Challenges and Future Directions for Integrating Healthcare Wearable Sensors into Smart Cities and Communities

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Abstract

This paper explores the challenges related to implementation of wearable sensors in the context of smart cities, particularly in the domains of health and wellbeing. Such sensors are increasingly used in clinical and public-health interventions, for early symptom identification, performance alerts, and real-time monitoring. While opportunities and benefits presented by wearable technologies are relatively well-known, this paper's goal is to highlight risks and challenges related to their implementation. Based on the existing literature and lessons learned from EU-funded projects in which smartbands are used to collect health-related data, we share insights from integrating wearable sensors into the smart city fabric.

Keywords: wearable sensors, smart city, s-healthcare, wellbeing, citizen science.

1. Introduction

In recent years, an increasing number of cities are initiating the transition into sensor-enhanced smart cities (Aivazidou et al., 2021), as well as kinetic and responsive urban design (Dąbrowska-Żółtak et al., 2021). Smart cities managers aim to leverage wearable sensors, such as smartbands, equipped with advanced sensing capabilities, to gather information about people's health or quality of urban environment, as well as facilitate data-driven decision-making processes. One can argue that wearable sensors are a crucial part of smart city systems, enabling real-time monitoring of individual and environmental data, advancing personalized services, and efficient resource management, which are the main goals of smart urban development.

Sensors are already increasingly used in clinical and public-health interventions, for early symptom identification, but also performance alerts, and real-time monitoring (Bonato, 2010; Appelboom et al. 2014). However, there are some challenges related to implementation of wearable sensors, particularly in the domains of public health and wellbeing (Chan et al., 2012). This paper's main goal is to highlight risks related to the current state and strategies of implementation of such technologies from the Civil City Framework point of view (Domaradzka et al., 2022).

We posit that the main challenge stems from the fact that while smart city applications leverage the datasets collected from wearables, the reliability and representativeness of such studies remains problematic, and there are concerns about who really benefits from those innovations (Zuboff, 2019; Morozov & Bria, 2018). Existing systems often end up treating citizens as sensors (Resch, 2013) rather than active, diversified agents with rights, own agendas and values that do not necessarily line up with smart city engineers' vision. Undoubtedly, data obtained from wearable devices can help gain insights into specific urban processes and enhance services. However, if such endeavors undermine citizens' right to the city (Lefebvre, 1968), including right to privacy (Rychwalska et al., 2022), they become part of an undemocratic notion of smartification.

As wearables continue to evolve, they hold immense potential to transform urban living and create more sustainable and inclusive communities. To enable smart cities involvement in promoting inclusivity for individuals with different health issues, more focus on users' rights and preferences is necessary (Domaradzka et al., 2022). As a result, wearable technologies could play a role in developing solutions tailored to the needs of individuals, like assistive systems that facilitate independent living for seniors and improved mobility or system monitoring the effectiveness of home-based rehabilitation (Patel et al., 2012).

2. Wearables in realm of cities

The growing popularity of wearable sensors can be attributed to their increasing affordability, proliferation of smartphones, and a growing health awareness, as well as big data-based medicine. Wearables in the form of smartwatches, or wristbands can monitor the wearer's activity and physiological parameters – such as heart rate or skin temperature. Many are marketed as exercise or lifestyle trackers, promising meaningful health information for individuals, clinicians, researchers, but also city managers, or employers. The growing body of literature focuses on the application of wearable sensors to monitor older adults and patients with chronic conditions in the home and community settings (Jiang et al., 2014).

Physiological monitoring can help in both diagnosis and ongoing treatment of individuals with neurological, cardiovascular, and pulmonary diseases such as seizures, hypertension, dysrhythmias, and asthma. Importantly, motion sensing might accelerate the receipt of assistance in the event of a fall and maximize the independence and community participation of elderly citizens. Additionally, remote monitoring systems have the potential to mitigate healthcare facilities access issues and improve patient monitoring in clinical trials (Bonato, 2010).

