Alliance for Internet of Things Innovation

IoT Improving Healthy Urban Living

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Executive Summary

This Paper reflects on the matter "How can IoT be deployed in a trustworthy manner to improve health and well-being in urban societies, placing focus on disease prevention instead of treatment?"

Modern society has become removed from several of the traditional ways of experiencing and interacting. Tactile information has always been central in understanding context and non-verbal signals. Research is being conducted to reintroduce this element in communication through technology: gloves with actuators, electricity to stimulate nerves, and a brain interface to directly convey the missing bits of jigsaw puzzle that is the human mind. The current situation is that we are still far from a working solution.

In the meantime, new fields within the domain of computer science have enabled the visualisation of large amounts of data through statistics and infographics, tools for simplifying scenarios through designing virtual users (personas), designing information architecture to make it more obvious what choices are relevant and how to avoid mental strain when navigating complex content.

Despite all the efforts being put into making cities smarter and homes more adaptable to individual needs, what is often observed in the domain of IoT is the focus on optimising the past and its problems. However, rapid urbanisation and the advances in the digital domain call for the deployment of innovation and technology as tools to help create a sustainable solution for individuals, the environment, and the future. New solutions require the development of new methods for those solutions to take hold and be widely adopted. In a smart society, healthcare responds to situations before they happen - not after. Prevention can save more lives than treatment afterwards. The cost for society will be much higher when the damage is already done.

Technology has been the driving force behind changes in human psychology, so it must be expected to take these aspects of human psychology into consideration when preparing living conditions and solutions that are improving lives. A good life does not only consist of a healthy body, but mental health is also just as important; in fact, it may be more important. Technology such as integrated home assistance devices and healthcare equipment can support fast response actions. Augmented reality and improved display technologies can contribute to the visual impact of a space by providing clearer images over a larger field of view, while noise cancelling or background sounds from natural sources can offer potential to soothe the mind or enhance the feeling of wellness.

IoT and related technology could play an important role in connection to physical and mental health and well-being. However, innovation does not come without its own risks and impact. The shift towards digitisation, particularly, in the domain of health care and healthy living must ensure that the right level of trust and accountability has been established in the relevant digital ecosystems. In order to do so, as a society, we must gain awareness and learn to appreciate and understand the various challenges and opportunities in order to work together to mitigate some of these risks and impacts. This is necessary to establish ideal scenarios that law a framework for an ecosystem that fosters innovation and development, not only of the relevant technological solutions but leaves room for truly healthy urban living, both on the level of the individual and the society.

Table of Content

Table of Figures

Definitions and Abbreviations

Internet of Things	The Internet of Things (IoT) merges physical and virtual worlds, creating smart environments. It represents the next step towards the digitization of our society and economy, where objects and people are interconnected through communication networks and report about their status and the surrounding environment.[1]
Healthy Urban Lifestyle	A lifestyle related to individuals and communities living in cities, that is characterised by the absence of disease as well as good physical and mental health.
Value-based Healthcare	Value-based healthcare is "the creation and operation of a health system that explicitly prioritizes health outcomes which matter to patients relative to the cost of achieving this outcome."[2]
Optimal Health	*The best health an individual can get given their physical, social and economic status […terminology still to be added and t.b.d.]
Complementary and Alternative Medicine (CAM)	CAM encompasses a variety of alternative treatments that have historic origins outside of, and are used in combination with, conventional medicine. There is no unique classification of CAM domains.

[1] 'Europe's Internet of Things Policy | Shaping Europe's Digital Future' <https://digital-strategy.ec.europa.eu/en/policies/internet-things-policy> [accessed 21 September 2022].

[2] *Value-Based Healthcare: A Global Assessment* (The Economist Intelligence Unit, 2016) <https://impact.economist.com/perspectives/sites/default/files/EIU_Medtronic_Findings-and-Methodology_1.pdf>.

Introduction

"Making sense of your senses through sensors"

Health is a word that means different things to different people. The most widely recognised definition of health was formulated by the World Health Organisation (WHO) in 1948 and defines health as a 'state of complete physical mental and social well-being, not merely the absence of disease or infirmity'. Wellness defines a healthy lifestyle, by taking into consideration mind, body, and spirit for an overall feeling of well-being. Wellness is not the management of a current condition, but wellness is a set of comprehensive, and individual-level choices made well before the occurrence of any such health condition.[3] Clearly stated: someone who is satisfying wellness is living well and is working towards the prevention of their own disease and disability. The term departs from traditional health because it does not focus on curing anything, but on living well.

Well-being is the state of being comfortable, healthy, or happy. Both concepts are part of the definition of health, there where wellness contains a lifestyle of prevention and the freedom from illness, wellbeing entails also wellness but also includes happiness which is not explicitly referenced in wellness. Simply put: traditionally, health just meant managing sickness. Wellness has come to mean living well, and wellbeing means living well and enjoying happiness. In essence, concise clear definitions of health, wellness and wellbeing respectively are to get well, live well and be happy.[4]

In recent years however, it has been argued that the WHO's definition of health has several limitations, for example, the use of the word 'complete' unintentionally contributes to the over-medicalisation of society, as it requires an unrealistic standard.[5] This unrealistic standard is as a result of the changing demography of populations and in disease prevalence with a shift from acute diseases to chronic disease coupled with an ageing population, a move towards effective self-management (the day-to-day management of chronic conditions by individuals over the course of an illness) is required.[6] In addition, recent trends have seen the development of new screening technologies to detect abnormalities at levels that might never cause illness and pharmaceutical companies produce drugs for 'conditions' not previously defined as health problems. For example, an 'over-diagnosis' of certain health conditions has resulted in a significant increase in the inappropriate use of prescription medication.[7] These factors arguably move us more towards a view of health as 'the ability to adapt and self-manage.'[8]

This new approach to defining health is increasingly applicable when one considers that in the early 20th century the leading causes of mortality were infectious diseases such as pneumonia and tuberculosis. Death was often as a result of an epidemic and linked to poor immunisation and inadequate sanitation facilities. During the 20th century the leading causes of death have changed from infectious diseases to those that relation to unhealthy behaviour, lifestyle and external environmental factors. This paper will combine both the WHO's definition of health as well as the more novel view of health, thus defining the notion as "a state of complete physical, mental and social well-being not merely the absence of disease or infirmity" as well as "the ability to adapt and self-manage."

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[3] Anna Kirkland, 'What Is Wellness Now?', *Journal of Health Politics, Policy and Law*, 39.5 (2014), 957–70 <https://doi.org/10.1215/03616878-2813647>.
[4] Max Albert Holdsworth, 'Health, Wellness and Wellbeing', *Interventions Économiques*, 62, 2019 <https://doi.org/10.4000/interventionseconomiques.6322>.
[5] M. Huber and others, 'How Should We Define Health?', *BMJ*, 343.jul26 2 (2011), d4163–d4163 <https://doi.org/10.1136/bmj.d4163>.
[6] Huber and others.
[7] Sujit Rambhade and others, 'A Survey on Polypharmacy and Use of Inappropriate Medications', *Toxicology International*, 19.1 (2012), 68 <https://doi.org/10.4103/0971-6580.94506>.
[8] Huber and others.

This paper represents a collection of theories and conceptual tools from various disciplines embedding the complexity science. Complexity science is a recent approach to research, it entails the study of a system and not a single theory. Complexity theory states that "if we really want to understand failure in complex systems, we need to explore how things are related to each other and how they are connected to, configured in, and constrained by large systems of pressures, constraints, and expectations."[9] Deploying a complexity science approach in IoT innovation to improve health in urban environments is the way forward. A complex outlook on novel problems will allow for the creation of novel solutions to mitigate problems of the future.

It is said that a smart city is not truly smart until the citizens feel they can naturally make the right choice. For most of history, human beings have lived in low-density, rural environments. Since the 1950s, there has been an increased embrace of urbanisation, resulting in the world's urban population rising almost six-fold, from 752 million to 4.2 billion in 2018, and by 2050 up to 68% of humans will live in urban areas.[10] There are several benefits to living in cities: urban dwellers, on average, are wealthier and receive improved sanitation, nutrition, contraception, and healthcare.[11] Overall life expectancy has also increased, and in many cases a greater quality of life for older people is achievable.

Yet, despite the benefits of urban living, there are also several shortcomings. Unfortunately, as human-beings gather in cities and become increasingly more removed from nature and natural impulses, incidences of both mental and physical ailments are increasing. Urban living is associated with increased risks of chronic diseases and disorders, including mood and anxiety disorders,[12] loneliness,[13] and substance abuse.[14] Moreover, environmental factors of urban areas pose, various and often negative, consequences for the health and well-being of urban dwellers. For example, depression and anxiety are symptoms of people being deprived of the senses that can be gathered in nature.[15] The sense of warmth from another person, the smell of fresh grass, the light trickling between green trees.

Urban environments have inevitably forced individuals to live closer and closer to one another; the paradox, however, is that urban dwellers have become lonelier than ever. According to a 2019 JRC study, based on the European Social Survey (ESS), 7% of the adults in Europe feel lonely, and 18% of all Europeans are socially isolated. Social isolation is particularly prevalent among people with poor health, those without jobs, and the elderly. With loneliness and social isolation on the rise, urban environments have caused urban dwellers to increasingly move away from the traditional 'community' based living structures, causing us to become more self-reliant. However, this need for a 'community' is inherent to the human nature and critical to survival from an evolutionary perspective. Consequently, social isolation has forced individuals to search for a sense of community in digital ecosystems as opposed to natural ones.

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[9] Sidney Dekker, Paul Cilliers, and Jan-Hendrik Hofmeyr, 'The Complexity of Failure: Implications of Complexity Theory for Safety Investigations', *Safety Science*, 49.6 (2011), 939–45 <https://doi.org/10.1016/j.ssci.2011.01.008>.

[10] '68% of the World Population Projected to Live in Urban Areas by 2050, Says UN | UN DESA | United Nations Department of Economic and Social Affairs' <https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html> [accessed 21 September 2022].

[11] Christopher Dye, 'Health and Urban Living', *Science*, 319.5864 (2008), 766–69 <https://doi.org/10.1126/science.1150198>.

[12] J. Peen and others, 'The Current Status of Urban-Rural Differences in Psychiatric Disorders', *Acta Psychiatrica Scandinavica*, 121.2 (2010), 84–93 <https://doi.org/10.1111/j.1600-0447.2009.01438.x>.

[13] Keming Yang and Christina Victor, 'Age and Loneliness in 25 European Nations', *Ageing and Society*, 31.8 (2011), 1368–88 <https://doi.org/10.1017/S0144686X1000139X>.

[14]Kim Parker and others, '4. Views of Problems Facing Urban, Suburban and Rural Communities', *Pew Research Center's Social & Demographic Trends Project*, 2018 <https://www.pewresearch.org/social-trends/2018/05/22/views-of-problems-facing-urban-suburban-and-rural-communities/> [accessed 21 September 2022].https://www.pewresearch.org/social-trends/2018/05/22/views-of-problems-facing-urban-suburban-and-rural-communities/

[15] 'Oxytocin: What It Is, How It Makes You Feel & Why It Matters' <https://www.psycom.net/oxytocin> [accessed 21 September 2022].

Air pollution has various health effects. The health of susceptible and sensitive individuals can be impacted even on low air pollution days. Short-term exposure to air pollutants is closely related to COPD (Chronic Obstructive Pulmonary Disease), cough, shortness of breath, wheezing, asthma, respiratory disease, and high rates of hospitalization (a measurement of morbidity).[16]

Moreover, technology has forced us to adapt to urban environments; cities with their sharp concrete corners and artificial lights, have evolved into 'normal' habitats for human beings. Sight, sound, and other senses shape the human impression of the surroundings. When one of these components is missing, other strategies need to be developed to compensate for the missing object. Alongside basic emotions like anger, fear, hunger, and lust, the need to be seen and accepted represent a psychological foundation for healthy living. Tying together mental and physical health with a functional society is central to reducing the cost of personal and public costs.

Due to the substantial and continual increase in urbanisation in the next two decades and the increasing life expectancy, it is, therefore, vital to assess ways in which the quality of life of urban dwellers can be improved. Urban societies and urban dwellers are dynamic, unpredictable, and multidimensional; they consist of a system of interconnected relationships and parts. Therefore, it is essential to take a human-centric and holistic approach to tackle the risks associated with living in urban societies.

Nevertheless, there is still room for improvement in the domain of IoT for healthcare and wellbeing; not only in the innovation and research and development front but in the surrounding policy and regulatory landscape that also form a vital part of the digital ecosystem in which these IoT solutions exist. Researchers suggest that a specific challenge to be addressed is to allow sensing technologies to make interferences when necessary and to adapt to the physical circumstances. However, when these techniques are applied, the systems need to be well-tested and suitable for the situation and available tools. The connotations may be many, but the toolbox is wide. For example, on-body sensors communicate with smart mirrors or machine learning that reacts to your needs and can provide suggestions or act independently if a medical situation arises or is about to be triggered. Apart from contributing to combatting physical and mental illness, IoT can also contribute to a general sense of safety in urban environments.[17]

Introducing value-added services that build upon this knowledge, opens markets that could not be envisioned at the turn of the millennium. Understanding one's own health and taking responsibility for one's own destiny through monitoring one's living conditions becomes an increasingly more central part of the services that smart cities and communities are expected to provide. These aspects are well understood, and many remedies have been marketed and sold for decades.

The last decade has seen significant advancements in the development of biotechnologies. These advancements, despite the monumental positive effects such technologies have delivered to our society; little consideration has been given to the risks and impacts resulting from such technologies, particularly the technologies that are directly available to consumers. Biotechnologies have forced the reconceptualization of the human body and its parts, as

[16] Ioannis Manisalidis and others, 'Environmental and Health Impacts of Air Pollution: A Review', *Frontiers in Public Health*, 8 (2020), 14 <https://doi.org/10.3389/fpubh.2020.00014>.
[17] 'ShotSpotter: Public Safety, IoT, and Big Data', *Harvard Business Publishing* <https://hbsp.harvard.edu/product/BAB358-PDF-ENG> [accessed 21 September 2022].

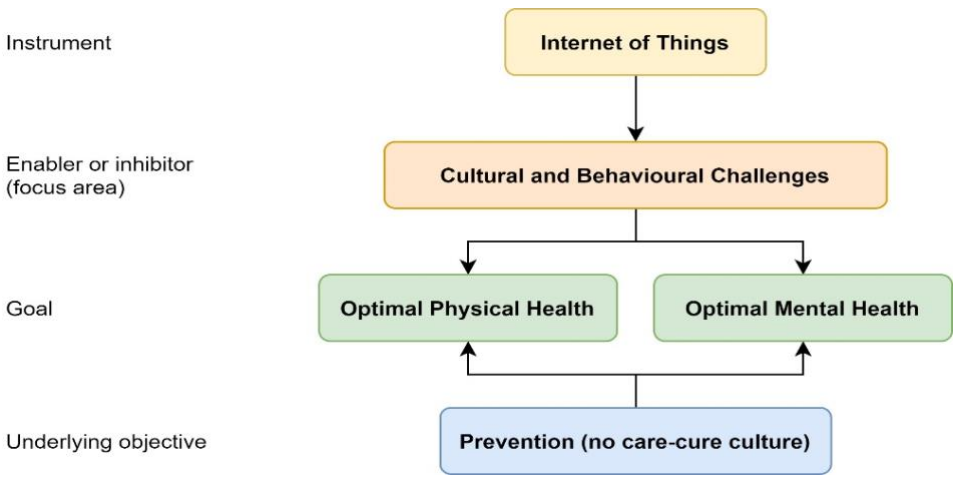
such.[18] These technologies "expose diverse constructions of the body, its potential for fragmentation, and ultimately, its commodification."[19]

Recent developments in the field of biotechnology have enabled the generation of new forms of body commodification and often are even essential to this process.[20]

Humankind and technology have traditionally been viewed as two separate systems. When these two systems do not interact or seem to be incompatible, individuals can easily develop feelings of alienation. Distrust grows from a lack of understanding, or the feeling of being insignificant as a small part of larger machinery, automated through processes far removed from human management and control. Technology and the digitisation of the world have led humankind and technology to become interconnected and intertwined. Technological developments that fail to adequately take the interconnectedness between digital systems and the human being into account have left individuals behind; feeling lost and disconnected from the world around them. Urban environments are complex systems. Therefore, solutions to pave way for better health outcomes for urban dwellers require a systems-based and interdisciplinary approach.

Scope

This report focuses on how IoT can be deployed to foster mental and physical health, thereby putting the weight on disease *prevention* as opposed to treatment. Furthermore, cultural and behavioural factors, including the degree of trust in IoT and other technical applications, digital data, governments and the industry itself, are explicitly included in the scope.



[18] Article 3(2), Charter of Fundamental Rights of the European Union
[19] Lesley A. Sharp, 'The Commodification of the Body and Its Parts', *Annual Review of Anthropology*, 29.1 (2000), 287–328 <https://doi.org/10.1146/annurev.anthro.29.1.287>.
[20] Sharp.

Figure 1 Scope Diagram

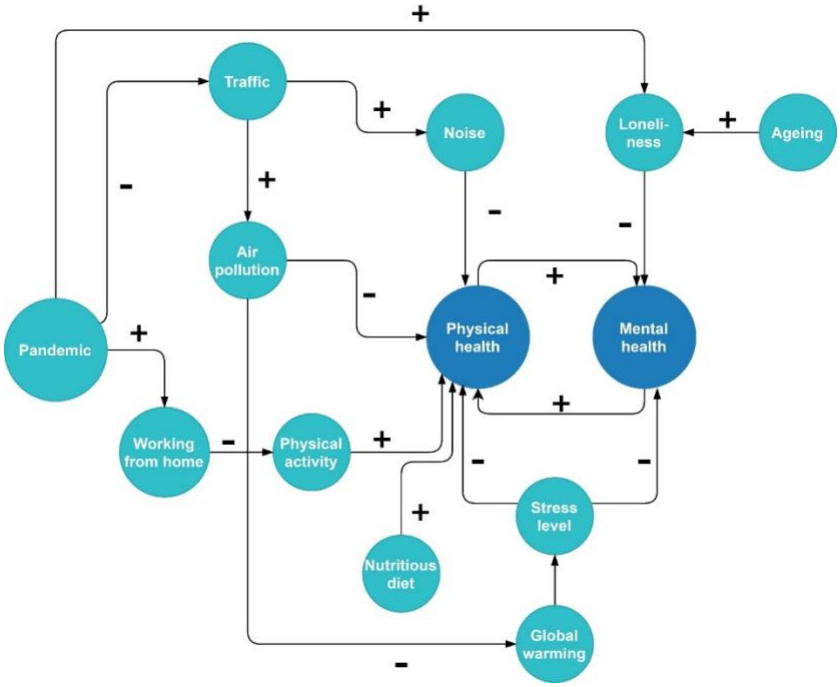


Figure 2 Flow Chart – Problem Framing

2. State of Health and Healthcare in Urban Environments

Currently, nearly 70% of the European population lives in towns and cities. The United Nations has stated that urban environments are frequently associated with unhealthy living environments; the presence of heavy traffic, pollution, noise, violence, and social isolation for young families and the elderly are major challenges of urban societies.[21]

The lockdown and home isolation due to the COVID-19 pandemic led to significant transformations in lifestyles. Moreover, with the budget reductions in health care spending across the EU over the last 20 years[22] and the spread of COVID-19, the capacity of the healthcare systems in Europe has been put under pressure in an unprecedented way. The crisis highlighted the strengths as well as weaknesses of dealing with an event of these proportions. This pandemic has made explicit that we should take the opportunity to implement an ambitious reform agenda for European health systems through the direct involvement of all stakeholders and policymakers at regional, national and EU level.

2.1 Physical and Mental Health

The World Health Organization (WHO) estimates that around 63% of deaths globally are a result of lifestyle related diseases and further estimates that by 2030, tobacco's annual death toll will rise to more than eight million.[23] Physical inactivity increases all-cause mortality risk by 20–30%, excessive alcohol use accounts for about 3.8% of deaths worldwide, and an unhealthy diet is linked to heart disease, stroke, diabetes, and cancer.[24] Many of the leading causes of death in Europe (Ischaemic Heart Disease, Cerebrovascular Disease, Cancer, and Chronic Respiratory Disease) are all strongly related to behaviour.[25] In 2016 the American Heart Association report stated that approximately 80% of cardiovascular diseases (CVDs) can be prevented through not smoking, eating a healthy diet, engaging in PA, maintaining a healthy weight, and controlling blood pressure (BP), diabetes mellitus, and elevated lipid levels.[26] A 10% weight reduction in men aged 35 to 55 through dietary modifications and exercise would produce an estimated 20% decrease in coronary artery disease, it would also lower the degree of degenerative arthritis, gastrointestinal cancer, diabetes, stroke, and heart attack.[27]

Communicable Diseases

The COVID-19 pandemic has greatly affected the lives of people around the world. COVID-19 may not be the only pandemic we will face in our lifetime, we may, again, be faced with the need to isolate and minimise social contact. Therefore, it is vital to find ways to mitigate the

[21] Steven Allender and others, 'Quantification of Urbanization in Relation to Chronic Diseases in Developing Countries: A Systematic Review', *Journal of Urban Health: Bulletin of the New York Academy of Medicine*, 85.6 (2008), 938–51 <https://doi.org/10.1007/s11524-008-9325-4>.
[22] 'Coronavirus : la doctrine de la fermeture des lits à l'hôpital « est venue se fracasser sur l'épidémie »', *Le Monde.fr*, 12 June 2020 <https://www.lemonde.fr/societe/article/2020/06/12/l-hopital-en-quete-du-juste-nombre-de-lits_6042577_3224.html> [accessed 21 September 2022].
[23] 'Tobacco' <https://www.who.int/news-room/fact-sheets/detail/tobacco> [accessed 21 September 2022].
[24] Ryan Ng and others, 'Smoking, Drinking, Diet and Physical Activity—Modifiable Lifestyle Risk Factors and Their Associations with Age to First Chronic Disease', *International Journal of Epidemiology*, 49.1 (2020), 113–30 <https://doi.org/10.1093/ije/dyz078>.
[25] *EHealth Research, Theory and Development: A Multidisciplinary Approach*, ed. by Lisette van Gemert-Pijnen and others (London: Routledge, 2018).
[26] Writing Group Members and others, 'Heart Disease and Stroke Statistics-2016 Update: A Report From the American Heart Association', *Circulation*, 133.4 (2016), e38-360 <https://doi.org/10.1161/CIR.0000000000000350>.
[27] Gemert-Pijnen and others.

impact of diseases on individuals and society. A reduction in physical activity and an increase in mental health problems were observed, mainly in the first year of the pandemic.[28]

Noncommunicable Diseases (Chronic Diseases)

It is estimated that over two-thirds of global deaths are attributed to noncommunicable diseases (chronic diseases). Lifestyle changes in the last three decades, including the increase in sedentary lifestyles and the setbacks caused by the SARS-CoV-2 pandemic, have led to an increase in the number of people suffering from chronic diseases.

Chronic diseases result from a combination of genetic, physiological, environmental, and behavioural factors. Cardiovascular diseases, cancers, chronic respiratory diseases, and diabetes are the most common chronic diseases. According to the WHO, chronic diseases account for 71% of all deaths globally.[29] Moreover, there has been a significant rise in the rate of cancer in individuals under 50, due to the changes in individual's diet, lifestyle, weight, environmental exposures, and microbiome in the last several decades.[30] There are several risk factors that increase an individual's likelihood of the development of chronic diseases in the course of their lives. For example, for cancer, risk factors for early onset include the level of alcohol consumption, sleep deprivation, smoking, obesity, and a diet of highly processed foods.[31]

Obesity

Individuals particularly susceptible to NCDs are those that are overweight and obese. Obesity is a serious chronic disease, and the prevalence of obesity continues to increase worldwide. The fundamental cause of overweight is an energy imbalance between calories ingested from food and calories used to carry out activities. Today, almost 40% of the global population suffer from overweight or obesity.[32] This epidemic affects general health, health costs and productivity. The rate of obesity continues to rise steadily and as such, is a major public health issue. According to statistics from the WHO, approximately 2.8 million people die per year due to being overweight or obese. Overweight individuals have a BMI of 25.0-29.9, whereas obese individuals have a BMI of 30.0 or greater; a healthy BMI is between 18.5 to 24.9. Obesity is prevalent in both high-income countries, as well as low- and middle-income countries. The prevalence of obesity almost tripled between the years 1975 and 2016. In 2016, more than 1.9 billion adults were overweight, and 650 million were obese.[33] However, adults are not the only people suffering from obesity, childhood obesity has also become a serious public health challenge. In 2020, the WHO (World Health Organization) reported that 39 million children under the age of five were overweight or obese. More importantly, the mortality rates linked to overweight and obese individuals is higher than the rates of underweight individuals globally.

