SmartWorkplace: A Privacy-based Fog Computing Approach to Boost Energy Efficiency and Wellness in Digital Workplaces

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ABSTRACT

The massive digitalization of modern society has transformed human lifestyles in several dimensions ranging from social interactions to healthcare and wellness, including transportation systems, jobs, machinery, or energy management. However, physical environments and people have not evolved at the same pace, leaving a challenging gap between the advances in technology and how society efficiently interact with it. One specific case is the workplaces where digital literacy is not widespread among all employees (e.g. blue or grey collars) and the advent of such digitalization is a reality. This work presents an architectural approach to improve energy efficiency and wellness at work (by suggesting new behaviours and dynamics) while maintaining user comfort and keeping user's privacy. More specifically, this approach—inspired by the Fog computing paradigm—features a hierarchical scheme based of privacy maintenance which (1) collects real-time data from the users at the workplace environment; (2) processes these data in either in the Fog or Cloud infrastructure depending on the data sensitiveness; and (3) provides feedback to the user along with a set of recommendations related to energy usage. As such, the user is included in the whole data-cycle which allows employees to decide what information can be monitored, where it can be computed and the appropriate ICT channels to receive the feedback.

KEYWORDS

Fog computing, energy efficiency, privacy, confidence, smart environments

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1 INTRODUCTION

With the advent of new ubiquitous technologies and the emerging creation of a new interconnected world, digital transformation is playing a crucial role in modern societies [52]. Several fields and domains such as healthcare [2], business [6], Industry 4.0 [48], transportation [20], or even education [15] have already taken advantage of the never-ending advances in the Information and Communication Technologies (ICT).

Under this context, the predominant presence of technology can play a relevant role in bringing added value services in a way never imagined before and facing existing societal challenges [33]. However, despite this continuous progress in services and technology, human beings seem to struggle on keep-ing the pace of such digital achievements.

An example can be found in office-based workplaces (i.e. those spaces in which employees perform their working duties in a workstation) [7] that basically have kept the same physical layout and configuration—typically composed of a table, a lamp, a (desktop) computer and a monitor—for the last three decades but the digital services and data they use have changed enormously.

Besides the digital gap that some white and grey collars have, this traditional set-up, contributes to increasing the large number of health issues related to the interactions of workers and their environment [40].

In particular, the unconscious habits and behaviors associated to this spaces take a primary role on the physical, mental and social well-being of the worker [36], including long periods of inactivity and sitting times [10], [38], ergonomic related problems [50],[17] or the development of computer vision syndrome because of the exponential screen time exposure [43], [28].

Workplaces are very sensitive places to conduct experiments [5] since they might affect to workers performance and, most importantly, compromise critical data from companies and their employees. For instance, installing a camera in an office might provide massive amounts of valuable data to enhance user's health and energy consumption (e.g., worker's postures, office illumination, hazardous situations, etc.) but it also may reveal private data regarding contents of contracts, meetings, etc.

Also, it has to be considered that people in modern societies are averse to be continuously tracked and monitored without knowing which data they are sharing [1]. Therefore, securing users' privacy while making them aware which data they are disclosing is a critical issue to be addressed when considering to design or deploy any (new) device in a workplace or using data generated in it [19].

The purpose of this work is contributing to this open challenge by discussing the feasibility of conceiving a platform able to transform the digital workplace into a proactive entity (coined as Smart Workplace) while ensuring user's data privacy. In the proposed architecture, the worker decides which data wants to disclose and until up to what extent and, from there, it is continuously monitored and then advised on the best actions to increase his/her comfort while optimizing energy usage.

More specifically, instead of con-ceiving expensive and new ad hoc gadgets, we aim to benefit from the off-the-shelf technology already deployed in digital workplaces (e.g., desktop computers, smartphones) to sense the environmen-tal status and worker dynamics and naturally interact with them. To overcome the data storage and computing limitations associ-ated to this continuous monitoring, the key idea of this proposal is to build a Fog Computing domain composed of all the digital devices deployed in a workplace (that can join or leave at will) and a Cloud Computing layer that will be used whenever the devices need to carry more complex computations.

