from Fortune 1,000 companies found that one third of the companies listed supply chain issues as a top-three concern among dangers facing their businesses. The required changes take time and will ultimately rely on technology innovation and implementation, often through the acquisition of technology disruptors by established industry players.

Supply chain resilience is a new imperative

The topic of supply chain resilience sprouted in the media and professional journals as a result of the coronavirus pandemic. Resilience is defined as the capacity to recover quickly from difficulties or get back into shape. Suketu Gandhi and Steve Mehltretter characterise the new situation in a recent report[79]: *"For many companies, supply chain excellence has long meant developing the most cost-effective way to deliver a product on time to your customers. While detailed modeling and analysis are often completed to design these 'optimal' supply chains, it was usually only done for a relatively narrow range of supply and demand variability options. When the COVID-19 pandemic hit, many businesses learned the hard way how this tight focus limited their abilities to cope with a sudden shock to their supply chains. The pandemic has proven that the definition of supply chain excellence must be expanded beyond cost effectiveness and on-time performance to also consider supply chain resilience."*

[79] Suketu Gandhi and Steve Mehltretter, Toward a more resilient supply chain, October 23, 2020. https://www.supplychainquarterly.com/articles/4061-toward-a-more-resilient-supply-chain

It is important to identify areas in which breakdowns have already occurred, and localise points of vulnerability like single sourcing, single point of income, outsourced operations, technology reliance, energy reliance, foreign currency exposure or specific human talent.

Once known threats and breakdowns are identified, Gandhi and Mehltretter argue, *"Companies need to evaluate how resilient their supply chains are in order to determine their strengths and vulnerabilities in light of unanticipated shifts and future crises. These evaluations or 'stress-tests' would resemble the banking stress tests that came into being and forced banks to shift focus from short-term profit toward the long-term resiliency. … These stress tests would examine supply chain resiliency along a number of different dimensions, including geography, planning, suppliers, distribution, manufacturing, product portfolio/platforms, and financial/working capital."*

A decades-long focus on supply chain optimisation to minimise costs, reduce inventories, and drive-up asset utilisation has removed buffers and flexibility to absorb disruptions. COVID-19 illustrates that many companies are not fully aware of the vulnerability of their supply chain relationships to global shocks.

Fortunately, new supply chain technologies are emerging that dramatically improve visibility across the end-to-end supply chain, and support companies' ability to resist such shocks. The traditional linear supply chain model is transforming into Digital Supply Networks (DSNs), where functional silos are broken down and organisations become connected to their complete supply network to enable end-to-end visibility, collaboration, agility, and optimisation. Leveraging advanced technologies (Internet of Things, artificial intelligence, robotics, 3D printing and 5G), DSNs are designed to anticipate and meet future challenges. Whether it is an event like COVID-19, a trade war, act of war, terrorism or natural disaster, regulatory change, labour dispute, sudden spikes in demand, or supplier bankruptcy, organisations that deploy DSNs will be ready to deal with the unexpected.

Preparedness

The lack of preparedness in the industry has had numerous impacts on the supply chain industry's ability to navigate this crisis. Those enterprises found to be lacking in risk management protocols struggled to maintain the flexibility and clarity that would have allowed their partners and customers to better navigate the crisis.

"We've always been focused on three main areas of innovation, which we believe will become even more relevant in a post-COVID-19 world. The first is dynamic data science. The second is intelligent logistics automation, which has been driven by the employees to make the warehouse safer and more efficient. The third

priority is the digitalization of transportation and the customer experience. These are trends we already saw before COVID-19, and that are accelerating now."[80]

Demand Planning

Software should attempt to create a picture of shifting market needs by taking into account factors such as the labour force, weather conditions and geopolitical events, and demand planning. The pandemic has introduced unexpected volatility into customer demand, making it even more difficult to discern demand patterns.

Furthermore, silos between sales and operations have hindered data-sharing which would have proved useful in navigating these issues. Supply and demand sides need to work together more effectively in order to identify these purchase behaviours early on. Orienting manufacturing pipelines in tandem with customer demand will help to build a cohesive and resilient supply chain strategy. Consolidating data flows within the organisation and managing procurement, demand and inventory are all opportunities that can be realised via demand-planning software.

Just-in-Time Inventory Management

Just-in-time (JIT) inventory management strategies are designed to increase efficiencies and reduce waste by scheduling the receipt of goods as they are needed in the production process, reducing overall inventory costs by operating on an as-needed basis. As the data shows, there is a great deal of uncertainty across the supply chain industry about the long-term viability of just-in-time management as an inventory strategy.