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[28] Priscila Marconcin and others, 'The Association between Physical Activity and Mental Health during the First Year of the COVID-19 Pandemic: A Systematic Review', *BMC Public Health*, 22.1 (2022), 209 <https://doi.org/10.1186/s12889-022-12590-6>.
[29] 'Non Communicable Diseases' <https://www.who.int/news-room/fact-sheets/detail/noncommunicable-diseases> [accessed 21 September 2022].
[30] Brigham and Women's Hospital Communications, 'Researchers Report Dramatic Rise in Cancer in People under 50', *Harvard Gazette*, 2022 <https://news.harvard.edu/gazette/story/2022/09/researchers-report-dramatic-rise-in-early-onset-cancers/> [accessed 21 September 2022].
[31] Brigham and Women's Hospital Communications.
[32] 'Obesity and Overweight' <https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight> [accessed 21 September 2022].
[33] 'Obesity' <https://www.who.int/news-room/facts-in-pictures/detail/6-facts-on-obesity> [accessed 21 September 2022].

Although individual behaviours significantly contribute to obesity, studies have shown that there are correlations between the urban physical and social environment and overweight and obesity.[34]

One particular concern is the upward trend in childhood obesity, which often continues into adulthood, highlighting the importance of early intervention,[35] and the absence of signs of stabilisation. It has been shown that almost 90% of children who were obese at 3 years of age were overweight or obese even in adolescence.[36] In Europe, the overall prevalence of obesity in children aged 7-8 years is 10% and 14% among girls (fig. 3) and boys (fig. 4), also stressing the importance of addressing sexual differences in the development of obesity.

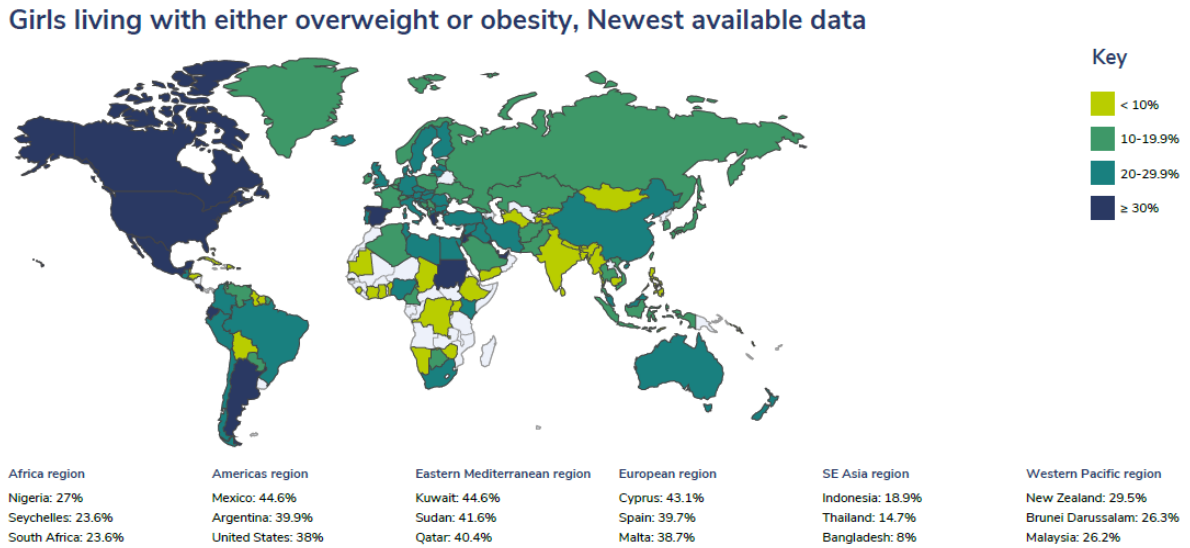

Figure 3 Girls living with either overweight or obesity in 2020

Source: World Obesity Federation

[34] Peter Congdon, 'Obesity and Urban Environments', *International Journal of Environmental Research and Public Health*, 16.3 (2019), 464 <https://doi.org/10.3390/ijerph16030464>.
[35] Mandy Geserick and others, 'Acceleration of BMI in Early Childhood and Risk of Sustained Obesity', *The New England Journal of Medicine*, 379.14 (2018), 1303–12 <https://doi.org/10.1056/NEJMoa1803527>.
[36] *WHO European Childhood Obesity Surveillance Initiative (COSI) Report on the Fourth Round of Data Collection, 2015–2017* (WHO Regional Office for Europe, 2021).

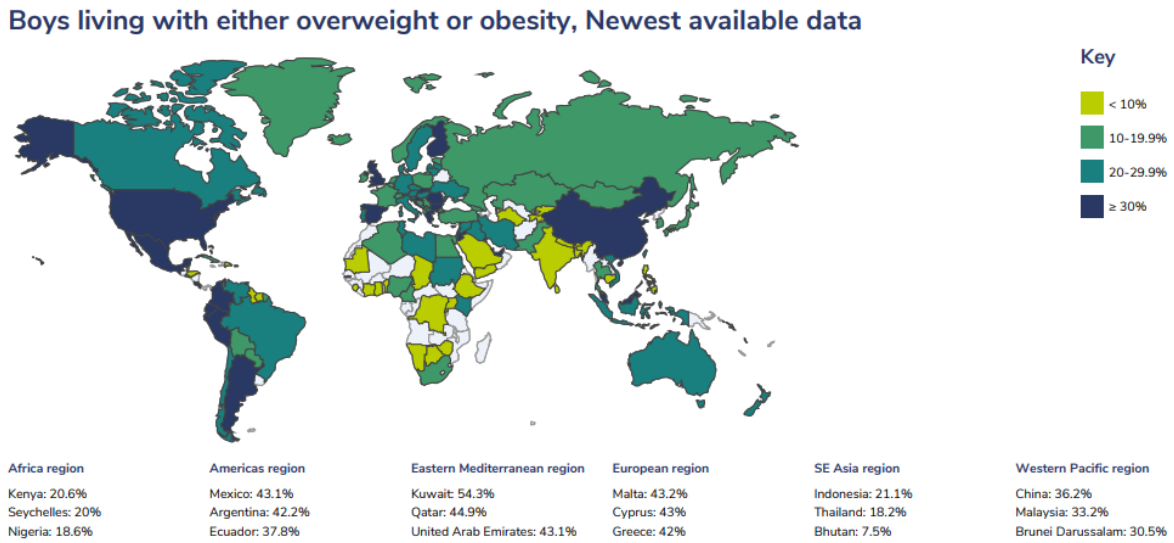

Figure 4 Boys living with either overweight or obesity in 2020

Source: World Obesity Federation

Being overweight can lead to the development of type 2 diabetes, cardiovascular disease (mainly heart disease and stroke), and some cancers (including endometrial, breast, ovarian, prostate, liver, gallbladder, kidney, and colon). A healthy diet and regular physical activity help people to achieve and maintain a healthy weight from an early age and continue throughout life. There has been an avid increase in the body mass index of children and adolescents, this index has stabilized in many high-income countries, although at high levels, but has accelerated in some parts of Asia, with trends no longer related to those of adults.[37]

To make matters worse, the levels of physical activity among individuals are substantially declining, and sedentary behaviour is continually increasing.[38] Due to changing patterns of transportation, increased use of urbanization, and technology, levels of inactivity can be as high as 70% with a significant correlation between the country's economic development and an increase in inactivity. Meeting recommended levels for these energy-related needs is especially low, particularly among adolescent girls, and those of lower socioeconomic status. Worldwide, one in four adults and three in four adolescents (aged 11-17 years) do not currently meet the global recommendations for physical activity set by WHO.[39] This represents 1-3% of national health care costs across all European countries. Energy-related behaviours (physical activity, sedentary behaviour) are the main modifiable determinants of several chronic diseases that track into adulthood, such as diabetes type 2, overweight, and obesity.

[37] Leandra Abarca-Gómez and others, 'Worldwide Trends in Body-Mass Index, Underweight, Overweight, and Obesity from 1975 to 2016: A Pooled Analysis of 2416 Population-Based Measurement Studies in 128·9 Million Children, Adolescents, and Adults', *The Lancet*, 390.10113 (2017), 2627–42 <https://doi.org/10.1016/S0140-6736(17)32129-3>.
[38] S. W. Ng and B. M. Popkin, 'Time Use and Physical Activity: A Shift Away from Movement across the Globe: Declines in Movement across the Globe', *Obesity Reviews*, 13.8 (2012), 659–80 <https://doi.org/10.1111/j.1467-789X.2011.00982.x>.
[39] *Global Action Plan on Physical Activitiy 2018-2030: More Active People for a Healthier World* (World Health Organization, 2018) <https://apps.who.int/iris/bitstream/handle/10665/272722/9789241514187-eng.pdf>.

Epilepsy

Based on a UK government report, it has been shown the SUDEP (Sudden Expected Death in Epilepsy) is responsible for 33,000 deaths in Europe each year, of which 40% are preventable.[40]

Epilepsy is a prevalent disease within neurological pathologies and affects 0.7-1% of the general population.[41] At least half of the patients with epilepsy are young and active. These patients need regular follow-ups with hospital Neurology services or Epilepsy Units. Waiting lists for successive appointments in the doctor's office is variable, with an average of 6-9 months. The number of unexpected visits is 1.7 per day, and the minimum wait for a scheduled review is 30 days, in case of decompensation for any reason.

One worrying figure is the increasing number of children with epilepsy affected by sudden death in Europe. For this reason, the effort in the field of epilepsy is concentrating on the development of automated seizure detectors, with portable or minimally invasive devices (bracelets, earpieces, etc.), which allow alerts to be generated in the event of a seizure and avoid potentially lethal situations, such as sudden death in epilepsy.

The data obtained from automatic monitoring systems (wearables) in the follow-up of these patients with epilepsy and the development of an automated seizure detection algorithm that generates an alert in case of life-threatening seizures represent a step forward in epilepsy care, bringing it closer to the desirable personalised medicine. E-consultation solutions to meet the demand for chronic pathologies have proliferated in recent years, especially after the pandemic situation resulting from COVID-19. However, epilepsy has particularities that require a more specific approach, and there are currently no technological tools available to fully meet these needs. There is a need for innovative solutions improve the quality of life perceived by epileptic patients by facilitating a more convenient communication with his doctor and empowering him to better manage his disease.

Mental Health

Mental illnesses, such as depression, anxiety and bipolar disorder impact approximately 165 million people in the European Union alone.[42] Research suggests that the prevalence and risks of depression can be associated with characteristics of modernisation. Cross-cultural studies in both urban and rural environments show that the degree of modernisation is correlated with a higher prevalence of depression, particularly in women.[43] In the developed world, incidences of psychiatric disorders, specifically mood and anxiety disorders, in urban dwellers is higher than that of their rural counterparts.[44]

A study performed across EU countries indicates that access to mental health care within the EU 'is far from satisfactory'. The researchers found that important barriers to mental health care are low perception of need, conflicting illness models between clients and professionals, and healthcare services not responding adequately to the needs of people.[45]

Therefore, it is vital to incorporate the promotion of mental health in health care policies and invest in solutions that will improve the overall mental health of urban dwellers. Mental health is

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[40] James J. Sun and others, 'Seizure and Sudden Unexpected Death in Epilepsy (SUDEP) Characteristics in an Urban UK Intellectual Disability Service', *Seizure*, 80 (2020), 18–23 <https://doi.org/10.1016/j.seizure.2020.05.004>.
[41] 'Epilepsy' <https://www.who.int/news-room/fact-sheets/detail/epilepsy> [accessed 21 September 2022].
[42] H. U. Wittchen and others, 'The Size and Burden of Mental Disorders and Other Disorders of the Brain in Europe 2010', *European Neuropsychopharmacology: The Journal of the European College of Neuropsychopharmacology*, 21.9 (2011), 655–79 <https://doi.org/10.1016/j.euroneuro.2011.07.018>.
[43] Judith Colla and others, 'Depression and Modernization: A Cross-Cultural Study of Women', *Social Psychiatry and Psychiatric Epidemiology*, 41.4 (2006), 271–79 <https://doi.org/10.1007/s00127-006-0032-8>.
[44] Peen and others.
[45] https://ec.europa.eu/health/sites/default/files/mental_health/docs/ev_20161006_co02_en.pdf

arguably the first line of defence against the emergence of physical ailments and may even be key in understanding the root cause of some of the most chronic and deadly diseases we face as a society.

Ageing Population

Today most people can expect to live into their sixties and beyond. At this time the share of the population aged 60 years and over will increase from 1 billion in 2020 to 1.4 billion in ten years. By 2030, 1 in 6 people in the world will be aged 60 years or over. By 2050, the world's population of people aged 60 years and older will double (2.1 billion). The number of persons aged 80 years or older is expected to triple between 2020 and 2050 to reach 426 million.[46]

The increasing elderly population puts extra pressure on healthcare systems globally in terms of operational costs and resources.

Furthermore, research shows that the COVID-19 pandemic has exacerbated the loneliness problem among the elderly population.[47,48]

Social Isolation & Loneliness

Loneliness is a major societal problem, particularly among elderly individuals. Although the ageing population is more socially isolated, feelings of loneliness and lack of belonging are becoming increasingly prevalent among people between 26-45.[49] Over the past 1.5 years, social isolation measures, such as working from home, social distancing and avoiding contact in general, have been encouraged to fight the COVID-19 virus. However, as we move past the pandemic it has been reported that that 49% of surveyed adults in the US were expected to be uncomfortable about returning to in-person interactions.[50]

Although reduced physical contact with others does indeed prevent the chances of viral infection, the loneliness and stress often caused by social isolation are known to have a negative effect on the immune system. Several studies show that the human immune response to viruses is strengthened by social connections.[51,52] Chronic stress triggers a sympathetic response and releases cortisol, this is by definition a catabolic reaction and goes against body self-regeneration and cellular preservation.[53]

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[46] 'Ageing and Health' <https://www.who.int/news-room/fact-sheets/detail/ageing-and-health> [accessed 21 September 2022].
[47] Theresa Heidinger and Lukas Richter, 'The Effect of COVID-19 on Loneliness in the Elderly. An Empirical Comparison of Pre-and Peri-Pandemic Loneliness in Community-Dwelling Elderly', *Frontiers in Psychology*, 11 (2020), 585308 <https://doi.org/10.3389/fpsyg.2020.585308>.
[48] Marla Berg-Weger and J. E. Morley, 'Loneliness and Social Isolation in Older Adults during the COVID-19 Pandemic: Implications for Gerontological Social Work', *The Journal of Nutrition, Health & Aging*, 24.5 (2020), 456–58 <https://doi.org/10.1007/s12603-020-1366-8>.
[49] 'How Lonely Are Europeans?' <https://joint-research-centre.ec.europa.eu/jrc-news/how-lonely-are-europeans-2019-06-12_en> [accessed 21 September 2022].
[50] *Stress in America: One Year Later, a New Wave of Pandemic Health Concerns* (American Psychological Association, 2021) <https://www.apa.org/news/press/releases/stress/2021/sia-pandemic-report.pdf>.
[51] Leonardo J. Gutierrez and others, 'Internet of Things for Mental Health: Open Issues in Data Acquisition, Self-Organization, Service Level Agreement, and Identity Management', *International Journal of Environmental Research and Public Health*, 18.3 (2021), 1327 <https://doi.org/10.3390/ijerph18031327>.
[52] Julianne Holt-Lunstad, Timothy B. Smith, and J. Bradley Layton, 'Social Relationships and Mortality Risk: A Meta-Analytic Review', *PLoS Medicine*, 7.7 (2010), e1000316 <https://doi.org/10.1371/journal.pmed.1000316>.
[53] Suzanne C. Segerstrom and Gregory E. Miller, 'Psychological Stress and the Human Immune System: A Meta-Analytic Study of 30 Years of Inquiry', *Psychological Bulletin*, 130 (2004), 601–30 <https://doi.org/10.1037/0033-2909.130.4.601>.

2.2 Environmental Factors

Environmental factors of urban environments not only significantly shape individual behaviour but has a direct impact on the health and well-being of individuals, regardless of whether or not an individual's lifestyle choices can be deemed as 'healthy' or 'unhealthy'. For example, pollution of air, noise, light, or water can induce negative health outcomes for urban dwellers. Climate change has the potential to exacerbate certain urban health risks and inequalities as a result of the increase in the occurrence and severity of extreme weather events.[54]

"Air pollution is the greatest external threat to human health on the planet, and that is not widely recognised, or not recognized with the force and vigorous that one might expect", said Professor Michael Greenstone, who developed the Air Quality Life Index (AQLI). The AQLI converts air pollution levels into a measurable matrix for the impact on life expectancy.

Air pollution is cutting short the lives of billions of people by up to six years.[55] Air pollution is a major environmental health issue that affects everyone; it is a significant risk factor for human health.[56] This form of pollution also contributes to various diseases, including but not limited to, respiratory infection, lung cancer, cardiovascular disease, and asthma.[57] However, reducing pollution comes with a price; it could force various industries to radically reform their business practices in order to ensure that the impact of their commercial activities on society is reduced.

In addition, there are several environmental influences on the dietary patterns of individuals. Areas with diminished access to fresh fruits, vegetables, and other whole foods, otherwise known as 'food deserts', tend to be more common in socio-economically deprived areas or ethnic minority neighbourhoods.[58,59] Poor dietary patterns of large groups of urban dwellers are attributable to the prevalence of fast-food outlets and convenience stores that offer processed foods, instead of access to supermarkets, grocery stores, and farmers' markets. Poor dietary choices and limited access to healthy food options play a major role in the rates of overweight or obesity in society.

2.3 Current State of Play of IoT

The global internet of things (IoT) in healthcare market size is expected to experience significant growth by reaching USD 446.52 billion by 2028.[60] This is attributed to the rising focus on active patient-centric care and patient engagement, rise in high-speed technologies for IoT connectivity, rising need for implementing cost-control actions within the healthcare sector. On top of this, the increasing awareness regarding fitness and health is leading to the demand for self-health management techniques. This has surged the demand for several medical wearable devices globally as people can easily access and monitor their health at any given time.

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[54] Sotiris Vardoulakis, Keith Dear, and Paul Wilkinson, 'Challenges and Opportunities for Urban Environmental Health and Sustainability: The HEALTHY-POLIS Initiative', *Environmental Health*, 15.S1 (2016), S30 <https://doi.org/10.1186/s12940-016-0096-1>.
[55] 'Air Pollution Is Slashing Years Off the Lives of Billions, Report Finds', *EPIC* <https://epic.uchicago.edu/news/air-pollution-is-slashing-years-off-the-lives-of-billions-report-finds/> [accessed 21 September 2022].
[56] Murat Darçın, 'Association between Air Quality and Quality of Life', *Environmental Science and Pollution Research*, 21.3 (2014), 1954–59 <https://doi.org/10.1007/s11356-013-2101-3>.
[57] Annette Prüss-Üstün and C. Corvalán, *Preventing Disease through Healthy Environments: Towards an Estimate of the Environmental Burden of Disease* (Geneva, Switzerland: World Health Organization, 2006).
[58] Renee E. Walker, Christopher R. Keane, and Jessica G. Burke, 'Disparities and Access to Healthy Food in the United States: A Review of Food Deserts Literature', *Health & Place*, 16.5 (2010), 876–84 <https://doi.org/10.1016/j.healthplace.2010.04.013>.
[59] Junfeng Jiao and others, 'How to Identify Food Deserts: Measuring Physical and Economic Access to Supermarkets in King County, Washington', *American Journal of Public Health*, 102.10 (2012), e32–39 <https://doi.org/10.2105/AJPH.2012.300675>.
[60] *Internet of Things (IoT) in Healthcare Market Size, Share & COVID-19 Impact Analysis, By Component (Devices, Software, and Services), By Application (Telemedicine, Patient Monitoring, Operations and Workflow Management, Remote Scanning, Sample Management, and Others), By End-User (Laboratory Research, Hospitals, Clinics, and Others), and Regional Forecast, 2021-2028* (Fortune Business Insights) <https://www.fortunebusinessinsights.com/infographics/internet-of-things-iot-in-healthcare-market-102188>.

Moreover, several manufacturers are focusing on introducing advanced monitoring devices to cater to the growing consumer demand.

Additionally, the COVID-19 pandemic has caused a change in providers' willingness to implement IoT solutions which helped in diagnosing the virus using IoT. Despite the potentially growing role of AHA-IoT services in the healthcare market, a systemic dimension of the innovation is still far to be reached. A value-driven innovation can really support decision makers' choices and promote innovation sustainability.

We are increasingly experimenting, both at local and global dimensions, that evidence of the AHA-IoT services value is needed for helping decision-makers in adopting innovation to support social and healthcare services sustainability. Limited available resources, an increasing number of elderly people and the level of demand for chronic diseases management services push decision-makers to choose a compromise between the resources they would need to fund all potentially useful interventions (e.g., social or healthcare programs) and those that are in their budgets. It's a fact that, in limited resources settings, it is important that the available budget is allocated as efficiently as possible, and decision-makers are called to make comparisons across alternative uses of the same amount of resources. The achievement of this objective, as well as the evaluation of the services' effectiveness level, can be supported by a structured process to generate objective evidence of services' costs-effectiveness.

It is important also to take into account that the IoT market in the healthcare sector is highly fragmented and a comprehensive picture of the AHA-IoT services value and sustainability is needed at EU level to promote the quality and equity of AHA services around Europe and strength the European Digital Market. That's the reason why the generation of a shared evidence generation process is perceived as a key objective to be pursued, able to lead replication and scaling up processes of innovative services.

3. Applications of IoT in Preventive Health Care

NCDs present a tremendous burden to both individuals and the health care system. Such diseases significantly reduce the quality of life for patients and for their families and involve high costs, either to the individual or to health care systems; these costs increase as the population ages. There exist several preventive strategies for many chronic diseases; these preventive strategies include primary prevention, intervening before the disease occurs, secondary prevention, detecting and treating diseases at an early stage, or tertiary prevention, managing a disease to slow or stop its progression. These interventions, combined with lifestyle changes, can substantially reduce the incidence of chronic disease, disability and death associated with such diseases.[61]

When deploying IoT in urban environments with the focus to promote healthy urban living and preventive healthcare measures; two main branches of solutions must be considered, namely, solutions catered to the individual and solutions to mitigate the impact of urban environmental factors that impact the urban society at large. Encouraging people to adopt healthier lifestyles, and supporting those who wish to do so, is a highly desirable goal.

On the individual level, improved overall well-being and preventive health can be achieved through the consideration of four main topics (see Figure 5): 1) physical activity, 2) healthy diet, 3) emotional management with positive psychology to manage our emotions to improve stress management),[62] and 4) sleep management. As illustrated in Figure 5, these domains are intertwined and effective combination of these four domains are crucial in promoting truly healthy urban living solutions for urban dwellers.[63]

Figure 5 Healthy Lifestyle Venn Diagram: 1) physical activity, 2) healthy diet, 3) emotional management with positive psychology, and 4) sleep management.