Studies show that data acquired by wearables is more accurate, as questionnaire data tend to overestimate the frequency of "desirable" behaviors, such as the amount of physical activity (Kwan et al., 2020). In that way wearable sensors have been proven to be helpful tools in changing habits related to health. However, it is important to keep in mind that while wearables have the potential to support healthy habits, they should not be viewed as perfect solutions on their own. Rather, they should be treated as part of a larger, complex, and coherent system of increasing citizens' wellbeing and livability of cities (Patel et al., 2015).

2.1. Smart cities and wearables

The concept of smart cities has gained significant attention due to the pressing need for sustainable urban development (Biesaga et al., 2023). In recent years, wearable sensors have emerged as valuable tools in realizing the vision of smart healthy cities by enabling data collection at a granular level (Solanas et al., 2014). Moreover, they have revolutionized personal health monitoring by enabling continuous and relatively non-intrusive tracking of vital signs, physical activity, and sleep patterns. Some sensors also provide an opportunity to collect environmental data in real-time, facilitating the monitoring of air quality, noise levels, and other health-related parameters.

Progressively, these technologies are being used for creation of health-related recommendations as part of the healthy city agenda. For example, smart devices (bands, watches, or smartphones) might make recommendations on how much one should walk or exercise to maintain good mental and physical health.

Many cities already use technology to provide better health-related services or create a healthy environment for urban-space users (EC 2021). Kamel Boulos et al. (2011) discussed the vision of the 'Internet-connected web of citizens (people) and electronic sensors/devices (things)' that serve to address health-related concerns. Recently, in many places, this vision has become reality.

2.2. Wearables application in citizen science

Growing usage of health trackers can be framed as a unique form of citizen science (Greshake Tzovaras et al., 2021) in which individuals employ empirical methods to explore and investigate their own health-related inquiries. Self-tracking has been primarily investigated in terms of gathering and managing personal health data (Almalki et al., 2015), but it also addresses the individual's right to engage in scientific activities and promotes a more participatory scientific culture (Vayena et al., 2016).

The COVID-19 pandemic has sparked interest in using wearable technology for infection prediction and surveillance (Sen-Crowe et al., 2021) and contributed to the popularization of wearable sensors and self-researcher. According to Senabre Hidalgo et al. (2022) the notion of "personal science" represents a more participatory and inclusive scientific culture that in a longer term can provide decision makers not only with data but also results and recommendations. The opportunity to contribute to research that could enhance healthcare for the broader population is a recurring motivation for involvement (Maus et al., 2021). The involvement in self-research activities can be also fueled by enjoyment and curiosity, tied to broader interest in understanding one's own body, or performance (Senabre Hidalgo et al., 2022). However, such endeavors are of interest to a minority of citizens and therefore remain hard to emulate in community-based research projects. However, the smart cities policies could capitalize on engaged citizens' involvement in data collection and implementation of resulting recommendations and services.

3. Methods and materials

In this critical paper we present the results of literature review concerning wearables in the health field as well as direct experiences from two EU-funded research projects in which wearables are used to collect health-related data (euPOLIS and HEART, funded from Horizon 2020). For the sake of this article, we focus only on the specific and widely used form of wearable technology, namely smartbands and smartwatches.

The literature review involved the examination of two sets of articles sourced from Scopus. In the initial search, we identified 51 articles related to the utilization of wearables within the realms of health and smart cities (using keywords: wearable, health, and smart city). In the subsequent search, our focus shifted towards identifying lessons gleaned from real-world use cases where wearables were employed to quantify individuals' health. In this search, we uncovered 67 relevant articles (employing keywords: wearable, health, case study). Subsequently, both sets of articles underwent thorough examination by two authors, who proceeded to code the identified risks and challenges.