Inventory management is intimately connected with sourcing. During this crisis, a dependence upon single-supplier sourcing has exacerbated inventory issues. Without proper visibility into alternatives or a previously validated and tested dynamic sourcing procedure, companies are left struggling and forced to shoulder potential quality risks as well as unexpected costs when switching suppliers or production locations. Just-in-time inventory is not going to go away. The challenge is who is going to be responsible for filling the gap between just-in-time and just-in-case. Excess capacity for redundancy would be difficult for private enterprises to handle themselves. It needs to be a collaboration between public and private in order to respond to these types of surges in the future, whether it be for personal protection equipment, pharmaceuticals, or other supplies. These are both policy and economic decisions. Similar to just-in-time inventory strategies, uncertainty around sourcing highlights the concern brewing in the industry as the pandemic forces companies to reconsider their sourcing strategies. What emerges as most

[80] Erik Caldwell, XPO Logistics - Supply Chain, Americas & Asia Pacific

necessary with respect to sourcing is the development of robust risk-assessment procedures. In the short term, companies can institute best practices in order to safeguard their supply chains against prolonged shocks.

There are several lessons learned, and opportunities have emerged from a review of the critical challenges and sector spotlights. These include:

1. *Strength of existing networks:* existing networks in supply chains are underpinned by existing relationships, knowledge and experience, which make it possible to identify where help is most needed. In the sectors explored in this study, rich networks enabled organisations in the supply chain to identify and successfully address the gaps in the supply of components, services, or skills. For example, a manufacturer trying to source a component in short supply can be connected to a supplier whose current client base has been reduced by the pandemic. Similarly, these networks can support workforce planning by helping those people with critical skills who have been made redundant to find opportunities for retraining or redeployment. The electronics industry and the oil and gas sector are current examples of where these networks have been best leveraged.
2. *Communication* around supply chains connected to critical resources and infrastructure: to limit the impact of a potential next wave of COVID-19 or other shocks in global supply chains, there is a need for clear communication and guidance for industries in the wider network of critical supplies. Critical resources and infrastructure providers were deemed essential and were given clear guidance while others that are equally important for the smooth running of a supply chain were not given clear instructions. These supply networks include component manufacturers for supplies, transport and logistics, and the workforce.
3. *Building back better and greener:* it is vital that recovery moves us forward not backwards. We need a future supply chain that is more resilient and greener, with a strong capacity for innovation. This will require evolution and alignment of multiple regulatory regimes, and consideration of risk, ethics and security issues. Given the right circumstances, technologies can reduce vulnerabilities, yet this will involve regulatory alignment across multiple policy areas that may be affected. For example, a shift to a more digitalised food supply chain may have implications for regimes that regulate transport, telecoms, health and safety and more.
4. *The role of digital technologies:* the pandemic has emphasised the importance of supply chain networks and the way in which digital technologies can enhance visibility of available capacity across the supply chain. Policy needs to be established to ensure 'critical national capability', which may require changes to the way some vital manufacturing and supply chains operate.
5. *A diversity of suppliers* and timely information about their capabilities can enable pivoting during a crisis and/or developing new ways of delivering existing supplies. For example, understanding the network of possible suppliers globally

can inform alternative plans to source materials. Knowledge of how suppliers have found new ways of transporting goods can also demonstrate the different stages of the supply chain where innovation is taking place. Although supply chain efficiency over the last decade has led to productivity, consolidation of supply has, in some cases, led to one supplier becoming a single point failure. The crisis has exposed how challenging it is to pivot away from such failures without a diversity of suppliers to draw upon. Having a diversity of suppliers and up-to-date information about their capabilities can enable pivoting during a crisis.

6. *A systemic, sector, sub-sector and firm level view:* understanding the supply networks at a systemic, sector and sub-sector level is required. With information at a systemic level, we can understand how shocks propagate to other parts of the system and how multiple disruptions are caused. A sector view can capture factors affecting stakeholders in relation to a product or service. It is also sensitive to industries (supply side) and markets (demand side) that share similar characteristics. A sub-sector view can demonstrate how these shocks and disruptions affect organisations at a firm level. For many firms and organisations, the challenges are wider than the supply chain itself and require an understanding of how value is created at different stages.

Finally, a reminder should be added to the development of the 'Physical Internet', as suggested by the KVAB in its recent standpoint on Mobility[81]:

"Physical Internet: an Internet for Transport

Physical Internet (PI) is increasingly presented as a way to smart, sustainable and fair logistics. PI is defined as "transforming the way physical objects are handled, moved, stored and realized, supplied and used, aiming towards global logistics efficiency and sustainability"[82], PI can be regarded as an application of the internet, but for transport. The underlying network is the so-called TEN-T (Trans-European Network for Transport), which links the European consumption and industrial centers by road, rail and (where possible) waterways, with Galileo as a navigation system. Transporting goods is similar to sending an email over the internet. In that network, the providers active in the various nodes know, thanks to the TCP / IP protocol, how to continue the e-mail over the network to the destination. Similarly, the shipper must register his cargo on PI. Thanks to the internet of things (IOT), the availability of all participating and certified carriers can be evaluated. Using algorithms, the available transport and storage capacity is combined into an optimal route across the transport network. For example, a transport from Spain to Belgium may be carried out in five stages and by five transporters, but in a lead time that is shorter than when using a reserved truck

[81] KVAB Standpunt, "De mobiliteit van morgen: zijn we klaar voor een paradigmawissel?", 2018. https://www.kvab.be/nl/standpunten/de-mobiliteit-van-morgen

[82] Benoit Montreuil, The PI Initiative's Manifesto, 2012, https://www.slideshare.net/physical_internet/physical-internet-manifesto-eng-version-1111-20121119-15252441

with a driver, where the driving times of the latter determine whether or not the truck drives."