Source: SAREF4HAW-Compliant Knowledge Discovery and Reasoning for IoT-based Preventive Healthcare and Well-Being. Amelie Gyrard and Antonio Kung. Elsevier Book: Semantic Models in IoT and e-Health Applications 2022

[61] National Center for Chronic Disease Prevention and Health Promotion. The power of prevention. Chronic disease: the public health challenge of the 21st century. Atlanta (GA): Centers for Disease Control and Prevention, US Department of Health and Human Services; 2009. https://www.cdc.gov/chronicdisease/pdf/2009-Power-of-Prevention.pdf. Accessed November 3, 2018.
[62] Martin E. P. Seligman, *Flourish: A Visionary New Understanding of Happiness and Well-Being*, 1. Free Press hardcover ed (New York, NY: Free Press, 2011).
[63] SAREF4HAW-Compliant Knowledge Discovery and Reasoning for IoT-based Preventive Healthcare and Well-Being. Amelie Gyrard and Antonio Kung. Elsevier Book: Semantic Models in IoT and e-Health Applications 2022. https://www.elsevier.com/books/semantic-models-in-iot-and-ehealth-applications/tiwari/978-0-323-91773-5

However, despite the need for individual-level interventions on behaviour to improve healthy living; it does not truly take into account the full reality of urban living. External factors, specifically the urban environment, have enormous implications for the health of urban dwellers. The combination of an individual's behaviour and their surrounding environment has been demonstrated to play an important role in an individual's health, this combination can be referred to as epigenetic factors. The impact of epigenetic factors has been demonstrated in twins: twins share the same DNA; however, different environments and lifestyle choices can vary the health outcomes between both individuals.[64]

Environment of evolutionary adaptiveness (EEA) refers to "the ancestral environment to which a species is adapted; it is the set of selection pressures that shaped an adaptation."[65] *Homo sapiens* are considered to be the species best adapted to the varied range of hunter-gatherer lifestyles that are characteristic to the evolutionary environments of the past.[66] As a result, the discrepancy between the modern, urban environment and the human EEA has been utilised as the theoretical foundation for understanding the causes and origins of chronic diseases, such as, type 2 diabetes and certain forms of cancers, often collectively known as "diseases of modernity."[67] Diseases of modernity all exhibit similar characteristics, in that the incidences of such diseases are increasing over time, due to the continuous deviation from the human EEA and longer life expectancy within urban environments.[68] Therefore, it is of utmost importance to also factor in environmental considerations in the development of IoT for preventive health care. More importantly, it is crucial to go even a step further in the innovative initiatives of IoT by considering how to effectively integrate both behavioural and environmental elements for a truly holistic approach toward preventive health in urban environments.

Greener, smarter, more adaptable, and more considerate cities through planning, design, and technology; are the guidelines that will decide whether a community will thrive or just expand. It's not only a matter of well-being but also a matter of economic and social stability. Innovation stems from identifying opportunities. There is more room for development and ideas in a safe environment, and a truly holistic approach towards the integration of technology and communities may provide just that.

IoT and related community-building technologies could be vital, particularly during the post-pandemic stages to alleviate stress and trauma in reintegrating into high-stress and high-pace urban environments. Moreover, there must be a shift in focus towards preventive care, predominantly on how to strengthen our immune systems and build mental and physical resilience against present and future diseases and challenges faced in urban environments.

Currently, there exists a plethora of IoT devices and applications that offer a variety of solutions for healthy living and an enhanced state of well-being. However, more often than not these applications and devices solely rely only a few basic physiological measurements, for example, heart rate or oxygen saturation, as parameters to define an individual's state of health or well-being on a day-to-day basis. Moreover, full integration of real-time environmental data gained through various IoT sensors with personal IoT devices has yet to reach its full potential.

3.1 The Individual

[64] Patrice van Eersel, *La révolution épigénétique: votre mode de vie compte plus que votre hérédité* (Paris: Albin Michel, 2018).
[65] Kevin Bennett, 'Environment of Evolutionary Adaptedness (EEA)', in *Encyclopedia of Personality and Individual Differences*, ed. by Virgil Zeigler-Hill and Todd K. Shackelford (Cham: Springer International Publishing, 2018), pp. 1–3 <https://doi.org/10.1007/978-3-319-28099-8_1627-1>.
[66] Jerome H. Barkow, Leda Cosmides, and John Tooby, *The Adapted Mind: Evolutionary Psychology and the Generation of Culture*, [2nd. ed.], 1srt issued as an Oxford university press paperback, cop. 1992 (New York (N.Y.): Oxford university press, 1995).
[67] S. Boyd Eaton and others, 'Evolutionary Health Promotion', *Preventive Medicine: An International Journal Devoted to Practice and Theory*, 34 (2002), 109–18 <https://doi.org/10.1006/pmed.2001.0876>.
[68] Brandon H. Hidaka, 'Depression as a Disease of Modernity: Explanations for Increasing Prevalence', *Journal of Affective Disorders*, 140.3 (2012), 205–14 <https://doi.org/10.1016/j.jad.2011.12.036>.

Healthcare costs have been rapidly increasing in part because the diseases that are currently most prevalent are chronic in nature and thus require continual treatment and monitoring. Successful modification of health behaviours may help to reduce both the numbers of deaths and the incidence of preventable disease as well as make a dent in the more than billions of euros spent yearly on health and illness internationally.[69] The promotion of good health then moves more from a biomedical model towards a focus on health behaviour.

It has become increasingly clear from the changing patterns of disease mortality that a central plank in our health hinges on health behaviours and in particular a capacity to self-manage. Self-management involves an individual managing their illness in a way that maximises control over symptoms and quality of life. For example, an individual with arthritis might self-manage through exercise, managing pain, eating healthily, taking arthritis medication and working with the doctor and healthcare team. Therefore, the notion of healthy urban living requires the encapsulation of the changes in patterns of health by incorporating the idea of increasing emphasis on self-management behaviours.

This conceptualisation of active self-management as a central feature of health and well-being is further emphasised in theoretical and research developments in psychology, particularly in the area of both positive psychology and health psychology, both of which are outlined in the following sections. Self-management can be further influenced by social environment, and in particular, social support networks.

Physical Activity

The correlation between sport and physical and mental well-being is now well established.[70] The lack of physical activity not only has a negative impact on society and people's health, but also results in economic costs. Studies have suggested that increased physical activity is associated with greater well-being, quality of life as well as lower depressive symptoms, anxiety, and stress, with a beneficial effect at any ages. It found that women were more vulnerable to changes in mental health and men were more susceptible to changes in physical activity. In the study performed, eligibility criteria include cross-sectional, prospective, and longitudinal designs and studies; outcomes to consider included physical activity and mental health (e.g., depressive symptoms, anxiety, positive and negative effects, well-being).[71] These studies found that physical activity was a good and effective choice for mitigating the negative effects of the COVID-19 pandemic on mental health.

In addition, sport has the potential to strengthen messages of tolerance and reinforce citizenship throughout Europe. Promoting the role of sport as a means of social inclusion will help address ongoing challenges in European society. Studies show that spending time in nature can reduce stress and anxiety, as well as physical activity. Therefore, different initiatives have been embraced by society, the cultural, sports and healthcare sector. Another example is the European Week of Sport[72] which aims to boost people's physical and mental health regardless of age, social background or fitness level, with activities across the continent. The initiative encourages European citizens to "**#BeActive**", not only during the Week, but to stay fit all year long.

Despite the growing body of research highlighting the importance of sport in maintaining our wellbeing as well as building an inclusive and economically vibrant society, levels of physical

[69] Writing Group Members and others.
[70] 'The Role of Physical Activity and Sport in Mental Health - The Faculty of Sport and Exercise Medicine' <https://www.fsem.ac.uk/position_statement/the-role-of-physical-activity-and-sport-in-mental-health/> [accessed 21 September 2022].
[71] Marconcin and others.
[72] 'European Week of Sport | Sport' <https://sport.ec.europa.eu/node/179> [accessed 21 September 2022].

activity are currently stagnating, and even declining, in some Member States. The European Week of Sport aims to respond to this challenge.

The use of IoT technologies for personalized monitoring can implement functions to more effectively target users to support their health and improve the quality of life. Assessing the effect of physical activity can help the physician make individual recommendations for assessing the health of the wearer of the technology. With evaluation of optimal physical activity customized according to the person who wears it, with a direct impact on sports performance and health. With the use of IoT in sports, athletes' training and analysis will be implemented with the help of IoT sensors. There has been a shift towards the development of smart fabrics and smart insoles. Such sensors can monitor athletes' health and performance and collect data for analysis. The data collected by the sensors can be integrated with the internal systems of the team to analyse the level of performance, health, stress and possible injuries of an athlete. An interesting role of IoT sensors is that of improving the safety of athletes by detecting potential injuries. Additionally, IoT sensors and wearable devices can be used for monitoring and suggesting optimal recovery times.[73]

Physical activities such as Yoga,[74] Taichi,[75] Qigong[76] benefits are already demonstrated. Tai Chi helps with depression, pulmonary disease, balance disorders, Parkinson's disease, cardiovascular health, osteoporosis, chronic pain, and cancer as it is scientifically proven by researchers at the Osher Center for Integrative Medicine at Harvard Medical School.[77] Qigong improves well-being and reduces anxiety, stress, and depression.[78] Practicing sports will help reduce stress, enhance better sleep, etc. Sport is more and more recommended for a healthy lifestyle, reduces stress, and improves well-being, among others. Several companies are creating new devices to support drills, such as smartwatches (e.g., Fitbit) and smart rings (e.g., Oura), among various others.[79]

Nutrition

The WHO lists four key metabolic changes that increase the likelihood of mortality from NCDs: high blood pressure, overweight or obesity, hyperglycemia, and hyperlipidemia. All these factors are closely linked to the health and nutrition of the subjects as well as to genetic factors, a correct diet can considerably attenuate these factors.

A nutritious diet is a common factor for the well-being of all living things. The food we eat has an enormous impact on our well-being; everything we consume feeds the microorganisms in our gut. An individual's diet directly impacts their microbiome composition, as a result, poor dietary choices significantly increase the risk of development of chronic diseases due to the intestinal microbiome's role in modulating the risk of several chronic diseases.[80]

Therefore, it is important to consider all the statistics of the nutrients that are available in food to fully understand the facts that are affecting the health of the person.[81] An example of an IoT

[73] https://www.allerin.com/blog/how-iot-can-be-the-real-mvp-in-the-future-of-sports (Visited 03 June 2022)
[74] James E. Groves and Marlynn Wei, *The Harvard Medical School Guide to Yoga: 8 Weeks to Strength, Awareness, and Flexibility* (Philadelphia, PA: Da Capo Lifelong, 2017).
[75] Peter Wayne and Mark Fuerst, *The Harvard Medical School Guide to Tai Chi: 12 Weeks to a Healthy Body, Strong Heart, and Sharp Mind*, 1st ed (Boston: Shambhala, 2013).
[76] Fang Wang and others, 'The Effects of Qigong on Anxiety, Depression, and Psychological Well-Being: A Systematic Review and Meta-Analysis', *Evidence-Based Complementary and Alternative Medicine: ECAM*, 2013 (2013), 152738 <https://doi.org/10.1155/2013/152738>.
[77] Wayne and Fuerst.
[78] Wang and others.
[79] Christine E. King and Majid Sarrafzadeh, 'A Survey of Smartwatches in Remote Health Monitoring', *Journal of Healthcare Informatics Research*, 2.1–2 (2017), 1–24 <https://doi.org/10.1007/s41666-017-0012-7>.
[80] Rasnik K. Singh and others, 'Influence of Diet on the Gut Microbiome and Implications for Human Health', *Journal of Translational Medicine*, 15 (2017), 73 <https://doi.org/10.1186/s12967-017-1175-y>.

[81] Chelsea Didinger and others, 'Nutrition and Human Health Benefits of Dry Beans and Other Pulses', in *Dry Beans and Pulses* (John Wiley & Sons, Ltd, 2022), pp. 481–504 <https://doi.org/10.1002/9781119776802.ch19>.

application in this field involves the use of technologies as a dietary monitoring tool. It is possible to acquire the food and calculate the statistics that help create a detailed report for the consumer to guide them with adequate instructions. These adequate instructions, in turn, increase the user's awareness through a mechanism that describes the nutrients that are highly recommended and those that lead to obesity. An application of this type generates a very accurate report of the person's nutritional intake and guides the user to include the necessary nutritional values at the expense of unnecessary ones.[82]

Mental and Emotional Well-Being

There have been numerous studies on the relationship between physical and mental health outcomes, these studies have shown that the correlation between the two is a strong one.[83,84,85] Common mental disorders, such as, depression and anxiety, are becoming increasingly prevalent among populations of western industrial nations.[86] The increase in prevalence of chronic diseases, the burden of which arise from an "evolutionary mismatch between past human environments and modern-day living," and may be closely correlated to the rise in rates of depression.

A review of different studies by the WHO shows that arts can play "a major role" in improving people's health across their lifespan, by helping prevent the onset of mental illness or by supporting its treatment or management.[87] The Brussels Project, the first of its kind in Europe according to its organisers, was inspired by a similar one in Quebec with prescriptions to the city's Museum of Fine Arts.[88] Canadian doctors and nurses have also been prescribing year-long passes to the country's national parks to patients living with physical and mental health problems.[89]

Psychological factors (i.e. factors related to life events, stress, emotions, behaviours and other events in the environment that have an impact on the individual's state of mind) can affect health both directly and indirectly. Direct effects include the negative impact of prolonged elevated levels of stress on immune function.[90] Indirect effects include the impact of behaviour on health, e.g. the harmful effects of smoking, excessive alcohol consumption; or the beneficial effects of exercise or a low-fat diet.[91]

A biopsychosocial approach is often used in the understanding of health and wellbeing, i.e. health is understood as the product not only of biological processes (e.g. a virus, infection etc.) but also of psychological (e.g. thoughts and emotions), behavioural (e.g. habits), and social processes (e.g. socio economic status).[92] Recent developments in the field of psychology have made important contributions to our understanding of health, in particular developments in

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[82] Hrushikesava Raju Sangaraju and others, 'An IoT Vision for Dietary Monitoring System and for Health Recommendations', 2022, pp. 863–72 <https://doi.org/10.1007/978-981-16-5529-6_65>.
[83] Hermann Nabi and others, 'Positive and Negative Affect and Risk of Coronary Heart Disease: Whitehall II Prospective Cohort Study', *BMJ (Clinical Research Ed.)*, 337 (2008), a118 <https://doi.org/10.1136/bmj.a118>.
[84] P. G. Surtees and others, 'Psychological Distress, Major Depressive Disorder, and Risk of Stroke', *Neurology*, 70.10 (2008), 788–94 <https://doi.org/10.1212/01.wnl.0000304109.18563.81>.
[85] Julius Ohrnberger, Eleonora Fichera, and Matt Sutton, 'The Dynamics of Physical and Mental Health in the Older Population', *Journal of the Economics of Ageing*, 9 (2017), 52–62 <https://doi.org/10.1016/j.jeoa.2016.07.002>.
[86] Jean M. Twenge and others, 'Birth Cohort Increases in Psychopathology among Young Americans, 1938-2007: A Cross-Temporal Meta-Analysis of the MMPI', *Clinical Psychology Review*, 30.2 (2010), 145–54 <https://doi.org/10.1016/j.cpr.2009.10.005>.
[87] Daisy Fancourt and Saoirse Finn, *What Is the Evidence on the Role of the Arts in Improving Health and Well-Being? A Scoping Review* (World Health Organization. Regional Office for Europe, 2019) <https://apps.who.int/iris/handle/10665/329834> [accessed 21 September 2022].
[88] 'Brussels Prescribes Visits to Manneken Pis and Museums for Mental Health', *POLITICO*, 2022 <https://www.politico.eu/article/brussels-museum-visits-mental-health-culture/> [accessed 21 September 2022].
[89] Sharon Pruitt-Young, 'A New Program in Canada Gives Doctors the Option of Prescribing National Park Visits', *NPR*, 9 February 2022, section Health <https://www.npr.org/2022/02/09/1079356799/a-new-program-in-canada-gives-doctors-the-option-of-prescribing-national-park-vi> [accessed 21 September 2022].
[90] Firdaus S. Dhabhar, 'Effects of Stress on Immune Function: The Good, the Bad, and the Beautiful', *Immunologic Research*, 58.2–3 (2014), 193–210 <https://doi.org/10.1007/s12026-014-8517-0>.
[91] Dhabhar.

[92] Derek Bolton and Prof Grant Gillett, *Biopsychosocial Conditions of Health and Disease*, *The Biopsychosocial Model of Health and Disease: New Philosophical and Scientific Developments [Internet]* (Palgrave Pivot, 2019) <https://doi.org/10.1007/978-3-030-11899-0_4>.

both positive psychology and the specialised domain of health psychology have provided valuable insights into factors influencing best practice in therapy and in building resilience.[93]

Positive Psychology

Positive psychology was first pioneered by Martin Seligman in 1998 and is defined as "the scientific study of positive human functioning and flourishing on multiple levels that include the biological, personal, relational, institutional, cultural, and global dimensions of life."[94] This field postulates that focusing only on psychological disorder may result in a limited understanding of a person's health and wellbeing. In its application to health, positive psychology suggests that positive emotional states have a favourable effect on mortality and survival in both healthy and diseased populations. Studies suggest that happier people seem to live longer even when health behaviours are controlled for. Intervention studies conducted also indicate that positive affect is associated with greater resistance to common viruses such as cold and flu.[95]

There is increasing evidence of a link between positive health behaviour and psychological wellbeing. Research in positive psychology has found that there is evidence of an association between fruit and vegetable intake and happiness.[96,97] This finding may not be fully explained by demographic or other variables including socio-economic status, body mass index, smoking and exercise, suggesting a possible causal link.[98] This may be as a result of the protective benefits from both chronic diseases as well as a greater intake of nutrients important for psychological health. These findings further emphasise the importance of developing interventions that target behaviours that promote both physical and psychological well-being.

Health Psychology

Health psychology takes a broader perspective than positive psychology and examines how people's behaviour, personality and emotions influence their health. Matarazzo defined health psychology as "an aggregate field in psychology, involving educational, scientific, and professional contributions, and accomplishing a variety of ends: the promotion and maintenance of health, the prevention and treatment of illness, the identification of etiologic and diagnostic correlates of health, illness, and related dysfunction and to the analysis and improvement of the health care system and health policy formation."[99]

A more recent analysis streamlines the definition as "an interdisciplinary field concerned with the application of psychological knowledge and techniques to health, illness and health care."[100] Health psychology emphasises the role of psychological factors in the cause, progression and consequences of health and illness. The aims of health psychology can be divided into (1) understanding, explaining, developing and testing theory and (2) putting theory into practice.[101] One of the key ways that health psychology has evolved in putting theory into

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[93] Jia-Yan Pan and Cecilia Chan, 'Resilience: A New Research Area in Positive Psychology', *Psychologia*, 50 (2007), 164–76 <https://doi.org/10.2117/psysoc.2007.164>.
[94] Pan and Chan.
[95] D.K. Sherman and G.L. Cohen, 'The Psychology of Self-Defense: Self-Affirmation Theory. Advances in Experimental Social Psychology', 2006, 183–242.
[96] Julia K. Boehm and others, 'Association between Optimism and Serum Antioxidants in the Midlife in the United States Study', *Psychosomatic Medicine*, 75.1 (2013), 2–10 <https://doi.org/10.1097/PSY.0b013e31827c08a9>.
[97] 'Would You Be Happier Living in a Greener Urban Area? A Fixed-Effects Analysis of Panel Data - Mathew P. White, Ian Alcock, Benedict W. Wheeler, Michael H. Depledge, 2013' <https://journals.sagepub.com/doi/abs/10.1177/0956797612464659> [accessed 21 September 2022].
[98] Tamlin S. Conner and others, 'On Carrots and Curiosity: Eating Fruit and Vegetables Is Associated with Greater Flourishing in Daily Life', *British Journal of Health Psychology*, 20.2 (2015), 413–27 <https://doi.org/10.1111/bjhp.12113>.
[99] Joseph D. Matarazzo, 'Behavioral Health's Challenge to Academic, Scientific, and Professional Psychology', *American Psychologist*, 37 (1982), 1–14 <https://doi.org/10.1037/0003-066X.37.1.1>.

[100] David F. Marks and others, *Health Psychology: Theory, Research and Practice, 2nd Ed*, Health Psychology: Theory, Research and Practice, 2nd Ed (Thousand Oaks, CA: Sage Publications Ltd, 2005), pp. xii, 485.
[101] Jane Ogden, *Health Psychology: A Textbook*, 5. ed (London: Open University Press, 2012).

practice is in attempting to understand and to change health behaviour and with a particular focus on the individual and not just population approaches to health behaviour change.

3.2 Urban Air Quality

To reach the goal of a pollution-free environment by 2050,[102] at least the four crucial domains of clean water, clean air, the industry and chemicals need to be addressed. Cleaner water resources will preserve biodiversity. This can be achieved though, for example, the farm-to-fork strategy, that leads to reduced pollution from excess nutrients. Furthermore, toxic materials such as micro-plastics and pharmaceuticals should be prevented from ending up in aquatic environments. The impact of noise on an individual's health is also something that must be explored. For instance, the benefit of introducing something like "sound showers" near heavy traffic areas and places where people gather. This can also be beneficial for visually impaired individuals, who are even more affected by noise or for the continuously increasing number of individuals suffering with tinnitus.

Given that air pollution is one of the biggest environmental challenges that urban dwellers are confronted with. IoT solutions that tackle the issue of air pollution and air quality represent a crucial starting point to reduce the impact of environmental factors on the health and well-being of urban dwellers. Typically, air quality is monitored through fixed monitoring stations distributed over a specific area and controlled by a municipal organisation. Given the cost of these stations and the policy obligation, usually, they are scarce within a specific location. Therefore, the number of monitoring stations within many cities may not characterise the spatial distribution of harmful pollutants. To overcome this issue, usually, the implementation of air dispersion modelling approaches is implemented. Besides providing the spatial distribution of pollutants, modelling techniques enable the forecasting of air quality and scenario analysis by implementing specific alternative solutions to diminish air pollution.

Some European organisations (including SMEs) are developing solutions to improve Air Quality in Smart Cities by implementing air quality and weather sensors and providing near-real-time data. Furthermore, IoT platforms, such as the Urban Platform,[103] are being developed and implemented to help cities correlate collected data with other inputs; analyse air quality impacts and enable better-founded decision-making. For instance, these decisions may be based on the digital twin of a specific city monitored and analysed. The AI4Cities project has looked for solutions that enable carbon reduction and neutrality.[104] FranchetAI is a solution that emerged from this project and looked beyond by using AI and IoT solutions to reduce the emissions of GHG and Air Quality pollutants.[105] This solution aims to inform citizens and municipal representatives of the emissions within a specific region without neglecting data protection.

[102] 'Zero Pollution Action Plan' <https://environment.ec.europa.eu/strategy/zero-pollution-action-plan_en> [accessed 21 September 2022].
[103] 'Urban Platform' <https://urbanplatform.city/> [accessed 21 September 2022].
[104] 'AI4Cities | Home' <https://ai4cities.eu/> [accessed 21 September 2022].
[105] 'Home, FranchetAI', *FranchetAI* <https://franchetai.com/> [accessed 21 September 2022].

Human beings spend on average 90% of their lives indoors. Knowing this, we cannot simply ignore our indoor environment quality (IEQ) or assume all is well. Studies in the past years have shown that this is a problem present in our daily life. Relevant in our work offices, in our children's schools and even in our own homes.

School children, and particularly younger ones, are more sensitive to poor IEQ than adults because their bodies are still growing and developing. Poor IEQ can affect both their learning ability as well as their health. One of the most pertinent problems triggered by poor IEQ is Sick Building Sickness (SBS). This is a group of health problems that are caused by an indoor environment such as an office building or a residence. Uncomfortable temperature and humidity, chemical and biological pollution, physical condition, and psychosocial status are some of the factors identified as root causes. Symptoms experienced by people with SBS include irritation of the eyes, nose and throat, headache, cough, wheezing, cognitive disturbances, depression, light sensitivity, gastrointestinal distress, and other flu-like symptoms. In addition, factors such as molds, dust, mite, indoor aldehydes, Volatile Organic Compounds (VOC), airborne fungi, pesticides, smoke, lighting, air exchange or circulation rates, carbon monoxide, carbon dioxide may lead to SBS.

Another worrying issue is how poor IEQ conditions can contribute to spreading infectious diseases, in particular airborne diseases like viral infections. IAQ is related to how easily these airborne infectious diseases can be transmitted, therefore monitoring parameters like ventilation rate, CO2 concentration and relative humidity can help reduce transmission rates. Low indoor RH is also related to increased disease transmission, since it allows viruses and bacteria (such as SARS, influenza, tuberculosis, and others) float in the air longer; this, linked with still air due to low ventilation rates increases the probability of infection. Working towards infection prevention with adequate tools and services is a better solution than infection mitigation. Measuring CO2 levels, as a direct link to poor indoor ventilation, and RH, by using sensors can offer such help in prevention. All virus/bacteria have different symptoms, treatments, and vaccines, it is more effective to create better coping mechanisms associated with prevention like measuring and controlling indoor environments.