The studied projects are focused on evaluating the effects of implementing nature-based smart innovations on urban health and social sustainability. Part of the evaluation process is based on collecting data from commercial wearable devices that cities provide its citizens with. The HEART project aims at investigating the benefits of regular visits to the green spaces enhanced by Nature-Based Solutions (NBS) on the health and wellbeing of patients with medical history of non-communicable diseases. The euPOLIS aims to create a methodology that will allow for designing and implementing NBSs, as well as the assessment of their direct and indirect impacts on community health and wellbeing. While both projects are not finished yet, we share the conclusions from 20 meetings with local experts who conducted a series of workshops (depending on the demo site the number of workshops varied between 2 to 4) during the implementation phase in each of the demo sites with project participants, as well as the results of a preliminary questionnaire with 260 participants from the HEART project.

4. Risks and challenges according to the literature review

The integration of wearable sensors into the fabric of smart cities offers immense potential for creating healthier and more livable cities. However, inclusive and fair data collection, citizen engagement, personalized services, and their successful integration require addressing various challenges. In the following subsections, we organized the identified challenges into five categories: 1) privacy and ethics of sharing sensitive physiological and location data; 2) data ownership and management; 3) data collection and storage; 4) data quality and the accuracy of interpretation; 5) users' acceptance and adaptation.

4.1. Privacy and Ethics

One of the foremost challenges in the integration of wearable sensors is ensuring privacy and addressing ethical concerns of such complex systems (Feng et al., 2021). As wearable sensors collect highly sensitive personal data, the need to establish robust privacy frameworks and regulations that safeguard data collected from users (such as physiological data, geolocation, and behavioral patterns) is crucial.

The existing privacy policies only partially meet the contextual requirements of transparency and trust (Maus et al., 2021). That is because technology providers whose profit is built around collecting data from users very often try to meet only the bare minimum of such legal requirements – using arguments about inhibiting the development of innovative technology. Providers often present users with an illusory choice between full access to service (which they already paid for by buying the device) and protecting their own personal data. As a result, users see sharing data as a necessary tradeoff between potential benefits from the given service or device and negative consequences of the disclosure (Li et al., 2015).

Even though technology providers highlight advances in developing privacy-preserving technologies, anonymization mechanisms, and consent management to protect individuals' privacy, those are often biased by the imbalance of power between individual users and technology providers. Producers of smart innovation are driven by economic (profit) and engineering interests (improvement of devices). As a result, Mause et al. (2021) point out that a loss of control is the most commonly expressed concern among participants. Likewise, in the study conducted by Huhn et al. (2022) participants have expressed apprehensions regarding the privacy of their sensitive information.

The right to disconnect and conceal identity could increase trust in using wearable devices (Albesher & Alhomoud, 2020). To maximize the benefits of wearable sensor data in smart cities, more power and control should be given to users, to ensure they can truly control privacy levels without losing the functionality. Alternatively, users must be reimbursed for their efforts as data collectors or sharing private data.

4.2. Data ownership and management

The integration of wearable sensors into smart city management requires developing a data management system that allows for handling big data from multiple sources and secures easy access for different stakeholders. Effective data management strategies and analytical techniques are necessary to handle the heterogeneous and real-time data streams generated by wearable sensors. In the context of smart cities these services very often are delegated to the private sector, i.e., tech companies as they already have experience in implementing solutions that the public sector lacks.

However, the integration of data from different sources (including wearables) especially conducted by the private sector raises the question of data ownership (Hummel et al., 2021). That is, the private tech companies, whose ultimate goal and priorities (unlike public authorities) are to generate profit may use gathered data for developing their commercial solutions. This poses a serious threat to citizens' data being monetized without their consent. Also, the question arises of who owns the data gathered through public-private collaboration, and who has the right to use it for training or validating machine learning models (Ahmad et al., 2022)?

Legal issues such as data protection and ownership are major concerns of any Internet-based application. This is why the balance between the user as the owner of data and the agents processing the data must be properly managed, with user confidentiality always at the forefront (Rychwalska et al., 2022), especially when the services are provided or advertised by public entities.