9. Conclusions

As happened with the advent of the printing press in the 15th century, the digital transition is disrupting many societal mechanisms. This process is ongoing and is quite comprehensive. It has been accelerated by the COVID-19 pandemic. It offers many opportunities for solving many of the challenges of the next generation as well as the sustainable development goals. But there are also many choices and design decisions that should be made in a synergetic interaction between ICT specialists, engineers, social scientists, and policy makers in order to avoid misuses.

Since the digital transition is a transformative process that has an impact on many aspects of our daily life and activities, this position paper addresses many strong links with various human activities. Those that are related to the digital transition are discussed in detail here with a number of case studies about the impact of digitalisation on various sectors and services. For those that are related to climate change and the green transition, we refer here to a next joint ARB/KVAB position paper[83]. In section 7.9 it is shown that an accelerated digital transition has a strong impact on electric energy consumption, and hence there is a need for urgent action regarding energy efficiency, energy sobriety, and energy-efficient digital technologies.

The future value for society can only be realised by powering innovation and data across all disciplines. Disruptive innovation must lead idealistically to a better personal experience and outcome for each individual and a lower cost for society. To realise this value, data must be connected, combined and shared in a safe, secure and sustainable infrastructure.

10. Recommendations

Now is the time to act. As Winston Churchill was working to form the United Nations after WWII, he famously said, "Never let a good crisis go to waste". There is now a unique opportunity to take profit of the issues, problems and lessons raised and learned during the pandemic.

- *A crisis can be leveraged by leaders to rally support* – The leaders of the country, regions and organisations should seize on the pandemic crisis to bring forward bold and profound measures courageously, like the regaining of efficiency in the regulations and responsibilities, work from home, online meetings, online teaching, etc.

[83] Joint KVAB-ARB position paper on an accelerated green transition expected for 2023.

- *Crises may help us challenge assumptions* – During the crisis a number of implicit and explicit behaviours were not permitted that were often based on unmentioned assumptions. After the crisis there is an opportunity to eliminate unnecessary rules and historical privileges.
- *Lessons from failures and how we address them* – In the text several examples are given on how we can learn from the failures that occurred in the pandemic, and how the digital transition can contribute to solutions and remedies.

Accelerated and sustained efforts for digital literacy for all

The digital transition will only succeed in our country if the efforts towards increased digital skills and insight in the digital world are accelerated for young and old. As explained in the previous sections, a good insight into the ingredients, the opportunities and the limitations of the digital transformation can lead to a responsible use of the digital instruments and services and can prevent unnecessary fear.

Role of formal education

Since the transition is still ongoing, digital skills and training should be improved at a continuous pace in all levels of schools and for all pupils and students. Digital tools should be an integral part in all subjects and should facilitate more flexible learning processes that are close to the needs of the individual pupils or students. Moreover, the need for professionals in ICT is expected to increase and the motivation for and appeal of such professional schooling should be addressed.

Encourage safe, responsible, ethical and sustainable IT

Collective actions and an awareness programme should be organised with media campaigns in order to stimulate the safe, responsible, ethical and sustainable use of all digital & ICT devices and services[84] with special attention to the significant energy consumption.

Role of the media

Influential mass and social media have an important role to play in avoiding unjustified projections of the digital transition. Fake news and some science fiction movies often present an unrealistic world where superhumans or AI enslave the masses. Rather regulatory and technological instruments, which keep the individual in control, are already in place and should be extended. Some of these are already presented in this position paper and project a flourishing society where humans and artificial systems and robots work together and complement each other.

[84] https://isit-be.org/

An appeal for a stronger deployment of adult training

Belgium is lagging behind in lifelong learning as discussed in Section 6.4. The digital transition will bring about a labour shortage that depends critically on the availability of skilled workers for all tasks in the digital society. This is not a one-shot effort; instead, since the transition is still evolving into more and better digital services and methods, there will be a continued task for better digital literacy, permanent education and skills development for the whole of society.

Increased attention for the comprehensive view on the non-negligeable energy consumption and environmental impact of the digital transition

ICT systems, including computing hardware, software and communications equipment, should be optimised so that their energy consumption and CO_2 impact is minimised while preserving the required quality of service specifications. In order to reduce its environmental impact, the reuse of old equipment should be stimulated and the rate of replacement of equipment should be minimised.

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See footnotes.

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