The Smarter School Platform is a spin of the Horizon2020 project (VICINITY) use case that was tested, demonstrated, and co/created within the DEMO environment with the stakeholders. By gathering and creating datasets for buildings, data analytics can be employed to transform gathered data into value-added information that users can comprehend and act upon, allowing for improvements across five key indicators: health & productivity (IEQ), energy efficiency, carbon footprint and predictive maintenance capabilities. This analytics is greatly enhanced by Big Data and AI since buildings can produce high volume datasets with various heterogeneous data sources, creating an exploitable valuable Data Value Chain for building users. It also presents an educational opportunity for children and adults alike to better understand the quality of the indoor environment they live in, as well as the impact that the building's resources consumption has within the climate change context.

The technical solution is based on the IoT-driven architecture with the development roadmap towards an edge-driven solution, enabled by advanced hardware and connectivity components. The Smarter School Index is a market-reaching tool and was devised as an end-user engaging solution for the optimisation of educational environments. The public sector is one of the largest user segments for buildings digitalisation. The solution addresses educational needs, and climate adaptation and optimises educational spaces management. It delivers optimal educational environments to address wellbeing, optimal resource usage for educational facilities and climate change adaptation purposes.

The Smarter School solution consists of:

- The state-of-the-art platform that facilitates a core set of services, is capable of onboarding value-added services and complementary solutions.
- Proprietary algorithm for index calculations and core services offered on the platform.
- Engaging user interfaces (virtual creatures that display feeling and educate) are appropriate for school children and teachers, while the data generated also serves as a backbone to resources management for buildings managers and municipal buildings management and resources consumption. Hence the solution delivers data and services to at least four stakeholders segments from the data sources.
- Help in infection prevention - the monitorisation of the indoor environmental quality naturally enables optimization of the indoor environment to reduce the risk of infectious disease transmission and few additional adjustments are needed.
- Engagement through participatory feedback and visualisation within the educational facilities premises coupled with climate change adaptation sensibilisation is the core of system and services design.
- Resources consumption monitoring and sequential management

4. Ideal Scenarios in Healthcare, Technology & Innovation

Digital technologies are often attributed magic powers in solving societal problems (Morozov 2013). Whether technologies eventually live up to their assignments depends on the actuality of their design as much as on their use. IoT has enormous potential to help individuals, particularly urban dwellers, drastically improve their quality of life. The last decades have seen a massive surge in health-tech (health-related technologies); however, the technology-centric approach has the wrong focal point. Health-tech has been focussed on pushing multiple devices, systems, and digital services, often overwhelming consumers and rarely making a meaningful impact on their quality of life. It is, therefore, important to take into consideration what makes sense, what does not, and how we stay aligned with human values.

The various domains of healthy living concern real individuals, each with their own backgrounds, dreams, particularities, and ethics. Each individual evolves in various ways during their lifetime; we've become increasingly aware that the one size fits all approach to health care is not the most beneficial approach. Healthy living, health care, and enhanced well-being are personal. The emergence of the IoT sector, alongside machine learning and the commercialization and accessibility to certain medical devices, has enabled personalised health advice to be both cost and time efficient.

IoT and related technology could play an important role in connection to physical and mental health and well-being. The disconnect between the mental and physical health poses an opportunity for IoT solutions to bridge the gap. Moreover, the application of IoT can be instrumental in minimising the pressure to provide efficient healthcare services.

4.1 Health Behaviour Change

Michie and colleagues continued to advance our understanding of health behaviour change by developing a taxonomy of "behaviour change techniques" (BCTs).[106] A BCT is defined as "the smallest active component of an intervention designed to change behaviour" and are both observable and replicable components of behaviour change interventions.[107] Relevant BCTs can then be selected based on a review of previous research and serve as the 'active ingredients' of a successful behaviour change (both traditional and digital) intervention. For example, 'goal setting and 'self-monitoring' have been shown to be effective strategies in increasing physical activity in a digital intervention using apps with university students.[108] It has been proposed that the BCT taxonomy will be updated and refined as time goes on.

Programs and devices using digital technology (digital interventions) have great potential to improve population health and the efficiency and reach of health care delivery. Mobile applications (apps), text messages, wearables and sensors, interactive websites, and social media, can improve health by supporting behaviours involved in disease prevention and self-management, and delivery of evidence-based health care.

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[106] Susan Michie, Michelle Richardson, and others, 'The Behavior Change Technique Taxonomy (v1) of 93 Hierarchically Clustered Techniques: Building an International Consensus for the Reporting of Behavior Change Interventions', *Annals of Behavioral Medicine: A Publication of the Society of Behavioral Medicine*, 46.1 (2013), 81–95 <https://doi.org/10.1007/s12160-013-9486-6>.

[107] Susan Michie, Caroline E. Wood, and others, 'Behaviour Change Techniques: The Development and Evaluation of a Taxonomic Method for Reporting and Describing Behaviour Change Interventions (a Suite of Five Studies Involving Consensus Methods, Randomised Controlled Trials and Analysis of Qualitative Data)', *Health Technology Assessment (Winchester, England)*, 19.99 (2015), 1–188 <https://doi.org/10.3310/hta19990>.

[108] Jane C. Walsh and others, 'An MHealth Intervention Using a Smartphone App to Increase Walking Behavior in Young Adults: A Pilot Study', *JMIR MHealth and UHealth*, 4.3 (2016), e109 <https://doi.org/10.2196/mhealth.5227>.

Mobile phone use has almost achieved complete penetration with 96% of the global adult population having a mobile phone subscription.[109] The collection of psychological, social, and contextual variables that are passively recorded or tracked (e.g., GPS location, social media activity etc) and can be used to understand processes and outcomes of behavioural health interventions and for empirically testing behavioural theories.[110] However, there are several significant unique challenges involved in developing, evaluating, and implementing effective digital behaviour change interventions (DBCIs). Understanding the various behaviour change theories is key to effectively personalising DCBIs.

These are interventions that employ digital technologies to encourage and support behaviour change that will promote and maintain health, through primary or secondary prevention and management of health problems. DBCIs facilitate health promotion by providing support in the "real world" to change specific behaviours in specific contexts and are used by individuals. The shift from traditional to digital platforms presents researchers with an opportunity to both develop and test theories using behaviour change techniques.[111] For example, goal setting and self-monitoring can be easily achieved by using an app to track step count enabling users to more readily achieve their goals.[112,113] Whilst this is a novel and exciting area of research, many of the early studies have been heavily criticised for lacking a strong evidence base in terms of both design and implementation. There is little doubt that there is an opportunity for technology to allow for greater specification of behavioural theories and models (e.g., defining how constructs relate to one another and the predicted magnitude and direction of those relations).[114]

Interventions to change behaviours related to health are usually complex in that they comprise several or many components that may interact with each other. These components include behaviour change techniques and modes of delivery (e.g., smartphone apps or face-to-face delivery). The interactions among these components create challenges in terms of identifying which techniques are contributing to any effects observed and the mechanisms of action of techniques contributing to the effect. To date, few digital health intervention developers specify how characteristics of their intervention map onto underlying evidence-based theories and techniques[115] and unsurprisingly, the current evidence around the effectiveness of technological devices as a health behaviour change tool is limited. Some researchers have had success in the field, for example, through increased physical activity in a primary care population using a simple pedometer app.[116] However, this study along with others requires clearer specification of BCTs and the underlying theory-based mechanisms. The reporting of complex behavioural health interventions, digital and traditional, often lacks sufficient details to know exactly which BCTs were included and how they were offered.

Morrison (2015) suggests that to achieve long term sustainability of digital interventions more research is required on effective components rather than of effective mHealth interventions. She argues that the reach and use of these interventions needs more scientific input to increase the public health impact of internet-delivered interventions.

The application of behavioural science theory provides a useful starting point to develop and evaluate such technological interventions in a similar manner to methods used in the

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[109] *ICT Facts & Figures: The World in 2015* (ITU, 2015) <https://www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFactsFigures2015.pdf>.
[110] Eric B. Hekler, Susan Michie, and others, 'Advancing Models and Theories for Digital Behavior Change Interventions', *American Journal of Preventive Medicine*, 51.5 (2016), 825–32 <https://doi.org/10.1016/j.amepre.2016.06.013>.
[111] Hekler, Michie, and others.
[112] Liam G. Glynn and others, 'Effectiveness of a Smartphone Application to Promote Physical Activity in Primary Care: The SMART MOVE Randomised Controlled Trial', *The British Journal of General Practice: The Journal of the Royal College of General Practitioners*, 64.624 (2014), e384-391 <https://doi.org/10.3399/bjgp14X680461>.
[113] Walsh and others.
[114] Hekler, Michie, and others.
[115] Eimear C. Morrissey and others, 'Behavior Change Techniques in Apps for Medication Adherence: A Content Analysis', *American Journal of Preventive Medicine*, 50.5 (2016), e143–46 <https://doi.org/10.1016/j.amepre.2015.09.034>.
[116] Glynn and others.

development of standard behaviour change interventions. By conducting an analysis of previous research, we can begin to understand the factors that predict the target behaviour and this provides a platform upon which to consider the key elements to target for a behaviour change intervention. Using a theory-based approach to developing digital interventions will enable us to develop and evaluate high quality effective interventions to change behaviour. Improving this would be expected to increase the effectiveness of interventions and advance our understanding of underlying theory. For example, a theory that stipulates that a construct such as "social support" is an important predictor of behaviour can be useful in designing an intervention that seeks to change this, (e.g. to reduce alcohol use). By adopting theories and models that are as precise, quantitative, and testable as possible for describing the complexity of behaviour change, we can achieve greater precision in specifying model structures, defining directionality and complex interactions influencing behaviour.

Positive Psychology and Humanistic approaches have increasingly influenced the design of technology for health in the last decade. Among these humanistic perspectives, there is an overlap with the terms often used in the computing disciplines, experience-centred design and value-sensitive design. Experience-centred design is concerned with the "richness of human experience", a focus that has become a mainstream aspect of software development.[117] Researchers have proposed a "positive technology" approach where technology is used to improve the quality of personal experience through its structuring, augmentation and/or replacement.[118]

They argue that using technology in this way can improve wellness and generated strength and resilience in individuals, organisations and society. A strong theory-based framework can serve as a framework to develop an intervention, however it is also important to involve key stakeholders and end-users in the initial design phase to properly inform elements critical to success such as individuals' and community characteristics as well as to determine effective modes of intervention delivery. A systematic review of online prevention interventions aimed at lifestyle behaviours reported low effect sizes and lack of sustained usage of mHealth interventions.[119]

One of the problems with eHealth and mHealth technology is that the growth is rapid and has not allowed enough time for research and theory development in its potential for health behaviour change. However, in recent years great strides have been made to develop sound scientific methodologies to help developers create effective solutions. In particular, there has been increased recognition and emphasis placed on the importance of involving stakeholders from the outset in intervention design and implementation. One method of approaching this is to take the person-based approach.[120] The person-based approach involves in-depth qualitative research is conducted with the users before the digital intervention is developed. This data is used to develop "guiding principles" that state the key intervention design objectives and describe the key features of the intervention required to achieve each objective.

They posit that both qualitative and quantitative research is crucial at all stages of intervention development and evaluation, including planning and design, early development, acceptability and feasibility testing, and evaluation in clinical trials and real-life settings. The person-based approach is highly compatible with the more in-depth approaches that have evolved within the disciplines of information systems and human computer interaction, such as human-centred and user-centred design. These approaches seek to understand the user's knowledge, skills,

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[117] Andrea Gaggioli and others, 'Editorial: Positive Technology: Designing E-Experiences for Positive Change', *Frontiers in Psychology*, 10 (2019) <https://www.frontiersin.org/articles/10.3389/fpsyg.2019.01571> [accessed 21 September 2022].
[118] John J. Riva and others, 'What Is Your Research Question? An Introduction to the PICOT Format for Clinicians', *The Journal of the Canadian Chiropractic Association*, 56.3 (2012), 167–71.
[119] Leonie F. M. Kohl, Rik Crutzen, and Nanne K. de Vries, 'Online Prevention Aimed at Lifestyle Behaviors: A Systematic Review of Reviews', *Journal of Medical Internet Research*, 15.7 (2013), e146 <https://doi.org/10.2196/jmir.2665>.
[120] Lucy Yardley and others, 'The Person-Based Approach to Intervention Development: Application to Digital Health-Related Behavior Change Interventions', *Journal of Medical Internet Research*, 17.1 (2015), e4055 <https://doi.org/10.2196/jmir.4055>.

behaviour, motivations, cultural background, and organizational context, and they involve users iteratively throughout development. This approach, however, is rooted within the discipline of health psychology and focuses primarily on the behaviour change techniques the intervention is intended to deliver, and their implementation by the people using the intervention.

In addition, recent studies have suggested that 'trust' in the source of the 'prescription' of an app or mHealth intervention is a key factor in relation to its potential effect on engagement with healthcare providers and motivation for engagement. The introduction of a new technology or platform for engagement requires concerted efforts to alleviate patient concerns and to create confidence in terms of quality and security, requiring stakeholder input at key stages of the design process. Patients' motivation to use mobile technology was influenced by the potential of technology to provide information, feedback, reward systems and automaticity which could embed new self-management habits. The potential for technology to facilitate a personalised flow of communication between patient and healthcare provider was recognised as important as was the ability of technology to facilitate tailored messaging and feedback for patients. The flexibility and inherent motivational ability of newer technologies seems to have the potential to improve the ability of patients to engage in sustained behaviour change. However, evidence of long-term engagement is still lacking in many studies as many users tend to stop using apps after just a few weeks.

A key challenge in the development of effective eHealth interventions for self-management is to harness the knowledge of a multidisciplinary team involving experts across all relevant domains. The development of the Behaviour Change Taxonomy, coupled with evidence-based user-centred methodologies (e.g person-based approach), have helped to create a universal approach to facilitate this teamwork. In addition, DBCIs should be developed with a clear understanding of which behaviour change techniques are to be incorporated and how they link to the theoretically driven mechanisms of change.

Personalisation

Researchers conducted qualitative research to explore target user's perspectives in the development of an app for self-management of hypertension.[121] They found that 'one size fits all' interventions to enhance self-management of lifestyle behaviour are undesirable. Rather, patients prefer a personalised programme via an app enabling them to prioritise their approach to self-management. Mobile technology solutions are by their very nature amenable to personalisation through for example, timely reminders, personalised goals (e.g. step count that takes into account baseline levels of activity).

The use of new digital technologies allows for increased personalisation based on an individual's unique profile, thus increasing the likelihood of successful health behaviour change.[122] This, however, poses another challenge for researchers to develop and monitor interventions that may change over time by adapting to the user's changing requirements and altered goals.

For example, a goal of 'couch to 5k' may be the focus over an initial six- or eight-week period, but a new goal or shift in focus and emphasis may be required to sustain levels of physical activity once this goal has been achieved.

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[121] Cibele D. Ribeiro and others, 'Educational Interventions for Improving Control of Blood Pressure in Patients with Hypertension: A Systematic Review Protocol', *BMJ Open*, 5.3 (2015), e006583 <https://doi.org/10.1136/bmjopen-2014-006583>.

[122] Eric B. Hekler, Predrag Klasnja, and others, 'Agile Science: Creating Useful Products for Behavior Change in the Real World', *Translational Behavioral Medicine*, 6.2 (2016), 317–28 <https://doi.org/10.1007/s13142-016-0395-7>.

This is particularly important in developing health behaviour change interventions that foster maintenance and long-term sustainability of the desired health behaviour.[123] These high-level adaptive changes are more achievable using new technology-based interventions by using live algorithmic analysis based on data collected by an app, both sensor-based and user-inputted. This type of analysis is complex and requires a strong multidisciplinary approach with information technologists, medics and health psychologists working closely together to make sense of the data in order to develop optimum solutions.

Right Time

The use of mobile apps also enables the specification of dynamic temporal relationships e.g., timescale, latency, and delay.[124,125] From a theoretical perspective, work on prospective memory suggests that people make effective use of cues that are appropriate for goal attainment and that people readily execute an intended action in response to a specified cue when the action cue is encountered later during ongoing activity.[126] For example, a recent study has shown promising finding using these methods with respect to smoking cessation.[127] Smoking behaviour is particularly prone to lapse and relapse during quit attempts as cravings are often triggered by cues from a smoker's immediate environment. Researchers have developed a context-aware smoking cessation app, Q Sense, which uses a smoking episode-reporting system combined with location sensing and geofencing to tailor support content and trigger support delivery in real time.[128] The development of this app was based on explanatory sequential mixed-methods design where data collected by the app informed semi-structured interviews. Although underreporting of smoking occurred, the findings suggested that geofence-triggered support was regarded positively by participants. Rothman has called for the need to specify when, where, and for whom a mechanism of action will produce a targeted effect through moderation testing.[129] The argument is the engagement required for behaviour change support is likely to differ, depending on the users and their contexts, and can only be determined by analysing complex patterns of relationships between usage, user experiences, and outcomes. This implies the need for not only understanding when, where, and for whom an intervention will produce an effect but also having a clear understanding of openness of participants to an interventional prompt at that time. This evidence suggests that when interventions are used in the real-world context where behaviours occur, they have greater impact. Mobile technology can provide detailed, unobtrusive assessment of behaviour and its context, while complementary qualitative methods are crucial to fully understand and interpret user experiences.[130]

Measurement

Traditionally, psychological research has relied heavily on self-report measures of health behaviour (e.g. self-reported smoking, food diaries, medication adherence, etc.) as well as observational methods. These, coupled with traditional clinical measures of health (e.g. BMI, cholesterol, BP, etc.) have helped to profile the links between health behaviour change and

[123] Daniel Almirall and others, 'Introduction to SMART Designs for the Development of Adaptive Interventions: With Application to Weight Loss Research', *Translational Behavioral Medicine*, 4.3 (2014), 260–74 <https://doi.org/10.1007/s13142-014-0265-0>.
[124] Felix Naughton and others, 'A Context-Sensing Mobile Phone App (Q Sense) for Smoking Cessation: A Mixed-Methods Study', *JMIR MHealth and UHealth*, 4.3 (2016), e5787 <https://doi.org/10.2196/mhealth.5787>.
[125] Inbal Nahum-Shani, Eric B. Hekler, and Donna Spruijt-Metz, 'Building Health Behavior Models to Guide the Development of Just-in-Time Adaptive Interventions: A Pragmatic Framework', *Health Psychology: Official Journal of the Division of Health Psychology, American Psychological Association*, 34S (2015), 1209–19 <https://doi.org/10.1037/hea0000306>.
[126] *Prospective Memory: Theory and Applications*, Prospective Memory: Theory and Applications (Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers, 1996), pp. xi, 418.
[127] Naughton and others.
[128] Naughton and others.
[129] Alexander J. Rothman, 'Exploring Connections between Moderators and Mediators: Commentary on Subgroup Analyses in Intervention Research', *Prevention Science: The Official Journal of the Society for Prevention Research*, 14.2 (2013), 189–92 <https://doi.org/10.1007/s11121-012-0333-y>.
[130] 'The Human Behaviour-Change Project: Harnessing the Power of Artificial Intelligence and Machine Learning for Evidence Synthesis and Interpretation | Implementation Science | Full Text' <https://implementationscience.biomedcentral.com/articles/10.1186/s13012-017-0641-5> [accessed 21 September 2022].

health outcomes. These assessments, however, are often collected at a few distinct points in time and whilst providing a useful snapshot of cross-sectional data, they often failed to grasp the personal, contextual, and social factors that influence the success of a health behaviour change intervention in achieving the desired changes in behaviour. In recent years the rapid growth of technology in the health sector has brought with it a golden opportunity for new objective measurements of health behaviour.

For example, the advent of wearable technologies such as Fitbit and smart glasses automatically provide minute-by-minute monitoring of objective measurements of behaviour (e.g. in the case of physical activity, heartbeat, location etc). This provides researchers with an excellent opportunity to measure health-related outcomes that were previously reliant on self-report or were confined to a lab environment (e.g., stress, mood etc). Even better, this time and place specific data opens up the potential for researchers to implement context and time appropriate user-friendly interventions for providing behavioural support at key times when a person has the opportunity to change and is receptive to such support.[131,132]

Collaboration

Innovations in digital health are emerging on multiple fronts. To capitalise on these enormous opportunities for health behaviour change, interventions should be based on state-of-the-art science in medicine, technology, and the social and behavioural sciences. Innovations in digital health must involve close collaboration with disciplines such as engineering, human-computer interaction, computer science and technologies. To do this successfully this requires the application of a multidisciplinary approach. Computer science models can define and test not just interactions between intervention components, methods of presentation, and behaviours, but also variations across individuals, populations, environments and time. Data modelling such as this provides enormous opportunity to advance our theoretical understanding of behaviour change so that we can answer with confidence the questions put by health practitioners and policy makers: "What works, how well, for whom, in what settings, for what behaviours, and why?"[133]

[131] Arlen C. Moller and others, 'Applying and Advancing Behavior Change Theories and Techniques in the Context of a Digital Health Revolution: Proposals for More Effectively Realizing Untapped Potential', *Journal of Behavioral Medicine*, 40.1 (2017), 85–98 <https://doi.org/10.1007/s10865-016-9818-7>.
[132] Naughton and others.
[133] Susan Michie, Lucy Yardley, and others, 'Developing and Evaluating Digital Interventions to Promote Behavior Change in Health and Health Care: Recommendations Resulting From an International Workshop', *Journal of Medical Internet Research*, 19.6 (2017), e7126 <https://doi.org/10.2196/jmir.7126>.

4.2 Complementary and Alternative Medicine

Preventive health-care solutions have become increasingly popular among European citizens. One of the Complementary and Alternative Medicine (CAM). CAM is defined as "diagnosis, treatment and/or prevention which complements mainstream medicine by contributing to a common whole, by satisfying a demand not met by orthodoxy or by diversifying the conceptual frameworks of medicine."[134] Although it is accompanied by controversy: with those who believe and experience its healing potential and others who denounce it as quackery or even fraud; nevertheless, statistics illustrate a confirmed societal trend in the acceptance of CAM. The estimated number of visits to CAM practitioners in 1997 exceeded the projected number of visits to all primary care physicians in the US by an estimated 243 million.[135] In Europe, France and Germany were found to have the highest prevalence of CAM use of eight European countries in 1992, with 49 and 46% respectively of the populations having used some form of CAM.[136]

CAM encompasses a variety of alternative treatments that have historic origins outside of, and are used in combination with, conventional medicine. There is no unique classification of CAM domains. Researchers propose to classify CAM into four categories:[137]

1. Traditional Asian medical systems (TAMS) are described as 'complete system[s] of theory and practice', having evolved independently from biomedical medicine - traditional Chinese medicine, acupuncture and acupressure.

2. Alternative medicinal systems (AMS) refer to the intake of substances thought to have healing potential. These systems included homeopathy and herbal treatment.

3. Manual body-based therapies, which involve body movements and focus on the structures and systems of the body - massage therapy, chiropractic, osteopathy, and reflexology.

4. Mind-body therapies, which emphasize the role of thought and emotion in healing - hypnotherapy and spiritual healing.

National Center for Complementary and Alternative Medicine (NCCAM) describes the following CAM categories:

- whole medical systems (e.g., acupuncture),
- mind-body medicine (i.e., various spiritual, meditative, and relaxation techniques),
- biologically based systems (e.g., vitamins and natural products),
- manipulative and body-based practices (e.g., massage, chiropractic, and osteopathy)
- energy medicine (e.g., Reiki therapy)

Data from the European Social Survey report that 25.9% of the study population had used CAM during the last 12 months, of which one-third of individuals also visited a general practitioner.[138]

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[134] E Ernst and others, 'Complementary Medicine — a Definition', *The British Journal of General Practice*, 45.398 (1995), 506.
[135] D. M. Eisenberg and others, 'Trends in Alternative Medicine Use in the United States, 1990-1997: Results of a Follow-up National Survey', *JAMA*, 280.18 (1998), 1569–75 <https://doi.org/10.1001/jama.280.18.1569>.
[136] P. Fisher and A. Ward, 'Complementary Medicine in Europe', *BMJ (Clinical Research Ed.)*, 309.6947 (1994), 107–11 <https://doi.org/10.1136/bmj.309.6947.107>.
[137] Laura M. Kemppainen and others, 'Use of Complementary and Alternative Medicine in Europe: Health-Related and Sociodemographic Determinants', *Scandinavian Journal of Public Health*, 46.4 (2018), 448–55 <https://doi.org/10.1177/1403494817733869>.

[138] Kemppainen and others.