4.3. Data collection and storage

The crucial element of integrating data from wearables into the smart city management system is the transfer of data from individual devices to the management system. It requires a reliable infrastructure that connects distributed devices, with enough storage space to grant flawless communication and dataflow. This might be challenging in case of real time data collection, when it must be transferred from the individual's wearable device to a secure database, and the volume of data grows exponentially (Bokefode et al., 2016). This may exceed a public institution's computer systems capacities and IT expertise.

With the necessity of the constant readjustment of the infrastructure the solution seems to be delegating the storage to third party cloud services. Alternative paradigm of fog computing and its effect on trustworthiness is considered (Meena et al., 2021).

Moreover, guaranteeing the integrity and security of data is a challenge. Especially in the case of health devices, even a very small data modification could pose a life-threatening situation (Albesher & Alhomoud, 2020). Risk of unauthorized access, sharing, or exploitation of sensitive data, can erode trust and impede adoption as it was observed in case of Corona-Data-Donation-App (Diethei et al., 2021). Consequently, users may perceive the continuous usage as a threat, and abandon the device (Markhimov & Joo, 2017).

4.4 Data quality/accuracy and interpretation

One of the key concerns that people raise in the context of the wearables' usage is low accuracy (Attig & Franke, 2020). The accuracy values of many market-ready wearables indeed remain undisclosed, lacking published validity and reliability data (Mills et al., 2016).

The entry barriers of obtaining reliable data from wearable sensors are still relatively high, requiring people to wear them for a minimum number of hours per day. But even then, they seem to provide the feedback based on enigmatically described norms or algorithms that are carefully guarded company secrets. Many wearables utilize algorithms to transform the obtained data, often resulting in estimates of physiological parameters. Numerous variables can influence these estimates, and their generalizability is unknown because of the lack of clinical trials.

Such doubts concerning reliability and efficiency of sensor systems and data processing software pose significant barriers to the implementation of wearable sensors. A recent literature review of IoT for elderly care indicated that many studies do not report drop-out and attrition; majority concentrate on functionality and assessment accuracy, but some include evaluation of user acceptance and experience. The authors suggest that future studies should include feedback on how the devices meet the needs of users, as data on this is scarce (Stavropoulos et al., 2020).

4.5. User acceptance and adoption

User acceptance and adoption of wearable sensors are critical factors in their successful integration into smart cities. While wearable sensors offer potential benefits, such as personalized services, health monitoring, and improved urban experiences, several challenges hinder their widespread adoption. Studies show that 32% of users abandon the device within the first 6 months of usage and 50% after one year (Piwek et al., 2016). To increase users' retention, wearable devices should be intuitive, comfortable to wear, and seamlessly integrate into daily routines (Chatterjee & Gupta, 2017). If wearables are cumbersome, intrusive, or challenging to operate, users may be reluctant to adopt them. Challenges include the design of user-friendly interfaces, ensuring device comfort and ergonomics, and addressing concerns regarding the aesthetics of wearable devices (Harrison et al., 2015). Involvement of user feedback about functionality and design of wearables as well as early engagement of a variety of stakeholders makes the devices and participation in the study less burdensome (Ross et al., 2016)

Societal norms, cultural perceptions, and individual attitudes towards technology also shape users' willingness to incorporate wearable devices into their lifestyles (Chatterjee & Gupta, 2017). Additionally, social acceptance and peer influence can play a significant role in the adoption of wearable sensors (Zhu et al., 2017). Overcoming these challenges requires conducting user studies and understanding the cultural contexts in which wearables are to be deployed.

Moreover, ensuring accessibility for individuals with disabilities or those from lower socioeconomic backgrounds is crucial for promoting inclusivity. The individuals who might have most to gain from these devices are likely to be older and less affluent. To better engage these individuals, wearable devices must be affordable, with low-cost maintenance (Patel et al., 2015). If people of all ages are to use the smartbands, the design of the devices should take into consideration needs related to declining eyesight or different manual abilities, and digital literacy. Some attempts have been made of tailoring solutions for the monitoring of the wellbeing of the elderly, and while wearing the smart band was evaluated as unintrusive, the participants did not interact with the devices, just wore them (Correia et al., 2021). In another study there was a big variation in assessment of smartwatch acceptance among patients with dementia, mainly due to lack of comfort of use (Thorpe et al., 2019).

While older adults may need assistance in adopting new technologies, their willingness depends on the perceived gains and efforts required to learn it (Moxley et al., 2022). Different groups of users may also have various requirements of the functioning of the smart bands. While younger users expect fast feedback, older users may perceive frequent feedback as tiring and confusing (Jia & Chen, 2021). Some studies suggest that participants' resistance towards new technologies increases with age, so older users might benefit from additional training to benefit from the devices (Taghian et al., 2023).

Providing user-friendly educational resources, conducting awareness campaigns, and engaging in community outreach efforts can help users understand the benefits, but also limitations of wearable sensors use. As a result, users could make informed decisions regarding the adoption of wearable sensors in the context of smart cities. Maus et al. (2021) developed a privacy calculus model specifically for IoT-based health research in citizen science. They prove that perceived control, transparency, and trust play a significant role in the willingness to participate in studies.

Sustaining long-term user engagement and encouraging behavior change present ongoing challenges in the adoption of wearable sensors. Users may initially be enthusiastic about using wearables, but gradually lose interest or fail to maintain consistent usage patterns (Kari et al., 2016). Fostering behavior change based on the insights from wearable sensor data requires ongoing support and interventions. Designing gamified experiences, providing personalized feedback, and other behavior change techniques can enhance long-term engagement and encourage users to leverage the full potential of wearable sensors.

Some researchers also believe that wearable sensors and digital healthcare introduce risks of social exclusion of some users (Percival & Hanson, 2006). Also, users striving for independence may perceive assisting technologies as limiting their freedom (Steele et al., 2009). Constant monitoring may limit users' freedom of behavior, especially if every "sin" related to everyday lifestyle is recorded and discouraged. However, studies show that increasing physical activity is facilitated with online social support (Kwan et al., 2020).

5. Specific challenges of wearable sensors application in health-related projects

In this section we look at the two European projects we have been recently involved in, from the perspective of the aforementioned risks and challenges that involvement of wearable technology poses. In both projects, we implement the Civil City Lab Framework (Domaradzka et al., 2022) that emphasizes that a right to a healthy city is immanent for every citizen and urban-space user, regardless of their technological competences, socio-economic background, education level, gender, age, ethnicity, or religion.

5.1. Privacy and ethics

In both projects, we are bound by the European GDPR. However, depending on the location, we encounter different practices concerning research ethics (the same research protocol accepted in one country within a month, in another country has been processed over six months) as well as different attitudes towards privacy. For example, in the case of one pilot site, in a very small neighborhood of four blocks of flats (with approximately 200 residents in total), in over two months three workshops were organized during which the wearables were rolled out (Figueras Anton & Briggs, 2023). In total, 50 residents were involved among whom only 8 finally decided to wear the device and even among them most dropped out (as of August 2023 there are only 2 active users). One of the reasons why the rest of the residents did not engage was the fact that only long-term native residents were willing to wear smartbands, while the majority (mostly immigrants and from ethnic minorities staying there temporarily as some flats are part of social housing projects) remained distrustful or disinterested. Local social workers who are involved in the project reported the reason was that not all community members knew English or local language well enough to operate the smartband and app. Moreover, during the workshops, some residents receiving welfare benefits expressed concerns that wearables could be used to monitor their activities by the municipality and re-evaluate their eligibility for such benefits. In the case of a second site, the municipality was unwilling to disseminate bands among low-income residents in fear that they would be stolen or sold. This resulted in the exclusion of one of the crucial study groups.

In other words, during implementation we encountered low levels of mutual trust between local community and authorities, especially in communities where people were less affluent and disempowered, unemployed and with lower education levels. At the same time, community members expressed fear of surveillance, or even biosurveillance, resulting from awareness of some governments or Big Tech practices that remain beyond democratic control, infringing on the citizens right to privacy.