Approximately 8% of CAM users had used CAM exclusively (alternative use), without any visits to biomedical professionals in the last 12 months. The rates of alternative use were highest for spiritual healing (14.9%) and acupressure (12.1%), and they were lowest for osteopathy (4.1%), homeopathy (5.6%), and acupuncture (6.3%). Motivations to use CAM include relaxation, improvements in subjective wellbeing, preventive care, a preference for natural care instead of biomedical medicine, a desire for more personalized and holistic care, dissatisfaction with biomedicine, and dissatisfaction with the doctor-patient relationship.[139]

As a strategic priority, GPW13 sets an overarching goal of reaching 3 billion more people, to move towards Sustainable Development Goal 3 (SDG 3) – ensuring healthy lives and promoting well-being for all at all ages – by achieving universal health coverage (UHC), addressing health emergencies and promoting healthier populations. According to the WHO, CAM can make a significant contribution to the goal of UHC by being included in the provision of essential health services.[140]

CAM can be considered as an emerging **economic sector**, with approximately 145,000 dual-trained doctors, i.e. trained in conventional medicine and a particular CAM modality in the EU. In addition, there are in the order of 160,000 non-doctor CAM practitioners, according to EUROCAM[141] Data on expenditure on CAM in the EU is lacking. US expenditure on complementary medicine was reported to rise 1990-7 from $13bn to $38bn a year, and twice as many consultations were with complementary medicine practitioners as with mainstream family doctors.[142] Moreover, the way CAM practitioners acquire knowledge and develop their talent can be compared to cultural and creative professionals. Some are trained in classic healthcare educational institutions and complement this knowledge with traditional healing practices (for instance, Chinese medicine, Indian Ayurveda medicine and Yoga, Indigenous medicine, etc.). Others receive their training in CAM training centres, immerse in other cultures and learn from CAM Masters. Compared to artistic professions, they go through an initiation journey to develop their healing talent; combine and refine alternative methods and tools through practice.

CAM practitioners, depending on the type of medicine they practice, tend to approach the human body from a holistic perspective. For example, traditional Chinese medicine (TCM) focuses on the circular movement of qi (air or vapor) and xue (blood). TCM practitioners understand ill-health as a stagnation, deficiency, or the improper movement of qi or xue, and may result in an imbalance of yin and yang.[143] TCM aims to do more than merely rid the body of disease, but also aims to restore and maintain harmony throughout the body and views the body as an *integrated whole*. Similar views can be found in other forms of CAM, where the focus is not purely on symptomatology and disease, but on finding an optimal balance for the body and mind. CAM practitioners use an array of diagnostic and evaluation techniques like direct questioning, observation, physical examination, inference, pulse monitoring, observing the tongue, eyes, and physical form, in addition to evaluating a patient's tone of voice.

[139] Kemppainen and others.
[140] 'Universal Health Coverage (UHC)' <https://www.who.int/news-room/fact-sheets/detail/universal-health-coverage-(uhc)> [accessed 21 September 2022].
[141] 'CAM Health Professionals in the EU', *Eurocam* <https://cam-europe.eu/cam-health-professionals-eu/> [accessed 21 September 2022].
[142] Lesley Rees and Andrew Weil, 'Integrated Medicine', *BMJ : British Medical Journal*, 322.7279 (2001), 119–20.
[143] Jennifer Freed, 'Chinese Medicine', *American College of Traditional Chinese Medicine* <https://www.actcm.edu/chinese-medicine> [accessed 21 September 2022].

Similar initiatives are also underway in Japan, where "kampo" (a traditional medicine regime developed in Japan that aims to address health issues at pre-symptomatic stage) prognoses are being analysed against clinical data in order to establish whether specific kampo classifications are linked to some diseases and physical conditions.[144]

Aggregating existing clinical data with data and findings from traditional/conventional medical practices can significantly aid in the improvement of the quality of life for individuals in urban societies, as traditional medicine tends to focus predominantly on the preventive aspect as opposed to treatment. The commercial availability of wearables and other IoT devices has the potential to provide individuals with unprecedented amounts of health-related data points which can be shared with CAM practitioners or general practitioners for a holistic and data-based approach for preventive care.

There are many lessons that can be learned from CAM practices and solutions. Particularly, the holistic approach towards treatment and core focus on prevention as opposed to cure. The IoT sector professionals have two options: either remain skeptical about these practices, building on the argument that proper scientific background is lacking. The second option is to acknowledge that a critical mass of evidence has been reached calling for thorough scientific investigation of underlying physical, biological and emotional processes of healing; unleashing opportunities for innovation in the digital sector as well. Combinatorial knowledge shared by professionals with various horizons – allopathic medicine doctors, CAM professionals and digital experts- is likely to generate new concepts, techniques, digital tools and applications for health care, well-being and prevention.

Collaboration between professionals who do not necessarily share the same background and the same vision of the healing process is not obvious. Allopathic medicine is extremely beneficial for immediate trauma treatments, whereas other forms of medicine, like CAM, can prove even more beneficial for treatment of chronic disease and preventive treatments. Therefore, we call for innovation ecosystems for digitalized integrated medicine (or integrative medicine as it is referred to in the United States), i.e. researching and practicing medicine in a way that incorporates complementary and alternative medicine into comprehensive treatment plans alongside conventional methods of diagnosis and treatment, with support of digital devices and applications.

Horizon 2020 program has successfully supported collaboration between cultural and creative industry professionals on one hand and the digital sector on the other hand. As a result, new creations, innovative digital tools, and applications emerged. The success story of the Horizon Europe program could be replicated in the CAM sector. The increasing popularity of CAM and other holistic or traditional health and wellbeing solutions, presents a unique opportunity for IoT manufacturers. Revisiting specific concepts from CAM and similar practices can allow for an extremely dynamic and holistic approach to health care and wellbeing that's never been done before.

The potential impact and economical uptake which can be derived from IoT applications in combination with CAM are numerous in terms of societal (decrease in criminality, dropouts, burn-outs, cultural acceptances, etc.), economical (financial and value-driven), job creation, and health impacts (increasing level of well-being, decrease of mental diseases etc.). Therefore, serious consideration should be taken into account to research and innovate in this domain to grasp the opportunities for new value/business within this growing domain and demand.

4.3 Value-Based Healthcare

[144] 'Modern Science Takes a Look at Traditional Herbal Medicine' <https://www.nature.com/articles/d42473-021-00207-2> [accessed 21 September 2022].

Today, health systems are key settings for the management of care. However, they are highly evolving and heavily interconnected environments, which means that a change in any one process affects several players involved. Thus, a challenge faced is both the proper integration of all components of these infrastructures and how to measure the success of the services delivered. In this context, it emerges that value-based healthcare is a proposed framework, introduced by Michael Porter and Elizabeth Olmsted Teisberg in 2006,[145] for restructuring healthcare systems with the overall objective of obtaining value for patients, defining value as health outcomes per unit cost.

Hippocrates stated that medicine must be based on detailed observation, reason and experience in order to establish a diagnosis, prognosis and treatment. In particular, he developed the six-sense methodology aimed at training doctors. Thanks to this new empirical method, physicians of ancient times began to use their intellect and five senses in order to gather information about their patients.

In modern times, healthcare providers continue to use the same methodology described by Hippocrates over two thousand years ago, but they also have access to new, vast, and valuable sources of data not coming just from experience but from additional tools. In fact, laboratory tests, imaging, DNA sequencing, molecular pathology, and the technological advances of hyper-connectivity, allow for the analysis of new individual health features. It is calculated that these new technologies produce close to a zettabit (1 billion gigabytes) of data per year, and they will generate even more in the near future.[146]

This volume of data cannot be analysed just through human capacity. Thus, Artificial Intelligence (AI) can provide a valuable support to use the knowledge gained to support the development of better health monitoring, better diagnoses and more personalized treatments, as well as live a healthier and more independent life in our societies. On top of this, AI can be the turning point instrument to address, at least, some of the current challenges such as a) the ageing population and the spreading of chronic diseases, b) the lack of health personnel, c) the sustainability of the social-healthcare system, d) the healthcare system inequalities, e) the promotion of advanced healthcare toward a personalised, predictive, and participatory health.

In the US, adverse drug events result in approximately 1.3 million emergency department visits per year.[147] The use of IoT devices and machine learning has the potential to lower the rate of adverse drug events. Researchers have developed a computer language that represents biological interactions. This language is used in combination with information from public databases and scientific literature to construct a network of potential interactions between various biological interactions. Such computer programs simulate virtual human bodies which has the possibility to help predict how individuals will react to new therapeutic drugs. These kinds of programs, if combined with existing health data collected from various IoT devices open the door to personalized drug recommendations or may offer other non-pharmaceutical options of patients.

[145] 'Value-Based Health Care - Institute For Strategy And Competitiveness - Harvard Business School' <https://www.isc.hbs.edu/health-care/value-based-health-care/Pages/default.aspx> [accessed 21 September 2022].
[146] Wullianallur Raghupathi and Viju Raghupathi, 'Big Data Analytics in Healthcare: Promise and Potential', *Health Information Science and Systems*, 2 (2014), 3 <https://doi.org/10.1186/2047-2501-2-3>.
[147] 'Adverse Drug Events in Adults | Medication Safety Program | CDC', 2022 <https://www.cdc.gov/medicationsafety/adult_adversedrugevents.html> [accessed 21 September 2022].

4.5 Inclusivity

Digital tools and innovations have tremendous potential to substantially improve the quality of lives of individuals in urban environments. However, gaps exist in most countries in terms of access to information and communication technologies, this gap is known as the 'digital divide.'[148] Multiple factors contribute to this 'divide', including, socio-economic factors, geographical factors, educational, attitudinal, generational factors and physical disabilities.[149]

The digital divide is an expected consequence of all these factors, however, it can also exacerbate and thus reinforce the existing social inequality, thus deepening the divide contemporary societies. The digital divide is a complex and dynamic phenomenon, which can be explained through different aspects and steps that explain the human-technology relationship:

- the access to digital media, such as computers and the Internet, starts with a motivation and a positive attitude for using these media;
- secondly, physical access getting to any type of computer and Internet connection is needed;
- and a series of digital skills to use the digital media have to be developed by the individuals;
- as a final result, users of the media benefit from some positive outcomes related to the use of their favourite apps and programs.

The core theory about the digital divide is called 'Resources and Appropriation theory' and has been developed by one of the most outstanding researchers in this field, Jan van Dijk.[150] The main statement of this theory is that "particular personal and positional categories of individuals have more or less resources in following this four phases process and its outcomes or benefits, a process called appropriation of a technology."[151]

[148] Rowena Cullen, 'Addressing the Digital Divide', *Online Information Review*, 25.5 (2001), 311–20 <https://doi.org/10.1108/14684520110410517>.
[149] Cullen.
[150] Jan van Dijk, *The Deepening Divide: Inequality in the Information Society* (Thousand Oaks, Calif: Sage Pub, 2005).
[151] Dijk.

The influencing factors have been outlined in the following explicatory framework (Figure 6).

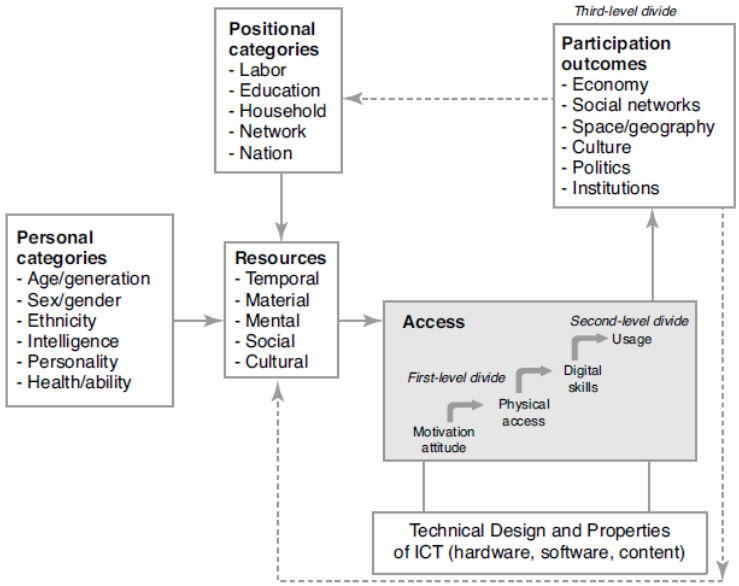

Figure 6 Causal Model of Resources and Appropriation Theory of the Digital Divide (adapted from Van Dijk (2005))

Today, the categories of age, gender, ethnicity, labour position, disability, education and nation or region are the most important factors in explaining digital inequality in all phases. These categories have unequal resources such as material (income), mental (knowledge), social (relationships) and cultural capital.

The report from ITU (International Telecommunication Union, Geneva) shows that the gap between more favourite categories (young people, with high education and occupations, males, part of the ethnic majority, living in an urban environment and in developed countries) towards people with less favourable characteristics (elderly people, with low education and occupations/unemployed, often females, ethnic minorities, from rural environments and developing countries) have been widening in the last 25 years: even if some factors such as motivation and physical access have improved, the gaps of digital skills, usage and outcomes are still increasing.[152]

In terms of **physical access** developed countries have about 70 to 98 percent Internet access while developing countries still average around 40-42 percent. On average, half of the world population have now Internet access and at least one access device (from PC to smartphone). In the meantime, technological development is not halting. People with low income, education and social class are trying to catch-up with using a mobile or smartphone. This type of device is the hope for the developing countries at least getting access via one medium, but in this way they cannot 'leapfrog' technological phases of evolution. Some observers are talking about the appearance of '*mobile underclass*' in both developed and developing countries.[153]

[152] *Measuring the Information Society Report Volume 1* (ITU, 2018) <https://www.itu.int/en/ITU-D/Statistics/Documents/publications/misr2018/MISR-2018-Vol-1-E.pdf>.
[153] Philip M. Napoli and Jonathan A. Obar, 'The Emerging Mobile Internet Underclass: A Critique of Mobile Internet Access', *The Information Society*, 30.5 (2014), 323–34 <https://doi.org/10.1080/01972243.2014.944726>.

Mobile (smart) phones are still inferior in work, education, business and citizen use as compared to PCs and laptops with fixed and broader connections.

The next phase is **digital skills or literacy**. Especially, people with high education and occupations are superior to people with low education and manual jobs concerning content-related digital skills. In terms of operational and formal skills young people are much better than seniors.

In **usage of the digital media/the Internet** differences between personal and positional categories have grown in the last 25 years.[154]

The result is that people with different social class, age, gender, ability level, ethnic and cultural origin and other backgrounds are increasingly using the Internet differently. A structural divide observed here is called the *usage gap*: people with high education and social class use more informational, educational, work and career enhancing applications and people with low education and social class primarily use applications of entertainment, chat or simple communication and e-shopping.

The final phase is **benefitting from Internet use**. Also in this case, people in favourable categories report more positive outcomes of Internet use in all domains of society (economy, social, politics, cultural etc.) and are better prepared to cope with the negative outcomes. Those people with unfavourable conditions report exactly the opposite.[155,156]

All these phases and divides show that existing social inequalities of all kinds are reflected in digital inequalities. In practice, they are even reinforcing these old inequalities because the inequality of outcomes supports better or worse resources and participation in society: on the job market, in politics and citizenship, social networking and cultural (online) activities.

Looking at the future, we cannot expect the gap to be closed. The more advanced the Internet applications become, the more digital skills are needed, especially content-related skills (information, communication, strategic). The more applications are offered, the more they are used differently by particular groups of people. Because social inequality is increasing in many parts of the world, digital inequality will follow. The simple reason is that digital media are important tools that tend to support people with high positions more than those with low positions. Digital inequality is of a relative kind (more or less) and not absolute (have or have not). Therefore, policy perspectives to solve the digital divide need to be multidimensional: technological, economic, educational, social and persuasive (creating awareness), and have to reduce social and digital inequality simultaneously.

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[154] Grant Blank and Darja Groselj, 'Dimensions of Internet Use: Amount, Variety, and Types', *Information, Communication & Society*, 17.4 (2014), 417–35 <https://doi.org/10.1080/1369118X.2014.889189>.
[155] Alexander JAM Van Deursen and Ellen J Helsper, 'Collateral Benefits of Internet Use: Explaining the Diverse Outcomes of Engaging with the Internet', *New Media & Society*, 20.7 (2018), 2333–51 <https://doi.org/10.1177/1461444817715282>.
[156] Dijk.

Ageing Population

The socio-economic and health changes that are taking place today, together with the increase in life expectancy, mean that there is a clear demographic shift towards more and more older people in our global environment. Consequently, this leads to an increase in the number of people living with chronic illnesses, multimorbidity, concurrent treatments and a range of additional health-preserving care. In this sense, technological tools are emerging to support this type of people, impacting on the health system with possible cost savings in the long term and improving the well-being of our elders.[157]

An ageing population means that there will be a significant increase in the amount of time individuals spend at home. Therefore, there is a paramount need to focus on facilitating a living environment for the elderly where they are able to live independently, any chronic diseases or ailments can be effectively managed, and where their physical and mental health can flourish.[158] Autonomy in daily activities plays a vital role in ensuring that the quality of life of elderly individuals is promoted and sustained. Moreover, the inability to adequately perform daily activities is correlated with an increased risk of falling and a higher rate of mortality.[159][160] These daily activities include simple activities like bathing, dressing or eating.

Elderly individuals who suffer from loneliness can also experience a lack of meaning in life. There are certain regions in the world with an above-average number of healthy, older individuals. The Japanese island of Okinawa is one of those areas with exceptional longevity, with 68 centenarians per 100,000 people.[161]

In the Japanese language, the concept of "ikigai" is described as "joy and sense of well-being from being alive" and of "realizing the value of being alive."[162] Studies in Japan have found that the lack of *ikigai* was substantially correlated with an increased risk of all-cause mortality.[163] In 2017, the UN's happiness report mentioned 'eudaimonia', a sense of meaning or purpose in life similar to ikigai, as an important factor. Although research on ikigai has traditionally been focused on its impact on longevity, more recent research has seen it used in career guidance, well-being training, and clinical practice.

Having a purpose in life is one of the most important human needs; however, finding purpose in life is not entirely obvious for a majority of individuals. Studies have shown that individuals with a greater sense of meaning and purpose, tend to take part in more health-promoting behaviours like exercising[164] and refraining from smoking.[165]

During the COVID-19 pandemic, higher levels of meaning of life were associated with lower levels of anxiety and distress.[166] Modern society can be distracting people from achieving their purpose in life. Although the concept of 'purpose in life' can be relatively unclear or undefinable, people can derive a purpose in life from various activities.

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[157] Jean Bousquet and others, 'Building Bridges for Innovation in Ageing: Synergies between Action Groups of the EIP on AHA', *The Journal of Nutrition, Health & Aging*, 21.1 (2017), 92–104 <https://doi.org/10.1007/s12603-016-0803-1>.
[158] Albert Haque, Arnold Milstein, and Li Fei-Fei, 'Illuminating the Dark Spaces of Healthcare with Ambient Intelligence', *Nature*, 585.7824 (2020), 193–202 <https://doi.org/10.1038/s41586-020-2669-y>.
[159] Margaret G. Stineman and others, 'All-Cause 1-, 5-, and 10-Year Mortality in Elderly People According to Activities of Daily Living Stage', *Journal of the American Geriatrics Society*, 60.3 (2012), 485–92 <https://doi.org/10.1111/j.1532-5415.2011.03867.x>.
[160] https://pubmed.ncbi.nlm.nih.gov/22352414/
[161] N. Seki, '[Relationships between walking hours, sleeping hours, meaningfulness of life (ikigai) and mortality in the elderly: prospective cohort study]', *Nihon Eiseigaku Zasshi. Japanese Journal of Hygiene*, 56.2 (2001), 535–40 <https://doi.org/10.1265/jjh.56.535>.
[162] Shinmura I. Koujien (Japanese dictionary). 3rd ed. Tokyo, Japan: Iwanamishoten; 1987.
[163] Seki.
[164] Carole Holahan and Rie Suzuki, 'Motivational Factors in Health Promoting Behavior in Later Aging', *Activities*, Adaptation&Aging (2005), 47–60 <https://doi.org/10.1300/J016v30n01_03>.
[165] Barna Konkolÿ Thege, Adrienne Stauder, and Maria Kopp, 'Relationship between Meaning in Life and Intensity of Smoking: Do Gender Differences Exist?', *Psychology & Health*, 25 (2008), 589–99 <https://doi.org/10.1080/08870440802460442>.
[166] Jerzy Trzebiński, Maciej Cabański, and Jolanta Czarnecka, 'Reaction to the COVID-19 Pandemic: The Influence of Meaning in Life, Life Satisfaction, and Assumptions on World Orderliness and Positivity', *Journal of Loss and Trauma*, 25 (2020), 1–14 <https://doi.org/10.1080/15325024.2020.1765098>.

Through ikigai, one of the tools used to find purpose is the practice of 'life crafting', defined as "a process in which people actively reflect on their present and future life, set goals for important areas of life – social, career, and leisure time – and, if required make concrete plans and undertake actions to change these areas in a way that is more congruent with their values and wishes."[167] Life crafting is associated to the most important areas of life, and therefore enables a more holistic approach in shaping one's life.[168]

The IoT sector can play an essential role in helping urban dwellers achieve their sense of purpose and subsequently improve longevity and overall happiness. IoT devices can be employed to help individuals save time in their day-to-day activities, freeing up time for activities that help to enrich individuals to lead meaningful lives and achieve their goals. IoT solutions can introduce meaningful interventions.

Virtual Reality (VR) can be utilised to help retrieve meaningful memories through reminiscence to promote the well-being of lonely older adults. Research shows that loneliness interventions should be designed in such a way that is tailored to the individual and engages older adults in the design process.[169]

Several efforts are being made all over the world to bring technologies closer to elderly users. The growing demand for technology and its rapid evolution has led to a number of efforts being made around the world to increasingly integrate technologies with consumers and make adoption more targeted.[170] One of the European reference projects that have addressed this issue, H2020 ACTIVAGE, has provided the following lessons learned that should be taken into account for subsequent research:[171]

1. It is key for health and social care policymakers to invest public and private funds in the extension of active and healthy ageing services to the whole population of demanding societies.

2. Service providers must adopt cost-effective business models that reduce costs for payers and increase benefits for providers and citizens, making overall health and social care systems more sustainable and reaching wider segments of users.

3. Older citizens and their families should be involved in the co-creation, adoption and demand for new services that make their lives better, safer and more autonomous.

4. Industry must support interoperability standards, to ignite the growth of the global health and wellbeing market.

[167] Michaéla C. Schippers and Niklas Ziegler, 'Life Crafting as a Way to Find Purpose and Meaning in Life', *Frontiers in Psychology*, 10 (2019), 2778 <https://doi.org/10.3389/fpsyg.2019.02778>.
[168] Schippers and Ziegler.
[169] Lars Veldmeijer and others, 'Reframing Loneliness through the Design of a Virtual Reality Reminiscence Artefact for Older Adults', *Design for Health*, 4.3 (2020), 407–26 <https://doi.org/10.1080/24735132.2020.1848976>.
[170] Clara I. Valero and others, 'AIoTES: Setting the Principles for Semantic Interoperable and Modern IoT-Enabled Reference Architecture for Active and Healthy Ageing Ecosystems', *Computer Communications*, 177 (2021), 96–111 <https://doi.org/10.1016/j.comcom.2021.06.010>.
[171] 'ACTIVAGE Project : Internet of Things (IoT) for Ageing Well' <http://www.activageproject.eu/> [accessed 21 September 2022].

To proficiently introduce IoT technologies into the daily life of an older adult some key specific needs must be taken into consideration and divided according to the following macro-areas:

1. Physical
2. Cognitive
3. Emotional
4. Social

Each of these needs can be unpacked in the following sub-needs:

Physical need	• Assistance with medical care and safety both inside and outside their home • Assistance with nutrition, showering, personal care • Maintenance of muscle tone
Cognitive need	• Help with stimulation • Help with learning new activities
Emotional need	• Help to overcome a feeling of not belonging, as they have often been unable to continue working or have lost friends and family in old age. • Make the person feel cared for, as this demographic group needs, above all others, to have this feeling
Social need	• Need for communication in their daily life to avoid isolation and feelings of frustration. • Need for social interaction outside their family, which may be from peers or others in society

Different type of IoT solutions can support the addressing of such needs, and in particular, the following ones are the most suitable:

- Presence sensors installed in a non-intrusive way in the home of the person to be monitored. The caregiver receives notifications and smart alarms by WhatsApp, email or SMS of the most relevant events occurring in the home and can access the information in real-time.
- Surveillance cameras allow the family member or caregiver to see what is happening inside the home in real-time.
- Smart bracelets helping to monitor the person's state of health in real-time, providing alerts for possible health problems that may arise.
- Assistance button worn by the elderly person around the neck. Once pressed, an alert is sent to the emergency centre.