We also encountered challenges in the process of cooperation with technological partners (who are part of the consortium), who supplied the ICT solutions. At the beginning the tech partners assumed we will be collecting all types of data including geolocation, vitals, and activities. However, continuously collecting location data is controversial as it creates risk of privacy infringements. Unfortunately, the smartbands have very limited privacy controls, so participants had to agree to such monitoring and could not turn some of the functions off. This resulted with some of the potential volunteers resigning from the study.

Another ethical concern we faced in our projects was a recommendation from wearables providers who are part of the consortium to not include older people because the readings from the available within projects devices (dedicated to the general public) and the norms were not precise enough to be able to draw meaningful conclusions. This requirement together with an often unintuitive and small-fonts interface might result in the exclusion of the groups that potentially would have benefited from monitoring health and well-being the most. Moreover, these additional exclusion criteria might affect the results of the HEART project, in which some of the potential participants already recruited are over 60 years of age.

5.2. Data ownership and management

In both projects, among partners are technological companies responsible for creating the Data Management System and safeguarding databases. However, outsourcing data management to commercial actors creates risks related to data use for the commercial benefits (to further develop products, and train models) or profiting from selling it to third parties. Consequently, citizens are reluctant to participate in such studies out of a fear that they might unwittingly serve as a testing ground for the experimentation of new features by commercial entities.

During the workshops with potentially interested residents, some expressed their concerns about the fact that one of the available devices (in both projects participants choose between two different devices of similar functionalities – one is a smartband with location and physiological data monitoring and the second is a smartband with location tracking and emotion recognition) was manufactured in China which was seen as a privacy concern.

In the long term, the crucial challenge is to ensure that the data is used in a transparent way and benefits for all sides are clearly stated.

5.3. Data collection and storage

Data collection over longer periods of time was one of the main challenges. Even if participants agreed to wear smartbands, they often gave up after a few days. As a result, we were not able to monitor change over time and collected just a few data points. In the case of the aforementioned demo site, as of August 2023, we have only 2 active users who still wear the smartbands. Participants who were potentially interested but finally resigned from the study reported that low battery life, and connection issues contributed to their decision. Moreover, they considered the onboarding process and daily usage of the device as tedious. Even though the former was done during the workshops with the assistance of the local social worker it required downloading two apps: one provided by the device manufacturer and the second by the project, setting geo-location and synchronization options in the mobile, registration of the device and signing up in the project app. The latter was mostly seen as inconvenient as less tech-savvy participants complained about the occasional necessity of pairing the device with a mobile.

In both projects, technical partners created a data management system that aimed at integrating data from wearables with data collected from traditional sources (medical examination results or questionnaires). What was meant to facilitate later access to data created an additional burden for medical partners who had to input data twice, to the hospital local database and the management system. The integration of our data system with existing hospital ones was impossible due to local regulations, i.e., in some countries the medical data can't be stored using third party cloud services.

5.4. Data quality and interpretation

As a result of technological imperfection of sensors, we often obtained unreliable data. Sensors differed in quality of readings and often generated errors when participants were in motion or were wearing the band too loosely. Participants who chose the device that allowed for emotion detection reported that it only detected a handful of emotional events over a prolonged period and often it got them by surprise as they struggled to recognize any emotional change that the device indicated. Some of the users admitted that the low quality of the data was due to their forgetfulness – they forgot to wear it or charge it. One participant said that since they were unable to reach the set goal, they gave the device to a younger household member.

Moreover, as mentioned before, we work with commercially available devices that are designed for healthy people under 60 to monitor their activities (and emotion recognition). Therefore, their accuracy is limited as they are not medical devices tested for example for fall detection, precise recognition of heart rhythm, or respiration change. This potentially might result in low precision of the detection of expected changes as a consequence of the lifestyle or environment-changing intervention. That is a tradeoff we decided to make for the sake of the availability of the devices, their cost, and accessibility of usage. However, as it turned out, the popular market-ready devices still were a challenge to use and created an additional burden that was an entry barrier for less tech-savvy participants.

5.5. User acceptance and adaptation

One of the most prevalent drawbacks reported by the users of the wearables was their design, which resulted in discomfort and constant need for readjustment. Some participants reported that wristbands were too tight or hard to adjust and therefore discouraged continuous wearing. Some participants complained about the allergic reactions like rash or skin irritation.

Another important barrier for maintaining engagement was lack of long-term motivational structure or specific incentives. Under the HEART project, before the rollout of the devices, we asked potential users two multiple-choice questions regarding wearables: 1) what could have supported a more active lifestyle; and 2) how technology such as wearables could encourage them to be more active (Collins et al., 2022). In three demo sites, in total, we gathered responses from 260 participants (Aarhus – 72; Athens – 150; Belgrade – 38). They almost unanimously indicated the wearables as the least likely factor to encourage them to visit the demo site more often or support a more active lifestyle (respectively 9% in Aarhus; 39% in Athens; 36% in Belgrade). Rather, our respondents considered the quality of the infrastructure (in Aarhus 43% indicated 'green walking routes' and 35% 'improved quality of green spaces'; in Athens respectively 43% and 35%; in Belgrade 42% and 50%) or support from others (in Aarhus – 24%; in Athens – 39%; and in Belgrade – 31%) as more prevalent factors than activity monitoring technology. While in Belgrade and Athens respectively 39% and 24% of respondents stated that wearables might be a source of motivation, in Aarhus 29% of respondents reported that the use of technology would not motivate them. However, in all demo sites, participants noted that wearables could be useful for tracking activities (Aarhus – 35%; Athens – 35%; and Belgrade – 39%) as it was one of the most often selected answers.

Our results clearly indicate that wearables cannot be treated as an only source of motivation for taking up a physical activity. To attract participants, projects that aim to motivate participants to engage in a more active lifestyle should offer either functionalities going beyond the standard devices (generating added value for those interested in their bodies' performance and health) or direct benefits in form of professional health advice, vouchers, or money compensation (to compensate effort relating to continuous wearing and synchronizing the device). Some participants reported that constant nudging and feedback (often negative) about their vitals, sleep, steps, stress etc., was counter-effective and led to discouragement. In some cases, it resulted in the feeling of failure or different forms of obsessive collection of steps or points. For other participants, wearing a sensor was perceived as a job – a boring, tiresome, frustrating task with no reward.

6. Discussion

Projects involving wearables fall into a bigger category of citizen science studies, in which data is gathered by citizens in cooperation with professional researchers and analysts. Several authors attempted to divide citizen science projects according to the level of citizen involvement (Aristeidou et al., 2017). Haklay (2013) identified four types of citizen science. In the first, participants act just as "sensors" (crowdsourcing); in the second, citizens can also make interpretations of results (distributed intelligence). In the third type, citizens are asked to define the problem by themselves and choose the method (participatory science). In the most engaging type of projects, citizens actively participate in the entire scientific process (extreme citizen science).

The most common types of citizen science projects are those that involve citizens on a basic level, where their participation is limited to data collection (Bonney et al., 2016). Unfortunately, this is also the case of our two projects as well as the majority of cases described in the literature. In these kinds of projects, the potential of participants is not fully used (Haklay, 2013) and does not contribute to the empowerment of communities.

Meanwhile, Shirk and collaborators (2012) have argued that a co-creative approach is crucial in the process of building empowered communities.

For health-related projects Stiglbauer et al. (2019) observations are relevant, where they demonstrated that monitoring and quantifying activities are to a small extent beneficial to self-reported wellbeing and health. The effect of wearing the device was stronger for people who spent more time on the accompanying app. Wristbands themselves did not provide any informative feedback, while the app offered more detailed reports about the recorded activities, completed achievements, and comparisons with peers. Having clear aims and standards and getting feedback on goals and achievements increased the self-regulation mechanisms. This way, people were able to track their progress and intensify their efforts towards predefined goals.