The foreseen benefits are various, and among them, we can list the following:

- Improved interaction between health professionals and patient
- Regular reporting of the user's well-being to the caregiver
- Continuous assessment of the cognitive status
- Reduced caregiver stress burden
- Improved energy efficiency
- Relief of depression and increased quality of life for both older adults and formal/informal caregivers.

Individuals with Special Needs

IoT can be deployed in homes in order to assist in easily controlling and managing environments. Home technology can help individuals and parents of children with specific disabilities in the living environment. Being a parent in this situation was not easy for anyone, much less for parents of children with special needs. The shutting down of special education systems meant that parents lost a vital support network and had to be the sole full-time caregivers despite often lacking the skills to cope with this new and daunting situation.[172]

For example, individuals with Autism Spectrum Disorder (ASD) have higher comorbidity for anxiety disorders than the general population. According to World Health Organisation (WHO), one birth out of 100 is affected by ASD. The inherent anxiety related to ASD itself makes many environments challenging for individuals with ASD. The inability to cope with change in addition to "sensory stimuli" are common and specific triggers of anxiety among individuals with ASD. People with ASD are comfortable following routine patterns and tasks. When faced with situations that are unusual for them, they may have episodes of stress, fear panic and even trauma. Some of these situations can happen daily or are necessary going to the doctor, cutting your hair waiting for the bus, or taking a trip.

Virtual Reality (VR) is a good approximation to what you will find in a real situation and, after a period of training and adaptation allows you to recreate the different moments that are part of a specific activity. In this way, you can prepare people with ASD to face a real situation and help reduce fear or discomfort. IoT and VR share the same basic idea as both merge physical and digital realms to create a new experience for consumers. While IoT manipulates real-world objects digitally, VR makes the digital world seem realistic. The convergence of virtual reality and IoT is a revolution and aims to merge the digital and physical worlds. In a way, it gives digital objects physical characteristics and interacts with them in the same way people interact in the physical world.[173]

[172] Itay Tokatly Latzer, Yael Leitner, and Orit Karnieli-Miller, 'Core Experiences of Parents of Children with Autism during the COVID-19 Pandemic Lockdown', *Autism: The International Journal of Research and Practice*, 25.4 (2021), 1047–59 <https://doi.org/10.1177/1362361320984317>.

[173] 'How IoT Is Empowering Virtual Reality - Techiexpert.Com', 2020 <https://www.techiexpert.com/how-iot-is-empowering-virtual-reality/> [accessed 22 September 2022].

Furthermore, wearable technologies have the potential to increase the quality of life and wellness for individuals with ASD and their families. The use of wearable technologies can reduce medical costs through discreet monitoring of health conditions and well-being, in addition to providing individuals with more freedom.[174] Designs of wearable technologies for individuals with ASD should ensure that it relieves and calms the wearer by "adding weights and pressure, minimizing sensory distractions, and using soft fabrics."[175] Furthermore, wearable technologies can be designed in a way which helps individuals with ASD increase their awareness, and manage their behaviour and tasks. For example, devices that can monitor emotional changes can help predict meltdowns by tracking anxiety symptoms through heartbeat, skin temperature, and sweat levels.[176][177]

Combatting Social Isolation & Loneliness

Establishing a link between the individual and society through technology, reforming social media as more than just an outlet for self-indulgence, and creating a safe environment for strengthening self-image and mental comfort through knowledge gained from digital personal assistants and sensors, maybe the way forward. Researchers found, for example, that social technology use, such as social media and video calling, could reduce feelings of loneliness, risk of chronic illness and depression.[178] More advanced technologies, such as social "empathic" robots can help to reduce the mental fatigue of those having to isolate during pandemic periods[179] or telerobots that can measure temperatures.[180]

4.6 Improving Air Quality

To reduce air pollution, the alignment of the air quality standards with the WHO guidelines should be assessed. This means, among others, that citizens should be protected against pollution from industrial plants, dangerous chemicals or other heavily polluting sources. Local authorities could use the support from the commission to strategically address the air pollution issue, including that from large industrial installations, whilst not compromising too much on the competitiveness of the industry in the given area. Finally, the new chemical strategy for sustainability toward a toxic-free environment[181] can be embraced to reduce the concentration of toxic chemicals in the environment and to develop more sustainable alternatives.

[174] Sungmee Park and S. Jayaraman, 'Enhancing the Quality of Life through Wearable Technology', *IEEE Engineering in Medicine and Biology Magazine*, 22.3 (2003), 41–48 <https://doi.org/10.1109/MEMB.2003.1213625>.
[175] Sumin Helen Koo and others, 'Wearable Technology Design for Autism Spectrum Disorders', *Archives of Design Research*, 31.1 (2018), 37–55 <https://doi.org/10.15187/adr.2018.02.31.1.37>.
[176] Koo and others.
[177] ibid.
[178] William J. Chopik, 'The Benefits of Social Technology Use Among Older Adults Are Mediated by Reduced Loneliness', *Cyberpsychology, Behavior and Social Networking*, 19.9 (2016), 551–56 <https://doi.org/10.1089/cyber.2016.0151>.
[179] Mauro de Gennaro, Eva G. Krumhuber, and Gale Lucas, 'Effectiveness of an Empathic Chatbot in Combating Adverse Effects of Social Exclusion on Mood', *Frontiers in Psychology*, 10 (2020), 3061 <https://doi.org/10.3389/fpsyg.2019.03061>.
[180] Mohammad Nasajpour and others, 'Internet of Things for Current COVID-19 and Future Pandemics: An Exploratory Study', *Journal of Healthcare Informatics Research*, 4.4 (2020), 325–64 <https://doi.org/10.1007/s41666-020-00080-6>.
[181] 'Chemicals Strategy' <https://environment.ec.europa.eu/strategy/chemicals-strategy_en> [accessed 22 September 2022].

Outdoor Air Quality

The most common approaches applied to simulate air pollution are top-down approaches due to a lack of detailed input information (e.g. traffic activity data at the road level instead of road fuel consumption at the municipal or national level). This technique enables the characterisation of a larger area; however, if we want to understand how air quality is distributed over a city with a spatial resolution of meters, modelling techniques based on bottom-up approaches are more appropriate.

Given the issues in monitoring and managing air quality at the urban level and the strict WHO air quality recommendations announced in 2021, IoT solutions may play an important role in surpassing these limitations. For instance, developments in IoT technology have introduced a range of comparatively inexpensive air quality and pollution sensors.

While many IoT sensors lack accuracy compared to the typical monitoring stations, they still offer a good indication of air quality and pollution.

With mobile air quality sensors, local authorities and councils can rapidly assess air quality across vast areas with lower but reasonable accuracy. Not only will this give policy-makers a high-level view of the area with heatmaps, but it may also help identify hot-spot areas requiring more focused measurement and mitigation interventions. All observations are related to specific GPS coordinates and time-stamps, allowing post-data analysis by time and location and cross-referenced against other data (e.g. weather data). Therefore, IoT sensors provide:[182]

- **Greater Coverage**.

IoT solutions allow monitoring of larger areas due to their lower costs.

- **Reduced Cost.**

Lower costs related to fixed and management costs, being able to constitute any holistic environmental management solution.

- **Identify pollution hotspots and problem areas**.

The overall coverage allows the identification of anomalies/pollution hotspots.

- **Shape policy and decision-making.**

The additional air quality data may be used in decision-making by policymakers, town planners, population health, education leaders and transport managers.

- **Improve outcomes.**

Monitoring air quality is the first step to addressing the impacts correlated to poor air quality (e.g. human air quality problems).

[182] Joe Hughes, 'Mobile Air Quality Monitoring with IoT', *Manx Technology Group*, 2021 <https://www.manxtechgroup.com/mobile-air-quality-monitoring-with-iot/> [accessed 22 September 2022].

Besides IoT solutions enabling the improvement in the quantity of air quality monitoring points within a specific region, IoT may also contribute to:

- **Thorough real-time monitoring, provide alerts to users and inform them of dangerous events (high concentrations of harmful pollutants)** and instantly notify them by a mobile app.

- **Use input from user IoT devices** to gather data for air quality modelling and forecast (e.g. traffic activity, proof of location), and data for air quality exposure studies (e.g. duration in different activities and environments). These data might be the key to a vast implementation of bottom-up approaches and allow air quality mapping with high spatial resolution.

- **Provide information and influence users** to change their behaviours towards greener choices (e.g. influence users to change to cleaner transport modes).

Furthermore, decreasing air pollution has a cooling effect on the earth, thereby reducing the global warming rate;[183] emphasises the need for a holistic, systems-thinking approach, taking into account all facets of the problem.

Indoor Air Quality

To keep the Indoor Air Quality (IAQ) at optimal levels, the rate at which outdoor air is supplied has to be proportional to the pollutants within the building. The amount of pollutants inside the building will vary depending on the load and number of occupants. Therefore, the building needs to have a mechanism to accurately assess the indoor pollutants and vary the rate of introducing outdoor air accordingly.

Thermal comfort is also necessary for occupants to be at full capability, their indoor space needs to be thermally comfortable. It's influenced by what could be classified as environmental parameters such as air temperature, mean radiant temperature, air relative humidity, and air velocity. There's also a direct relationship between acoustic comfort and occupant productivity in buildings. Despite being recognized as an important parameter, research indicates that acoustic comfort is not considered a high priority in building design leading to several post occupancy productivity related issues. Visual comfort defines lighting conditions and the views from one's workspace. Insufficient light and especially daylight or glare reduce the ability to see objects or details. Visual comfort at work has an impact on comfort after work as well, studies have looked at the impact of visual comfort on sleep quality at home after work.

It would be recommended that alongside insulation and air quality, devices for better living should also be included in housing standards. Machine learning combined with lower prices and standards being applied and accepted has made it possible for more seamless inclusion of such IoT devices in modern homes.

[183] 'Luchtvervuiling heeft een verkoelend effect. Zorgt schone lucht voor meer opwarming?', *NRC* <https://www.nrc.nl/nieuws/2021/08/19/luchtvervuiling-heeft-ongemakkelijk-voordeel-een-koeler-klimaat-a4055345> [accessed 22 September 2022].

4.7 IoT to Disconnect

Despite wide concern about privacy, security, trust and cyberattacks, IoT will expand successfully linking an increasing number of people and objects together. Eventually not only connecting with anything and everything; but perhaps even lending a hand to human-beings to help us have an improved understanding of ourselves by hacking our brains. This can be seen through the various public and private sector initiatives developing devices that interface directly with the brain.[184] The encroachment of technological devices, IoT or otherwise, into an individual's mental domain poses novel risks and humanistic threats. Though these risks and threats are novel, action should already be taken to ensure that the impact of such technologies can be avoided before they even arise.

Connection is inevitable, it is a human craving. The 21st century has seen a massive upsurge in human interconnectivity, through innovation in cellular communication technologies and online social networking. Therefore, the discussion is not *if* we are connecting, but *how* we should connect; IoT can significantly play a crucial role in assisting the latter. Deep, meaningful, mental connections are the form of connections that human-beings desperately yearn for in the digital age; it is also vital for our health and overall well-being as highlighted across the previous chapters. Connectivity has become something we as a species have grown to become reliant on; regardless of whether it is this connectivity to other individuals or the connectivity to the endless flow of information that exists on the Internet. The notion of connectivity, formerly a valuable commodity, has transformed into a basic need in the digitalisation of our society, without us even realising it. The shift in connectivity as a nice to have, to a need to have has fundamentally transformed the way individuals interact with the ecosystem in which they live. Give the average, modern day, teenager a physical map and many would probably struggle to navigate without the use of their smartphones. Does that mean that as a society, we are getting dumber as our devices get 'smarter'?

What we see, what we feel, where we go, who we meet, among others, collectively form part of 'the human experience'. Formerly, the human experience remained with the individual experiencing it and those they have chosen to share it with; be it through shared experiences with others or sharing stories with friends and people you meet. However, the digitalisation of society has also spearheaded the digitalisation of the human experience. Before we even realised, we now exist in a society where third parties unilaterally claim our "human experiences as free raw material for translation into behavioural data."[185] As we increasingly experience the world through the plethora of 'smart' devices we now own, we are complicit in the decrease of our own real-life, physical connectedness and ultimately, our own ignorance of what's happening in the real world. With the metaverse around the corner, we will soon sense our world through various IoT devices, such as haptic gloves that augment the sense of touch. Ultimately, this could potentially cause a shift in human evolution in many ways, particularly in the instinctive human responsiveness and response. As various industry players pump funds into the creation of virtual worlds, the design of these digital 'ecosystems' will fundamentally shape how human beings interact with one another and their surrounding virtual environments.

Crucial sensory elements that used to dictate with whom and how we interact will be ignored; for example, the sense of smell or the sensation of touch from someone in the same room.

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[184] 'BrainCo Train Your Brain', *BrainCo* <https://brainco.tech/> [accessed 8 June 2022].; 'Homepage', *EMOTIV* <https://www.emotiv.com/> [accessed 8 June 2022].; Studio Freight, 'Neurable', *Neurable* <https://neurable.com/> [accessed 8 June 2022].; 'ABOUT US', *MELTIN MMI* <https://www.meltin.jp/en/about/> [accessed 8 June 2022].; 'Advanced Neurotechnology', *Bitbrain*, 2019 <https://www.bitbrain.com/homepage> [accessed 8 June 2022].; 'Fact Sheet: BRAIN Initiative', *Whitehouse.Gov*, 2013 <https://obamawhitehouse.archives.gov/the-press-office/2013/04/02/fact-sheet-brain-initiative> [accessed 8 June 2022].; 'Human Brain Project Home' <https://www.humanbrainproject.eu/en/> [accessed 8 June 2022].

[185] Shoshana Zuboff, *The Age of Surveillance Capitalism: The Fight for a Human Future at the New Frontier of Power*, First edition (New York: PublicAffairs, 2019).

In the creation of various digital ecosystems, the metaverse or social networks that have been in existence for over a decade, it can be argued that the notion of a 'digital identity' or a 'digital persona' has increasingly gained importance. What would be the state of our health and well-being if our digital personas become more important than our real-world persons? Perhaps, we already are living in a world where place more focus on our online selves than our actual physical form. Due to the possible and probable disconnect between our digital personas and our carbon-based physical form; how are we able to trust our interactions in the digital domain?

The shift from connectivity as an asset to a necessity comes with its own pitfalls. Modern, particularly urban societies have now started to encounter the side-effects of our hyper-connected existence. Arguably, connectivity has transformed beyond a necessity into an addiction;[186] the inability to disconnect a profound and oftentimes detrimental consequences to our health and well-being, be it physical or mental health. As a community, we can no longer neglect the plethora of research and studies showing the detrimental effects of novel technological solutions that have emerged in the past four decades.

Nowadays, it takes more discipline that ever to switch off completely from the wide array of connected devices we have adopted into our daily lives. Studies have found that individuals under 25 do not know how to wind down and completely relax; this coupled with rampant addiction to digital products and services[187] that facilitate connectivity, forces the sympathetic nervous system into overdrive.[188]

The sympathetic nervous system drives the "fight or flight" response in stressful situations.[189] When the sympathetic nervous system is working in overtime, our parasympathetic nervous system, responsible for "rest and digest", takes a back seat; as a result, the plethora of health issues that urban dwellers are already plagued with, for example, anxiety, depression, burn-out, digestive issues, and chronic fatigue, among others, are further exacerbated. The shift towards hyper-connectivity has created an added layer of stress in our urban societies. The continual stress because of constant connectivity has caused our hippocampus, the part of our brain that controls stress response, to not function properly. As a result, our amygdala, the part of our brain that is in our prefrontal cortex, responsible for planning, forward-thinking and coming up with sensible solutions, is unable to function properly.

[186] Chien Chou, Linda Condron, and John C. Belland, 'A Review of the Research on Internet Addiction', *Educational Psychology Review*, 17.4 (2005), 363–88 <https://doi.org/10.1007/s10648-005-8138-1>.
[187] Chou, Condron, and Belland.
[188] Andrew Chih Wei Huang, 'Autonomic Nervous System and Brain Circuitry for Internet Addiction', in *Internet Addiction: Neuroscientific Approaches and Therapeutical Implications Including Smartphone Addiction*, ed. by Christian Montag and Martin Reuter, Studies in Neuroscience, Psychology and Behavioral Economics (Cham: Springer International Publishing, 2017), pp. 161–80 <https://doi.org/10.1007/978-3-319-46276-9_10>.
[189] Jacob Tindle and Prasanna Tadi, 'Neuroanatomy, Parasympathetic Nervous System', in *StatPearls* (Treasure Island (FL): StatPearls Publishing, 2022) <http://www.ncbi.nlm.nih.gov/books/NBK553141/> [accessed 22 September 2022].

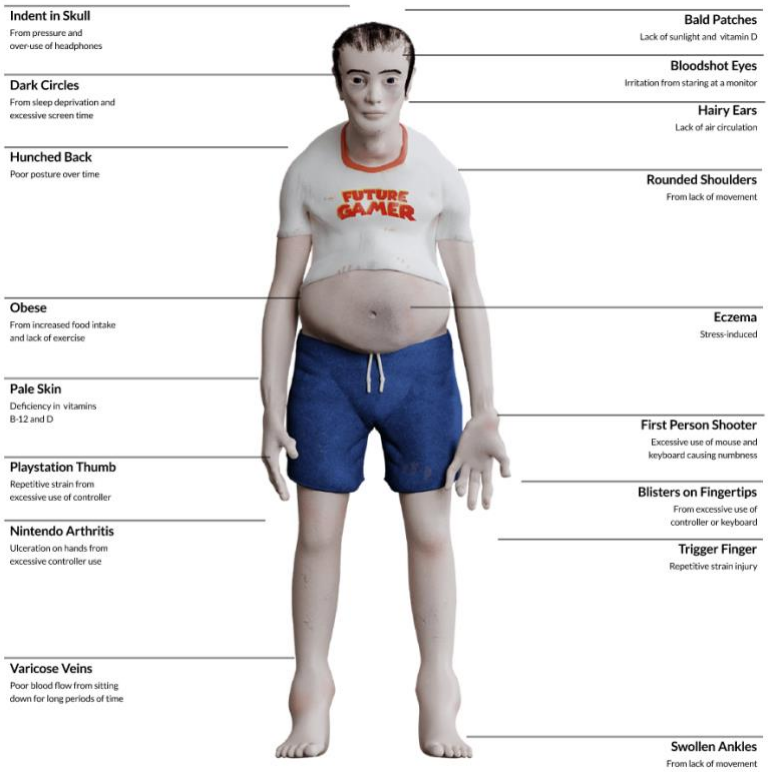

Figure 7 Future Online Gamer Body

Source: https://www.onlinecasino.ca/future-gamer/

Considering the severe implications on both our physical and mental health (see Figure 7 as an example of the potential physical implications) as a result of the hyper-connectedness of modern, urban societies, it is arguable that the 'right to be left alone' should emerge as a novel right in this digital age. Facilitating the right to be left alone, to be disconnected, may arguably wind up promoting more meaningful interactions in the digital world.

Realistically speaking, despite the downfalls of digital technologies, there are also several benefits that can be derived from their use. Is there possibly a way we can reimagine a scenario of a happy 'in between'? Modular ways of using IoT to enhance your health and well-being, that considers the very human need to disconnect. Digital solutions that have a holistic understanding of what truly optimal health and well-being is for everyone, on a personal level. A safe digital ecosystem where our human experiences aren't commodified, where we are in control. A kind of world where Internet of Things exist to cater for Internet of Human-Beings.

5. Trust and Trustworthiness

One thing the human mind is good at is recognizing patterns. This is how we navigate and identify each other. The same can be applied to experience. We are good at learning and remembering. By applying that experience to new experiences, we can estimate the right cause of action, despite not actually experiencing that particular situation before. However, we make a conjecture; if there is something amiss in a given situation, and an object is missing, or keywords are lacking, this generates a sense of uncertainty and anxiety. Although the details may be subtle, we notice when something is different - either consciously or unconsciously. A unique quality based on our ability to recognize patterns and apply past experiences, a gut feeling may be the deciding factor for which choices are made. The feeling is not necessarily correct, but it's worth taking seriously. Integration with technology is unavoidable in the long run, but it may also provide a sense of security and community. The ability to share experience, share senses, and build upon a gut feeling may assist us in making the right choices - even in a technologically advanced society.

People, society, public and private sectors have grown to become over-dependent on undependable systems. It has exposed us to increasingly deteriorating levels of sovereignty and other meaningful control. This trust we have given away ourselves, for whatever reason, but generally not for the right reasons and more often than not, without us even knowing it. As a result, the level of mistrust within society is continuously growing.

As much as we would love to trust, the 'smart' devices marketed by this Digital Age, it has proven not to be immune to evil, ignorance, build-fast-fix later business models and other breaches of norms and vales, including public trust and trust by individuals. As a result, systems, services, lives of people, key networks and even entire nations, democracies and societies are threatened, further eroding trust. We need to bring back and sustain the integrity of trust. Although not an easy feat, it is a prerequisite for being able to lead, use and being in meaningful control of the next phase of this Digital Age.

Through the course of evolution, human beings have discovered certain evolutionary stable strategies that are unique to our species alone.[190] Evolutionary biologists have noted that the evolutionary success of *Homo sapiens* can largely be attributed to its ability to manage complex social relationships.[191] Our ability to function cooperatively as a species has become instrumental in ensuring the survival of our species. Regardless of whether social cooperation happens out of inherent altruism or selfish reasoning, as humans, we behave the way we do because it is essential to our survival. As put forth by neuroscientist Damasio, "in our inalienable need to maintain ourselves, we must, of necessity, help preserve others. If we fail to do so, we perish and are thus violating the foundational principle, and relinquishing the virtue that lies in self-preservation."[192]

[190] J.H. Clippinger, 'Human Nature and Social Networks' <http://www.dodccrp.org/files/Human_Nature.pdf>.
[191] Kim Sterelny, 'From Hominins to Humans: How Sapiens Became Behaviourally Modern', *Philosophical Transactions of the Royal Society B: Biological Sciences*, 366.1566 (2011), 809–22 <https://doi.org/10.1098/rstb.2010.0301>.
[192] Antonio R. Damasio, *Looking for Spinoza: Joy, Sorrow, and the Feeling Brain*, 1. ed (New York: Harcourt, 2003).

In Europe, this 'foundational principle' is the concept of human dignity enshrined in the European human rights framework. Human dignity is a multi-dimensional concept, it entails the balancing of individual and collective interests; it can act as an empowering force or a limiting force and is crucial to ensure that democracy flourishes and the rights and protections offered by the European human rights framework can be enjoyed by all individuals in society.[193] Therefore, when designing digital ecosystems and deploying IoT devices, it is of utmost importance that human dignity is taken into account throughout the entire innovation and development process. The concept of human dignity "emerges as a principle that brings to expression the interconnectedness between persons and their bodies,"[194] this is relevant in the context of IoT devices, in particular wearables devices.

Finding the right symbiosis between individual needs, particularly in the digitisation of health care, and the impact on the wider society is not an easy feat. Technology changes the world at an ever-increasing pace, whether we like it or not. The change is expedited by both non-digital global occurrences such as the ongoing COVID-19 pandemic as well as by increased and ever-converging technical capabilities such as connected devices, platforms, available data, artificial intelligence, among others. These enable connecting, inter-connecting and hyper-connecting billions of individuals, organizations, communities, societies, and data, with tens of billions of objects and entities. As a result, this networking effect has forced digital technologies to become a necessity, for people, society, and our ecosystems, both on the European Union level and globally. Getting these technologies to function is the easy part; however, difficulty arises in establishing the appropriate level of contextual trust, preserving integrity of the user (in terms of safety, security, privacy, data management and resilience) and demonstrating accountability and compliance in this Digital Age. The notions of trust, integrity, accountability and compliance are all vital to ensure that individuals are empowered in participating in the digital economy and are free to enjoy the fundamental rights granted to them by the European human rights framework.