However, in the goal-oriented approach, the key factor is the source of these goals, whether it's intrinsic or external. Etkin (2016) showed that when the goal is set externally, the activity measurement might result in less enjoyment and argued it is because participants treated these tasks as work. Consequently, when the monitoring device was removed, their engagement in the task decreased as the fun factor was lacking.

Therefore, in case of projects where participants are expected by doctors to perform physical activities, the crucial element is to invoke intrinsic motivation and set reasonable goals. Otherwise, participants might associate completing certain project requirements as work or a way to "please" medical professionals, and not as part of their new healthier lifestyle.

Moreover, setting goals with individual citizens must be done according to their capacities. Otherwise, wearing the monitoring devices might have unfavorable effects on the patient's wellbeing, as unrealistic or unachievable external goals lead to discouragement rather than motivation (Fu et al., 2009; Etkin, 2016). The inability to perform a desirable amount or level of physical activity might result in dissatisfaction, apathy, and lower overall wellbeing (Maier & Seligman, 2016). Therefore, it is of crucial importance to set reasonable goals for individuals, considering their physical capacity, overall fitness, and suggest contingency plans in case the agreed regiment is derailed by external forces (like weather or health conditions).

While wearables for participants serve mainly a monitoring function, we need to make sure that they are not an entry barrier for some less tech-savvy participants or the ones that are concerned about the data privacy issues and surveillance (Domaradzka et al., 2022; Rychwalska et al., 2022). Therefore, in all projects employing such devices, potential participants need to be fully informed about the data collection policy and instructed on the capacities of their devices. As researchers we must ensure that wearable sensors empower diverse participation and override social division instead of creating an entry barrier, as was the case in two of our projects. Addressing these concerns requires implementing robust privacy frameworks, data encryption mechanisms, and transparent data handling practices. Furthermore, educating users about the security measures implemented in wearable devices can alleviate privacy concerns and promote user acceptance. Establishing ethical oversight models that respect participants' autonomy could unlock the potential of such smart innovation for wider use in cities (Greshake Tzovaras et al. 2021).

7. Conclusions

Both the existing literature as well as our cases suggest that user acceptance and adoption of wearable sensors are critical for their successful integration into smart cities systems. Overcoming challenges related to usability, privacy, social and cultural factors, tech skills, and long-term engagement is necessary to foster their widespread adoption. We believe that only by addressing these challenges and designing user-centric solutions, researchers and practitioners can enhance user acceptance, promote the adoption of wearable sensors, and unlock their transformative potential in building smarter and more inclusive cities, in line with right to the smart city idea (Domaradzka et al., 2022)

Integrating wearable sensors into smart cities policies presents exciting opportunities for enhancing citizens' experiences, enabling data-driven decision-making, and promoting sustainable urban development. However, challenges related to privacy, data infrastructure and management, must be urgently addressed. In our opinion, only with concerted and participatory efforts, wearable sensors can contribute to creating more inclusive, efficient, and sustainable urban environments that prioritize both citizen rights and wellbeing. Collaboration between citizens, researchers, engineers, and policymakers is essential to develop comprehensive solutions and ensure the successful integration of wearables into the smart city ecosystem.

Future research should also focus on designing user-friendly wearable devices, addressing issues related to comfort, aesthetics, and usability. Additionally, efforts should be made to increase user trust and awareness, by ensuring tangible benefits of wearing sensors and explaining the importance of data for better and quicker service provision. Specifically, users should have a certain degree of control over their private data management and in case of programs involving long-term wearing of sensors should be offered adequate benefits to enhance their experience and involvement. Programs involving wearable sensors that are used within smart cities should be transparent and subject to regular evaluation in the context of the challenges and risks described above. The preliminary goal of acquiring data from wearables should always be to enhance the community and individual wellbeing as well as city livability, with users involved in creating related smart cities policies, providing feedback, and exercising control over collected data.

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