In the deployment of IoT devices, be it wearables, home devices or devices in public spaces, it is of utmost importance to ensure that both individuals and society as a whole are able to enjoy the fundamental human rights, freedoms and protections guaranteed by the European human rights framework, namely the rights to privacy, individual autonomy (mental and physical integrity), and the prohibition of discrimination, among others.

Healthy living involves a diverse group of stakeholders, including but not limited to, professional care givers, physicians, doctors, hospitals, health service providers. These diverse group of stakeholders are, or should be, trust anchors for any individual that needs (preventative) care, cure or post-cure care. For example, research has shown that (Glynn et al. (2015)) found that hypertensive patients were far more likely to engage with an app to self-manage their condition if it was recommended by their doctor. This multi-stakeholder approach is essential in the complex domain of healthy living and should also be taken into consideration when implementing any capabilities of IoT.

[193] Beyleveld Deryck and Brownsword Roger, *Human Dignity in Bioethics and Biolaw* (Oxford University Press, 1993) <https://doi.org/10.1093/acprof:oso/9780198268260.001.0001>.
[194] Britta van Beers and Gareth T. Davies, 'Human Dignity and Bioethics at the Beginning and End of Life', *SSRN Electronic Journal*, 2021 <https://doi.org/10.2139/ssrn.3952537>.

Personal data, in particular, health related data is extremely sensitive in nature and the individual may be put in a vulnerable position should the data fall into the wrong hands. Therefore, it is vital to ensure that these data are collected, processed, and stored in trustworthy ecosystems. However, trustworthy ecosystems require accountability from all stakeholders involved and the starting point for accountability is the individual user.

Awareness by the individual is required to build and achieve the appropriate level of trust, although this is obvious. It's not always easy. Having sufficient knowledge is generally seen as a blocking factor that is even more essential than concerns about security, privacy, or compliance. Insufficient knowledge, for instance, means a lack of access to relevant information, and the lack of clarity and reliability of supplied information. A sense of continual individual awareness is a crucial starting point to build and maintain trust. Awareness is usually followed by understanding; however, providing merely an explanation does not always mean an individual is able to understand, particularly, when discussing digital technologies and its underlying and surrounding ecosystems. True understanding could mean a certain level of appreciation, which arises from multiple considerations, including among others, benefits, risks, impact, and the individual's risk appetite.

These nuances of trust are essential to ensure human-centric innovation. The fact that one starts to adopt certain capabilities in the Digital Age, does not necessarily mean the appropriate level of trust has already been achieved or will continue to be achieved. Trust requires continual consistency and represents a pivotal point in which adoption transforms to acceptance. Trust enables individuals to be truly informed and autonomous in their decision-making.

In order to build trust, individuals should not be treated as mere data points, nor should they be coerced or nudged towards unfavourable outcomes. Personal data is something personal and should be processed and protected by accountable custodians, for a single clear purpose only. IoT devices embody the capacity to collect and process large amounts of personal data, such as general geographic information, as well as levels of physical activity, heart rate, oxygen levels, and the presence or absence of diseases. In order to protect the privacy of a user of these devices, it is important that nobody has access to these personal data.

5.1 Privacy

With an ever-growing ageing population and increasing alienation between the generations and natural habitats, methods need to be developed to bridge the gap. Technology is able to detect subtle signals indicating changes in behaviour and psychosocial issues. However, this comes at a cost: the intrusion of privacy. Even more serious is the security risk that data gathering presents. Internet-of-Things devices present a plethora of opportunities for the healthy living and the overall improvement in quality of life for urban dwellers. In the quest to innovate and design new technical solutions for 21st century problems, it is crucial that the notion of privacy is discussed and included in these technical solutions.

For example, opting for acoustic[195] or radar sensors[196] instead of visual sensors in bathing or toileting areas in assisted living homes for the elderly. Such solutions can ensure individuals do not feel like they are under constant surveillance and therefore are unable to be comfortable in their living environment.

[195] Chen, J., Zhang, J., Kam, A. H. & Shue, L. An automatic acoustic bathroom monitoring system. In Proc. International Symposium on Circuits and Systems 1750–1753 (IEEE, 2005).
[196] Shrestha, A. et al. Elderly care: activities of daily living classification with an S band radar. J. Eng. 2019, 7601–7606 (2019).

However, opting for alternative solutions and sensors to promote privacy is not enough, the underlying system and infrastructure of the technologies used by individuals must be privacy-preserving my design.

IoT devices and its networks introduce new types of risks that can cause privacy and surveillance problems. The deployment of IoT contributes to the expansion the scope for personal data collection. IoT devices, generally, are continuously observing and monitoring the surrounding environment through various sensors and are able to acquire information human behaviour. Data will be collected not only while using the device, but also during other activities in our personal lives. This could amplify privacy risks that are already existing in the online world. Depending on the device, the sensors will collect images, video, audio, temperature, motion, heart rate, or related data streams. With its built-in sensors IoT devices can continuously translate our physical worlds into digital data, even when users are not *actively* engaging with a digital device. Imagine a fitness tracker monitoring our sleep patterns and sending this to the manufacturer. Likewise, a security camera in a corner of the room could quietly send everything it observes to unwanted third parties, without permission or awareness of the owner or user of the device.

As healthcare services increasingly shift to distance or non-contact services, the advancement of sensors can promote convenience and access to healthcare. However, despite the increased level of convenience, increased knowledge on an individual's health can also lead to possibly inferring medical conditions of individuals that they would have preferred to keep private. Not only those who own or intentionally use the IoT devices are subject to continuous data gathering processes; individuals who don't own or intend to use or interact with such devices can, at times, be at risk of their data being gather without their consent or any other valid legal bases under the GDPR. For example, a visitor of someone who has a smart doorbell installed risks images of their face being shared with third parties. Similarly, vulnerable groups, for example, children may be subject to the processing of personal data through interaction with IoT devices without their parent's knowledge or consent.

Some types of personal data collected by IoT devices can be highly sensitive in nature. As previously explored, the market for IoT health devices, such as smart scales and fitness trackers, has grown substantially over the past years and continues to grow. These devices will observe and process data on physical health and could potentially affect the human rights to bodily integrity when not managed properly. A new upcoming field that builds upon highly sensitive personal information 'femtech'. Femtech manufacturers claim to design technology or technology-based services that enhances the women's health. These devices typically collect data on menstrual cycles, hormone levels and body temperature, and use machine learning to predict fertility levels. Without denying that these technologies can be very useful and have great benefits for society, it is important to recognise that the data should be handled with care.

Data concerning health is defined in the GDPR in the broad sense as "*personal data relating to the physical and mental health of a natural person, including the provision of health care services, which reveal information about his or her health status*."[197]

Special categories of personal data like health data are afforded a higher level of protection and require a valid legal basis for processing. One of the legal bases for processing special categories of personal data is explicit consent, among others.[198]

[197] Art. 4(15), GDPR.
[198] Art. 9(2). GDPR.

These forms of data should only be processed where necessary to achieve those purposes for the benefit of natural persons and society as a whole.[199] The higher level of data protection afforded under the GDPR for special categories of data stems from the "*presumption that misuse of these data in general is likely to have more severe consequence for individual's fundamental rights, such as the right to privacy and non-discrimination*."[200] The GDPR states that it should provide for harmonised conditions for the processing of special categories of personal data, namely health data, "*in respect to specific needs, in particular where the processing of such data is carried out for certain health-related purposes by persons subject to a legal obligation of professional secrecy*."[201]

Although the EU data protection framework includes provisions for processing special categories of data (including health data), there is no concrete and harmonised definition of health data. Moreover, there exists a lack of a unified definition of health data among the individual Member States.[202]

In 2011, the EU's Article 29 Working Party ("WP29") issued an Advice Paper on special categories of data. The Advice Paper acknowledged that because of the wide range of personal data that may classify as health data, health data represents one of the most complex forms of sensitive data. The Advice Paper refers to 'quantified' self apps and devices "*that allow people to register all kinds of aspects about their personality, mind, body, behavioural patterns and whereabouts.*"[203] As these apps and devices increase in popularity, they may be combined with other data to make inferences about data subjects' health.[204] Although these forms of data processing do not seem, on the surface, to be the processing of health data, there are apparent privacy risks considering the prevalence of Big Data practices and processing activities in today's society. Aggregation of information allows for inferences to be made; these inferences have the potential to reveal information about an individual's health status or other sensitive information about an individual's life. There is a need to provide a set of criteria that will help assess the cases in which lifestyle data constitutes health data.

Health data in practice is associated with "*any personal data generated within healthcare systems, including data concerning health which are collected by citizens and patients through wearable devices, apps and self-reported information*."[205] The European Data Protection Supervisor ("EDPS") published an opinion in 2015 on Mobile Health ("mHealth"), stating that "*lifestyle and well-being data will, in general, be considered health data, when they are processed in a medical context (e.g. the app used upon advice of a patient's doctor) or where information regarding an individual's health may reasonably be inferred from the data (in itself, or combined with other information), especially when the purpose of the application is to monitor the health or well-being of the individual (whether in a medical context or otherwise)*."[206]

The EDPS went further to add that the notion of what constitutes health data should be construed broadly in the absence of a clear definition, to include any data that relates to a person's physical and mental health information; because both categories of data (lifestyle and

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[199] Preamble §53, GDPR

[200] Article 29 Working Party. (2015). 'Health data in apps and devices', Annex to Communication between the Article 29 Working Party and DG Connect. <https://ec.europa.eu/justice/article-29/documentation/other-document/files/2015/20150205_letter_art29wp_ec_health_data_after_plenary_annex_en.pdf. Accessed 12 May 2022.>

[201] Recital 53, GDPR.

[202] Report from the Commission, First Report on the Implementation of the Data Protection Directive (95/46/EC), 15 May 2003, COM (2003) 265 final.

[203] Article 29 Data Protection Working Party, 'Advice Paper on Special Categories of Data ("sensitive data")' (European Commission) <https://ec.europa.eu/justice/article-29/documentation/other-document/files/2011/2011_04_20_letter_artwp_mme_le_bail_directive_9546ec_annex1_en.pdf>.

[204] Article 29 Working Party (n 148)

[205] Consumers, Health, Agriculture and Food Executive Agency., *Assessment of the EU Member States' Rules on Health Data in the Light of GDPR*. (LU: Publications Office, 2021) <https://data.europa.eu/doi/10.2818/546193> [accessed 4 February 2022].

[206] European Data Protection Supervisor. (2015). Mobile Health—Reconciling technological innovation with data protection (Opinion 1/2015). European Data Protection Supervisor. <https://edps.europa.eu/sites/edp/files/publication/15-05-21_mhealth_en_0.pdf>

well-being data) may involve the processing of personal data relating to health, thus triggering the higher standard of protection. The European Court of Human Rights ("ECtHR") has stated that "*the protection of personal data, in particular medical data, is of fundamental importance to a person's enjoyment of his other right to respect for private and family life as guaranteed by Article 8*" of the ECHR. The Explanatory Report on Article 8 of the ECHR includes that "*respecting the confidentiality of health data is a vital principle in the legal systems of all the contracting parties.*"[207]

Not all data collected from IoT devices are sensitive data; however, this does not mean that such data may not inadvertently contribute to the violation of an individual's privacy in the digital domain. IoT devices collect a diverse set of data, many of these 'smart' devices are accompanied by a companion app that should be installed on a mobile device. In order to register an account, these apps usually require input on name, email address, password, payment details, address, location, among various other personal data. Accordingly, the accumulation of all these forms of data makes it very easy for the individual user to be identified. The high volume of data collected by IoT devices and their companion applications can include data on usage of a device; such data has the ability to reveal the individual user's patterns of interactions with the device. As a result, such data could potentially provide insights on user behaviour and subsequently be instrumentalised to exert control over user behaviour to nudge them towards unfavourable outcomes. Moreover, devices collect information on configurations, settings, permissions, device identifiers, firmware, software, GPS and several other valuable data points. All this information combined can produce a highly accurate profile of the user. Once a large set of user profiles is generated, intelligent algorithms can use this profile to predict behaviour and preferences of individual users.

The user profiling increases risks for surveillance for commercial or political purposes. It is not a secret that some of the largest tech companies sell processed user data to advertisers for more targeted advertising. Information on fertility cycles, can, when abused, allow advertisers to know the optimal day of the month to target a woman with a certain product advertisement. More concerningly, however, the recent US decision on Roe v. Wade has highlighted the potential risks of surveillance by public authorities through digital health care applications, services and devices.[208] The decision shows that in the digitisation of health care, trusted digital ecosystems that are privacy-preserving by design are vital to ensure that individuals are still able to enjoy their fundamental rights despite the ever-changing political and social landscape. Moreover, Amazon, for example, has provided data from its well-known Ring doorbell to the policy without users' consent.[209]

[207] European Court on Human Rights (2016): Guide on Article 8 of the European Convention on Human Rights, <http://www.echr.coe.int/Documents/Guide_Art_8_ENG.pdf>.
[208] Rina Torchinsky, 'How Period Tracking Apps and Data Privacy Fit into a Post-Roe v. Wade Climate', *NPR*, 24 June 2022, section Roe v. Wade and the future of reproductive rights in America <https://www.npr.org/2022/05/10/1097482967/roe-v-wade-supreme-court-abortion-period-apps> [accessed 22 September 2022].
[209] 'Amazon.Com's Ring Gave Police Data without User Consent 11 Times in 2022 | Reuters' <https://www.reuters.com/technology/amazoncoms-ring-gave-police-data-without-user-consent-11-times-2022-2022-07-13/> [accessed 22 September 2022].

Although the developments in IoT are unfolding quite rapidly, currently existing *and* proposed regulatory frameworks offer tools to regulate privacy of users in IoT environments. The GDPR, for example, formulates the data minimisation principle, which implies that the processing of personal data must be limited to what is directly relevant for a specific purpose. The GDPR also provides users tools to control their data, such as sending requests for accessing data companies hold about then, asking companies to delete data or ask for rectifications.

However, in practice companies avoid this by formulating their purposes vary vaguely such as: 'optimising the provision of our products and services'. This results in more data being sent over the internet than necessary for the functioning of the devices. Further, many companies do not have the technical and organisational measures in place to give users meaningful control over their data.

It is essential to ensure that in the deployment of IoT, the rights of privacy and user privacy are continuously respected. Maintaining user privacy in IoT devices can also aid in users' feeling confident in the use of new technologies and contribute to long-term market acceptance. To this end, manufacturers of devices should consider whether it is truly necessary to collect and store the personal data. The framework below could provide a tool for this:

Registration data (name, email, address)	Is it necessary to ask and store these data for the set-up of the device? Are the user or device identifiers we use be related to an identifiable natural person?
Device usage data	Is it possible to process audio, video, images, temperature or heartbeat data locally, and only send attributes over the internet? When device usage data is collected, is it anonymised in a way that it cannot be related to an identifiable natural person?
GPS	Is it necessary to store the location of a user? Can a user automatically delete the GPS after a certain period of time?
Data storage	Is my data stored within the EU? Are there sets of data that can be automatically deleted after X days, without affecting the functioning of the device?
Data sharing	Has the user provided informed consent for data sharing? Will the data that I share be anonymised? Does the organisation with which I share the data know how to handle the data with care?
Privacy policy	Is it clear from the privacy policy what kind of data I collect from the user? Is there a clear and concise purpose formulated for the collection of each dataset? Can I allow users to 'opt-out' for sharing certain sets of data
Data sharing	Do I have a list of the parties with whom I share the data, and for what purposes? Do I feel confident sharing this list of parties with the users?

It is important to be aware that data, when shared over the internet, are not floating in the air as a 'cloud' but are always *physically* transferred and stored. The physical presence of data out there in the world, introduces security risks. For cheap IoT devices, it is not uncommon that unencrypted data is shared over the internet. This means that anyone with a proper technical background can tap into the cables and extract the data. This is a large violation of trust and privacy of users of IoT devices.

However, encryption on itself does not guarantee security. Certain encryption methods are relatively easy to hack. Current developments with advanced data processing make it easier to decrypt data. This could particularly be a risk when very vulnerable data are at stake, such as political data or health data from persons that are considered important.

Security measures, such as encryption and decentralised data processing, will help to protect the data against malicious actors. Similar to privacy issues, a good rule of thumb is that the less data is shared, the lower the risk for security violations. It is therefore recommended to build the hardware and firmware in such a way that most data is processed locally, and only attributes will be send over the internet.

5.2 Risks

Wearables

The increase in promotion and popularity of '*smart*' wearable devices has enabled a steady stream of personal data to flow from individual users into the digital ecosystems. However, personal data collected from '*wearables*' differs from traditional personal data forms. Some wearables provide information on various biological aspects of an individual, be it heart rate or blood oxygen level. As a result, such data are subject to the same level of intrusiveness and vulnerability as other bits of information circulating in digital ecosystems.[210]

'Smart' wearable technologies ("wearables") are used in various sectors of society, from health and wellness to fashion[211] and gaming.[212] Wearables are worn close to or on the surface of the skin and "*detect, analyse, and transmit information concerning body signals of the wearer.*"[213] In the EU, there exists no legal definition of wearables; however, the European Commission ("EC"), in their report on Smart Wearables, quoted Mann's definition of smart wearables as "*the study or practise of inventing, designing, building, or using miniature body borne computational and sensory devices. Wearable computers may be worn under, over, or in clothing, or may also be themselves clothes*."[214]

[210] Marcello Ienca and Roberto Andorno, 'Towards New Human Rights in the Age of Neuroscience and Neurotechnology', *Life Sciences, Society and Policy*, 13.1 (2017), 5 <https://doi.org/10.1186/s40504-017-0050-1>.
[211] 'Wearable X | Fashion Technology Company Building Future of Clothing' <https://www.wearablex.com/> [accessed 8 June 2022].
[212] 'Quest 2: Our Most Advanced New All-in-One VR Headset | Meta Quest' <https://store.facebook.com/gb/quest/products/quest-2/> [accessed 8 June 2022].
[213] A. Godfrey and others, 'From A to Z: Wearable Technology Explained', *Maturitas*, 113 (2018), 40–47 <https://doi.org/10.1016/j.maturitas.2018.04.012>.
[214] Andrew Ruck, *Information and Stakeholders' Day on Smart Wearables Report* (Brussels, Belgium: European Commission, 11 December 2015); Steve Mann, 'Wearable Computing', *The Encyclopedia of Human-Computer Interaction*.

Despite the increasing prevalence of the word '*smart*' in the digital domain, neither scholars nor legislators have reached a consensus on the term. Smart wearables have been defined as devices equipped with wireless sensors and fixed in garments or accessories which users can continuously wear.[215]

Scholars outside the legal field have defined wearables as "*every device which is worn for an extended period of time, processes and controls its user's inputs and enhances his experience*."[216] The EC's Smart Wearables Report further explains that "*wearable devices may also be built into the body itself and in this way become a part of it.*"[217] Individuals' personal information is collected from wearables, such as vital signs, location, environment, and movements.[218] Wearable sensors themselves are not novel technologies; however, the inclusion of the word 'smart' entails wireless communication capabilities, enabling internet connectivity.[219] Wearables have attracted attention as a motivational solution to enhance the health and wellbeing of individual consumers.[220] However, there is also an increasing trend in reference to wearables as a tool to improve health, well-being and performance within the workplace.[221]

In 2015, the EC's Joint Research Centre ("JRC") published a technical report stating that "*personal wearable sensors could become the most powerful individual self-surveillance technology available to citizens*."[222] The JRC also included that it is "*crucial*" for individuals to rely on "*trusted and trustworthy implementations*" of wearable technologies to ensure wider adoption.[223] The JRC defines trusted systems as "*systems functioning normally and delivering what it is promised and what the user expects.*"[224] The JRC concurs that trustworthiness is "*mostly objectively defined according to specific criteria and can be considered a metric for how much a system deserves the trust of its users*."[225]

The Medical Devices Regulation ("MDR") defines medical devices as "any instrument, apparatus, appliance, software, implant, […] or other article intended by the manufacturer to be used, alone or in combination, for human beings for […] the following specific medical purposes: diagnosis, prevention, monitoring, prediction, prognosis, treatment or alleviation of disease investigation, replacement or modification of the anatomy or of a physiological or pathological process or state" among others.

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[215] John W. Cheng and Hitoshi Mitomo, 'The Underlying Factors of the Perceived Usefulness of Using Smart Wearable Devices for Disaster Applications', *Telematics and Informatics*, 34.2 (2017), 528–39 <https://doi.org/10.1016/j.tele.2016.09.010>.
[216] Eva Dimou and others, 'A Conceptual Design of Intelligent Shoes for Pregnant Women', in *Business Models and ICT Technologies for the Fashion Supply Chain*, ed. by Rinaldo Rinaldi and Romeo Bandinelli, Lecture Notes in Electrical Engineering (Cham: Springer International Publishing, 2017), CDXIII, 69–77 <https://doi.org/10.1007/978-3-319-48511-9_6>.
[217] Ruck.
[218] Cheng and Mitomo.
[219] Cheng and Mitomo.
[220] Andrea Aliverti, 'Wearable Technology: Role in Respiratory Health and Disease', *Breathe*, 13.2 (2017), e27–36 <https://doi.org/10.1183/20734735.008417>.
[221] PricewaterhouseCoopers, 'How Wearable Technology Could Promote Trust and Wellness at Work', *PwC* <https://www.pwc.com/gx/en/services/people-organisation/leveraging-wearable-technology.html> [accessed 8 June 2022]; 'How Wearable Technology Is Transforming Wellbeing in the Workplace', 2021 <https://www.jll.co.uk/en/trends-and-insights/workplace/how-wearable-technology-is-transforming-wellbeing-in-the-workplace> [accessed 8 June 2022]; 'Technologies That Touch You', *Deloitte Insights* <https://www2.deloitte.com/us/en/insights/topics/talent/employee-wellness-technology.html> [accessed 8 June 2022].
[222] European Commission. Joint Research Centre. Institute for the Protection and the Security of the Citizen., *Wearable Sensors and Digital Platforms in Health: Empowering Citizens through Trusted and Trustworthy ICT Technology: TRUDI Deliverable 3.1.* (LU: Publications Office, 2015) <https://data.europa.eu/doi/10.2788/788525> [accessed 4 February 2022].
[223] ibid.
[224] European Commission. Joint Research Centre. Institute for the Protection and the Security of the Citizen.
[225] European Commission. Joint Research Centre. Institute for the Protection and the Security of the Citizen.; Ioannis Kounelis and others, 'Building Trust in the Human?Internet of Things Relationship', *IEEE Technology and Society Magazine*, 33.4 (2014), 73–80 <https://doi.org/10.1109/MTS.2014.2364020>.

In accordance with the MDR, to classify as a medical device, a manufacturer must intend for devices to be used for specific medical purposes. The MDR states in its preamble that "*certain groups of products for which a manufacturer claims only an aesthetic or another non-medical purpose, but which are similar to medical devices in terms of functioning and risk profile should be covered by this Regulation*."[226]

It remains vague how this applies in the context of consumer wearable technologies. However, the MDR goes on to define '*intended purpose*' as "*the use for which a device is intending according to the data supplied by the manufacturer on the label, in the instructions for use or in promotional or sales materials or statements and as specified by the manufacturer in the clinical evaluation*."[227] Therefore, this suggests that by declaring that their device is not a medical device, manufacturers are able to bypass classification as a medical device under the MDR.

Allowing manufacturers to dictate the intended purpose of such technologies, completely disregards the actual use by the consumer. Moreover, it also leaves consumers in the dark with regards to how trustworthy the technologies are and the underlying data derived from such devices.

Privacy & Security

There is always a risk that data is leaked, erased, altered or modified in any other way that infringes the privacy rights of an individual. In these cases, it is important that people have the capacity to hold anyone accountable for their harm. Generally, for devices this is a well-regulated issue. But more advanced infrastructures consisting of hyperconnected devices and associated constant data sharing will complicate the agency of an individual to hold someone accountable. In other words: within hyperconnected IoT infrastructure, individuals risk losing autonomy over their data, and the applicability of legal frameworks becomes more complex. It is important to build the software in such a way that someone or some institution can be held accountable for what happens with the data of the individual.

IoT has helped to improve the lifestyle of individuals through the automation of various services. However, with the convenience that IoT devices provide, oftentimes comes with its own privacy and security related risks and challenges. IoT devices are vulnerable points for cyber-attacks due to weak security protocols and policies.[228] The intertwined nature of IoT networks bring along accessibility from anonymous and untrusted Internet, calling for novel security solutions.

[226] Preamble §12, MDR

[227] Article 2(12), MDR

[228] Lo'ai Tawalbeh and others, 'IoT Privacy and Security: Challenges and Solutions', *Applied Sciences*, 10.12 (2020), 4102 <https://doi.org/10.3390/app10124102>.

The wider adoption of IoT is hindered by some associated risks preventing the full trust by its users. In particular, the main associated risks are variegated but can be summarised as follow.

1. **Lack of transparency and trust:** lack of understanding and trust in IoT,
2. **AI algorithms errors due to for example:** data shift between AI training data and real-world data, unexpected variations in clinical contexts and environments,
3. **Privacy and security issue:** risk of data being exposed, shared without any consent, re-purposing, etc.,
4. **Misuse of medical IoT tools:** lack of training, lack of digital literacy among patients, etc.,
5. **Gaps in IoT accountability:** Legal gaps in current regulations, lack of ethical and legal governance for IoT,
6. **Obstacles in IoT's implementation into real-world healthcare:** limited data quality, lack of clinical & technical integration and interoperability of IoT with existing clinical workflows

5.3 Consent, Control & Autonomy

Although the appropriate measures have been implemented to anonymise and de-identify personal data, it is vital to recognise that anonymisation and de-identification procedures are not permanent and are highly dependent on the ecosystem in which data is stored.[229] Moreover, due to the business practices of several corporations, personal data gathered are continuously shared and reprocessed by various parties in a way that does not provide users of these products or services with any form of transparency as to the lifecycle of their personal data.[230] The lack of transparency, combined with the dynamic nature of data, raises several issues regarding the notion of informed consent as required under the GDPR. Moreover, the lack of awareness and control over what information can be collected from consumer neurotechnologies poses even further issues in relation to informed consent.

It is crucial to keep in mind that the notion of informed consent in the GDPR represents the exercise of an individual's free power of choice over their personal information. Put simply, consent safeguards autonomy in relation to personal data.

The Court of Justice of the European Union ("CJEU") assessed the requirements for clear and affirmative action requirement approach in its interpretation of the criteria for obtaining valid consent. The CJEU clarifies that freely given consent requires the "indication" of the data subject's intention points to active behaviour and requires that the data subject is autonomous in giving consent.

[229] Mark Elliot and others, 'Functional Anonymisation: Personal Data and the Data Environment', *Computer Law & Security Review*, 34.2 (2018), 204–21 <https://doi.org/10.1016/j.clsr.2018.02.001>.
[230] Timothy Morey, Theodore "Theo" Forbath, and Allison Schoop, 'Customer Data: Designing for Transparency and Trust', *Harvard Business Review*, 1 May 2015 <https://hbr.org/2015/05/customer-data-designing-for-transparency-and-trust> [accessed 9 June 2022].

The relationship between data and consent has many complexities. Data, as previously explored, is in practice dynamic. However, consent given to allow data collection represents a relationship between two static points of information at a specific moment in time, namely, the information the user has been provided with to give free and informed consent and the nature and function of the data at the moment in which consent was given. The dynamic nature of data perpetually invalidates freely given and informed consent due to consent's static nature.

the static nature of consent and dynamic nature of data has opened the door to the potential of undermining individuals' autonomy. The collection and processing of health-related data could unintendedly lead individuals to relinquish control and potentially ownership over information about themselves that they are not aware of.

Every day, users are presented with multiple and unnecessarily long and complex privacy notices; designed in a way that arguably coerces individuals to consent to hand over information they don't even realise they are giving up. Consent notices are often so broadly drafted, or are presented in voluminous detail, that they "inhibit the user's comprehension" and, as a result, render "conscious choice" entirely meaningless. Consumers are frequently "overloaded with digital information" and do not have the time or attention needed to make autonomous decisions regarding their privacy; this, in turn, hampers their ability to evaluate the trustworthiness of their online interactions. Moreover, privacy notices presented in such forms arguably create the illusion of choice curated by so-called 'choice architects' and often distract users from their own privacy protection. As a result, consumers do not choose to share their private information but "surrender" it. to ensure that consent requests are, indeed, clear and concise.

Walker describes the phenomenon of surrendering to technology as the willingness and readiness of individuals in the digital age "to exchange information under conditions and in circumstances that they do not adequately understand." The purpose of informed consent is that individuals should be provided with sufficient information to allow individuals to make an informed and, therefore, autonomous decision with regard to certain activities. Nevertheless, claiming that a signed consent form represents evidence of informed consent cannot always be taken at face value. Moreover, although the GDPR states that when a "subject's consent is to be given following a request by electronic means, the request must be clear, concise and not unnecessarily disruptive to the use of the service for which it is provided," there seems little to no enforcement by governing bodies

In the era of Big Data, a lot of the value of the personal information that individuals seemingly willingly relinquish control of is not entirely apparent when the information is collected and when notice and consent are typically given. Big Data involves the continual collection and processing of data, to the point where consent, let alone informed consent, becomes an impossibility. The information asymmetry between users and several digital services means that users cannot accurately determine the risks of exposing their privacy. The relationship between users and personal data processors has become progressively more complicated because data sets are combined, transferred, shared, or sold. Consent notices that do not disclose the identity of third parties who can access user data limits the consumers' ability to give consent that is regarded to be genuinely "informed."

To reasonably suggest that consent is informed, a balance must be struck between the two criteria to obtain informed consent. Requirements for full disclosure and complete understanding may be exceedingly arduous, making truly informed consent virtually impossible to obtain. Equally, if the criterion for informed consent is simply a signed consent form, the "moral significance" of informed consent is arguably diluted. Consent waives a right an individual has against interference with one's person or property, rendering something that was formerly impermissible permissible.

Conversely, when coercion is present, it completely negates the act of consenting. The reliance on explicit consent by manufacturers of wearable IoT as the sole legal basis for the processing of health-related personal data means that the burden of understanding is placed entirely on

the consumer. The poor implementation and lack of enforcement of the GDPR, means that too much trust is placed on the fact that individuals can make truly free and informed decisions, particularly in digital ecosystems.

The notion of informed consent in data protection law emerges from the biomedical domain. In Europe, in the field of medicine and biology, making the human body and its parts as such a source of financial gain is prohibited. Although IoT devices, specifically, wearable devices do not lead to the commodification of organs in the literal and traditional sense. Such devices allow for the influx of health-related personal data, into the digital ecosystem, subjecting this data to commodification and commercial exploitation.

5.4 Cultural & Behavioural Challenges

There are two ways of looking at behavioural and cultural challenges. On the one hand, there are behavioural and cultural challenges that prevent an individual or society from making healthier decisions, such as cultural cuisine or persistent unhealthy habits. On the other hand, there are challenges to the adoption of IoT technologies that can enable people to live in a healthier way. Given the scope of this report, this section focuses on the second category. One of these challenges is related to age and generation. Elderly people are generally less 'technologically savvy', which presents a barrier for this group to effectively harvest the benefits the IoT, such as health wearables, potentially present. In contrast, the adaption rates of these types of gadgets are usually higher among digital natives. Furthermore, due to on average more time spent on social media networks, the digital natives are more exposed to marketing campaigns of, for example, influencers promoting certain applications or devices, which could reinforce the adoption rate of these in this group and those interacting with individuals in this group.

Another social challenge is the degree of trust in organisations and institutions that offer IoT for health. In countries where trust is high, people are more likely to adopt certain technologies recommended by the government. Contrarily, those in low-trust countries may be more sceptical. Thirdly, the degree of individuality or communitarianism in a society influences the adoption rate. In a highly individualized society, individuals may be more hesitant to decide to adopt IoT hardware, due to, for example, privacy concerns. Finally, the economic status can also be of influence. Low-income households may lack budget to afford smart fridges and wearables.

6. Deployment

Various strategies could be implemented in order to smooth these risks and to favour the trust toward IoT and to support its impact assurance. In particular, what is relevant is to start from the needs and to analyse a possible solution in terms of: feasibility, available resources, acceptance from users' standpoint, management and sustainability elements. In order to promote data quality and users' trust towards IoT based solutions, different steps could be implemented (fig. 8):

1. Needs and contexts analysis: in order to ensure the IoT based solution alignment towards stakeholders' expectations and envisioned benefits as well as context's status in terms of services on stage, technological infrastructures, etc.

2. Co-design and stakeholders' training: co-creation of requirements and services' scenario based on identified needs and local ecosystem determinants. In this phase stakeholders training toward the innovative AI based tool/service is envisioned in order to share to them the values of innovative tool/service and smooth the issue of "misuse of IoT tool.

3. Evaluation and monitoring: the IoT based tool/service is implemented in a specific context. In this phase, a strong evaluation pathway with Key Performance Indicators (KPIs) has to be designed according to identified stakeholders' needs and expected benefits. A continues monitoring has to be executed in order to ensure the correct IoT based innovation's implementation.

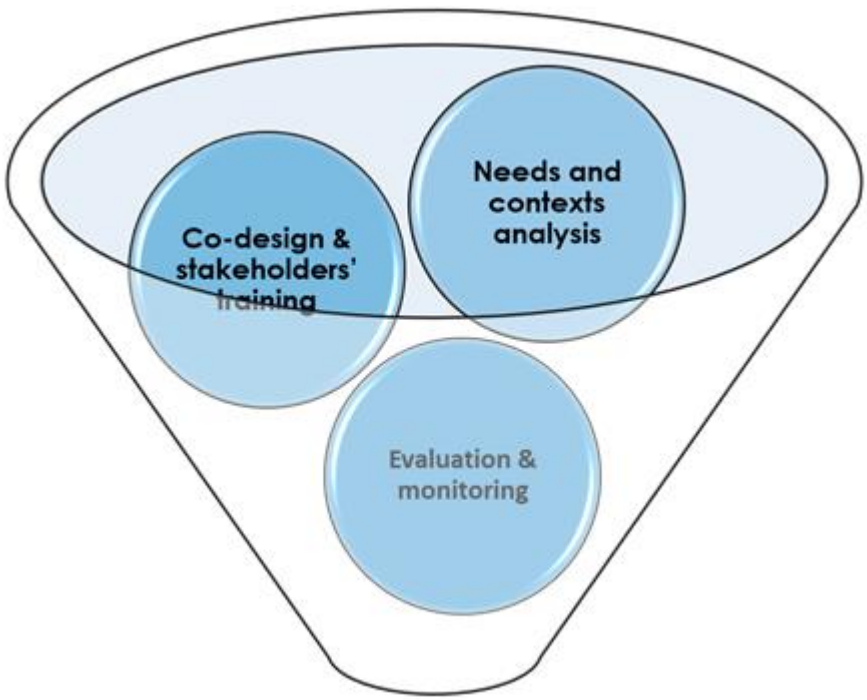

Figure 8 impact assurance key steps

Implementing this concept, it follows that change in healthcare systems must start by measuring patient outcomes and costs incurred, shifting the focus from fee-for-service to fee-for-performance. In addition, integrated care is another critical aspect of this transformation and way of reasoning[231] as all services must function as integrated units, with a central care unit acting as an overseer to ensure that care is consistent across the network and value metrics are in place. Finally, to facilitate this transition, health technologies are the best allies, adopting them in the care, logistical and resource processes in the complex hospital infrastructures so that the quality of patient care can be definitively improved.

6.1 Value Sensitive Design

Digital technologies are often attributed magic powers in solving societal problems.[232] Whether technologies eventually live up to their assignments depends on the actuality of their design as much as on their use.

The discussions in the paper already demonstrated the importance of values for health related IoT applications including privacy, informed consent, ethical responsibility, usability among others. A central concern for those in charge of technology development therefore is how these processes actually need to be planned and coordinated to support these ethical values.

A variety of research from different disciplines has contributed in the last thirty years to this task and provided methodological guidance. Common to both introduced approaches is a strong stakeholder and user orientation as well as the belief in iterated assessment and audit. The value-sensitive design approach (VSD) emerged in the 1990s around the efforts of Batya Friedman and co-authors to design a computer system that accounts for human values.[233,234] With recognition for culture, context and diverse actor relations of technologies VSD suggests a pro-active methodology organized in three (iteratively repeated) phases: (1) conceptual investigations to integrate direct and indirect stakeholder, (2) (qualitative and quantitative) empirical investigations to focus on the human response to technology and how it is situated and used and (3) technical investigations that focus on how the observed technology and its properties and mechanisms hinder or support human values.

A more recent approach is agile worth-oriented systems engineering (AWOSE) which shares many convictions of VSD but believes it less practicable within ongoing procedures.[235,236] AWOSE gives guidelines on how to integrate worth-centered development into a process model which is compatible with existing agile methods. Based on a method or instrument called Worth-Maps development tasks and design alternatives are supposed to be evaluated along worth-oriented prioritization. Worth-Maps make choices and decisions visible and thereby facilitate the identification of suitable criteria for an ethical system evaluation. Evaluations are based on a multi-dimensional model that takes into consideration how decisions support core values on the social, organizational as well as on the individual level. Evaluations ought to be performed in diverse stakeholder workshops.

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[231] NEJM Catalyst, 'What Is Pay for Performance in Healthcare?', *NEJM Catalyst*, 2018 <https://catalyst.nejm.org/doi/full/10.1056/CAT.18.0245> [accessed 22 September 2022].
[232] Evgeny Morozov, *To Save Everything, Click Here: The Folly of Technological Solutionism*, First edition (New York: PublicAffairs, 2013).
[233] Batya Friedman, 'Value Sensitive Design', *Encyclopedia of Human-Computer Interaction* <https://old.vsdesign.org/publications/pdf/friedman04vsd_encyclopedia.pdf>.
[234] Batya Friedman and David Hendry, *Value Sensitive Design: Shaping Technology with Moral Imagination* (Cambridge, Massachusetts: The MIT Press, 2019).
[235] Arne Manzeschke and others, *Ethical Questions in the Area of Age Appropriate Assisting Systems*, 2015.
[236] Benjamin Strenge and Thomas Schack, 'AWOSE - A Process Model for Incorporating Ethical Analyses in Agile Systems Engineering', *Science and Engineering Ethics*, 26 (2020) <https://doi.org/10.1007/s11948-019-00133-z>.

The task for political governance is to bring the existing ideas on how to organize technology design in a way that allows us to follow societal into practice. A first step is to raise awareness among decision-makers for the general complexity of the endeavour. Bringing forth technology for the public good is not only a question of technology alone. The outcome of design processes is shaped along manifold dimensions - legal, organization, cultural, economic and technical ones - and decisions made on each dimension may reinforce or revoke each other. Consequently, solutions for the public good can be realized from intertwined relations of these dimensions.

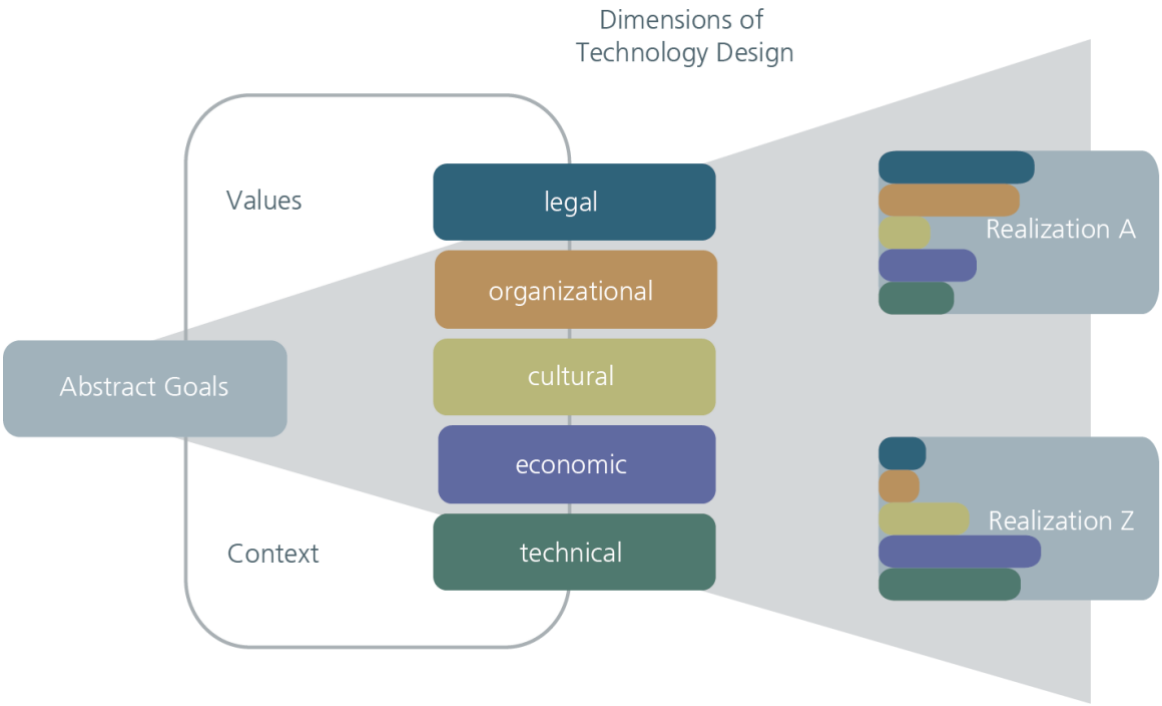

Figure 9 Krenn Karoline, Jens Tiemann, and Nassrin Hajinejad. 2022. Ein Ko2mpass für IT im öffentlichen Raum. Übersetzung wertorientierter Ziele in Technik. Kompetenzzentrum Öffentliche IT: Berlin.

Several instruments can guide those in charge of value-based technology design, especially the relevant public health actors. Starting off with reflections on the governance process itself, this involves a clear orientation on standards as well as best practices or the use of guidelines for specific contexts (for example such as the compass for smart city projects in Krenn, Tiemann and Hajinejad 2022).

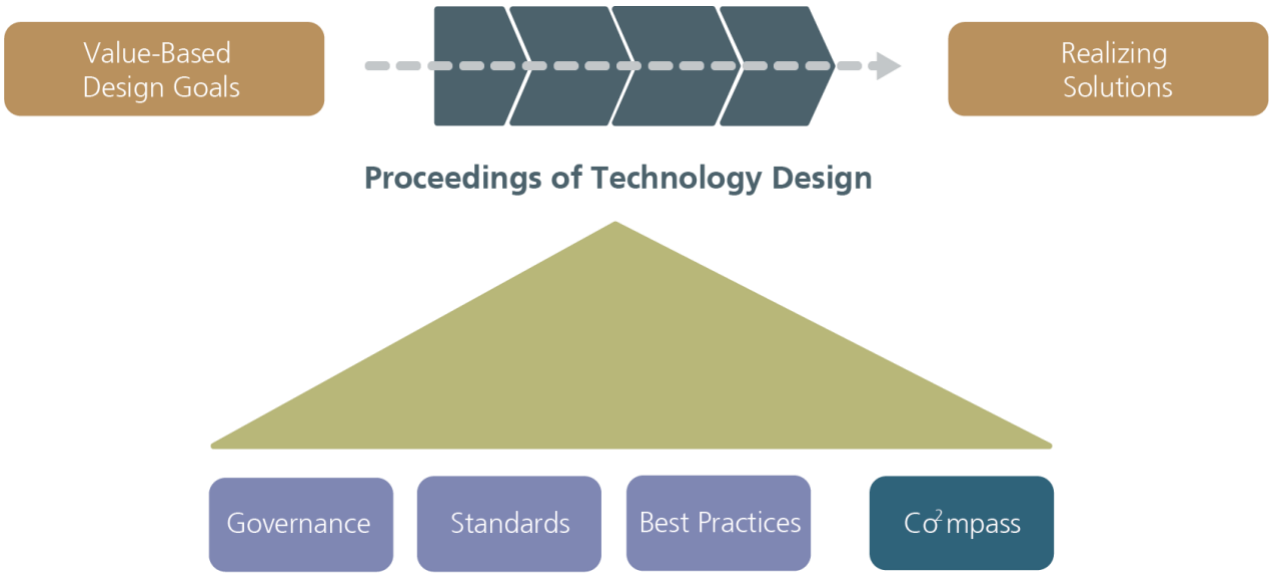

Figure 10 Krenn Karoline, Jens Tiemann, and Nassrin Hajinejad. 2022. Ein Ko2mpass für IT im öffentlichen Raum. Übersetzung wertorientierter Ziele in Technik. Kompetenzzentrum Öffentliche IT: Berlin.

6.2 Interoperability & Health Data Spaces

The environment of proprietary IoT technical implementation remains fragmented, as a result the intrinsic value for users has been substantially limited. Although full interoperability is not always feasible across all products and services, there must be measures in place to ensure maximum flexibility for consumers to avoid vendor- or dealer lock ins.

The interdependencies of individuals, technical capabilities, data, and related stakeholders can be leveraged to deliver useful and valuable contributions to health care and cure, both on the individual and public level. These interdependencies present novel challenges and opportunities. These challenges and opportunities can align with and contribute to the EU (Path to the) Digital Decade 2030 policy initiatives, including, for example, the proposed Health Data Space Regulation and Data Act, with its aim to put and keep people at the centre, sharing data based on trust, and address the many societal challenges at hand in a future-proof, sustainable way.

Improved investments in the EU's health data infrastructure and digital health. Despite the fact the pandemic made manifest the potentiality of digital solutions to free up resources and make health systems more resilient, the deployment of digital health tools and infrastructure is still fragmented across the EU. On top of this, the ability to rapidly access real-time and comparable data on how patients and populations are affected by disease, and on the effectiveness of different public health measures and treatments, is of crucial importance for high-quality analysis and support to the decision-making process. Additionally, in this scenario, became relevant to invest in the improvement of the EU standardization process of health data quality, collection, and interoperability and to improve and accelerate the creation of a European Health Data Space with a clear governance framework for access to data including for secondary use for research.

7. Conclusion

As we are approaching the first quarter of the 21st century, IoT solutions holds the promise to enhance the health and well-being of urban dwellers. Investing in prevention by means of IoT could ultimately reduce healthcare costs in long run. The first series of Large-Scale Pilots implemented by the European Commission, along with impulse by the activities conducted by AIOTI in the past years has enabled the generation of unique insights. These insights shed light on how to create, activate, and empower urban ecosystems to make innovations in social care cost-effective, and sustainable from a business and procurement perspective; while making sure that the quality of life of end-users is realistically measured through IoT, complementing standardized measurements from traditional instruments, and making them more powerful and relevant. Such an experience is the first of its kind in Europe and can be used as a starting point for better decision-making and new structural interventions from local authorities and eventually better use of structural and regional funds through targeted interventions that will maximize success and sustainable uptake.

Active and Healthy Living in the Digital World takes legacy from the 2012-2020 experience of the European Innovation Partnership on Active and Healthy Ageing. The Reference Site Network, where regions and municipalities are establishing themselves as relevant Living Labs; where innovations on new technology, services, and business must be deployed before reaching full scale. Top-down interventions from national and regional healthcare authorities, that aim to better treat our population can only be effective when these interventions are standardized. The standardization allows it to be scaled within and across regions, but at the same time, they need to respond to local needs that are to be captured by cities and urban environments. It is not by chance that the concepts of social medicines and AI for policymaking are appearing in the new Horizon for the first time.

Urban dwellers are often under heavy external and internal pressures often causing them to neglect their own health and well-being. IoT can play a crucial and facilitative role in promoting individual accountability for their health and well-being and signal urban dwellers when things may be going wrong. However, this means that we reach a paradigm shift, the paradox being on one end advocating for more IoT devices, thereby increasing connectivity, and on the other end, demand for less connectivity, less remote and smart controls to get facility dysconnectivity. In our attempts to push for a healthier urban society, it is our duty towards future generations and the current society to find the right symbiosis, between innovation and evolution.

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About AIOTI

AIOTI is the multi-stakeholder platform for stimulating IoT Innovation in Europe, bringing together small and large companies, start-ups and scale-ups, academia, policy makers and end-users and representatives of society in an end-to-end approach. We work with partners in a global context. We strive to leverage, share and promote best practices in the IoT ecosystems, be a one-stop point of information on all relevant aspects of IoT Innovation to its members while proactively addressing key issues and roadblocks for economic growth, acceptance and adoption of IoT Innovation in society.

AIOTI's contribution goes beyond technology and addresses horizontal elements across application domains, such as matchmaking and stimulating cooperation in IoT ecosystems, creating joint research roadmaps, driving convergence of standards and interoperability and defining policies. We also put them in practice in vertical application domains with societal and economic relevance.