The combination of Fog and Cloud layers enables the system to limit the scope of the sensed data according to the worker's preferences in relation to the privacy they wanted to preserve, while obscuring its data when needed (i.e., splitting the computation process in several distributed nodes improves data security [31, 32]).

Hence, privacy is considered throughout the whole data-cycle: since data collection, through data intensive computing and user feedback. The user is then in-volved from the very beginning of the design of the architectural approach presented. Thus, an employee can decide in real-time which information is sensible to him/her and what information can be more or less flexible to share or compute. This intermediate step will help to decide if the computation of the activity recognition or the best moment to send feedback can be computed on a secured and reliable Fog environment or it can be sent to the Cloud layer.

With this, the novelty of the proposed system strives on our goal to combine innovative data processing architectures, distributed intelligence processes and advanced immersive interaction interfaces between users and things to give place to a more healthy and secure working environments.

This idea of "Smart Workplace" seeks to turn a working space into a more efficient, trustworthy and acceptable environment by its workers. Thus, transform the way we work and we interact with our environment while promoting more healthier behaviours or increasing levels of comfort and the productivity to their occupants in return. To summarize, this paper contributes with a two-fold approach:

(i) We present our concept of a Fog Computing architecture, designed both from the technical and the user perspective, to contribute to the transformation of smart workplaces while keeping users' privacy. Through this implementation, we seek to convert the workplace into an appropriate setting to motivate workers toward more sustainable and healthier behaviours while promoting changes that hopefully persist over time.
(ii) We illustrate the principal challenges associated with every layer of the architecture and the needs that should be taken into account for succeeding in the transformation of workplaces.

The remainder of this paper is organized as follows. The next section reviews the related work on smart workplaces. Later, the proposed system architecture required to transform a digital workplace into a smart workplace is outlined. Finally, a discussion on the limitations of the proposed approach and some conclusions are provided.

2 RELATED WORK

From occupational risk assessment and ensuring safety in the workplaces [34], the idea of transforming the workplace has progressively evolved from a safety-first concern to a more holistic approach that includes persistent lifestyle changes within such spaces [37]. Since technology allows the possibility to provide context-aware guidance and influence on the users, technology-based solutions can be considered appropriate drivers to promote wellness and energy awareness on the workplace. Therefore, several attempts have been made to design enhanced workplaces [5] through the adoption of ICTs, offering different solutions for facing indirect risks associated with these spaces and bringing energy awareness while reaching large audiences. The PEROSH initiative [22] studied how wearable devices could be part of wellness promotion interventions and elaborated a decision support framework for selecting useful sensors and a proper data collection strategies for avoiding sedentary behaviors neglecting data privacy issues. In the same way, Jimenez et al. [26] presented some guidelines to promote workplace health by using electronic and mobile health tools to provide easier administration for campaign proposers while considering data privacy from a technical and psychological points of view. However, no specific ICT architectures are proposed to conduct this processes.

Indeed, assessing occupational sedentary behavior standouts as one of the most relevant factors to consider in these spaces and several initiatives have been designed from diverse perspectives to face this problem. In this direction, in 2018, Taylor et Al. reviewed the existing literature addressing interventions designed to reduce sitting time and the role of the organizational culture [47]. Digital technologies have also been proposed for reducing sedentary behaviours[23] as well as to increase energy expenditure [39].

Moreover, other approaches have addressed the influence of interruptions on high cognitive loads [45], and non-intrusive monitoring systems specifically designed to avoid lower back injuries have been proposed [51], modeled physical fatigue in workplaces [34] or designed a smart chair to improve the sitting behavior [44]. More in particular, some works have already explored how people and the devices that populate Smart Workplaces can cooperate towards higher energy efficiency [13] or bringing health awareness to the workplace by increasing technology acceptance [18]. Whilst other works have considered how to enhance safety [41] and comfort[3] in working spaces through 5G and IoT. Other platforms, such as Comfy [1], which proposed a cloud-enabled platform to connect employees directly to their physical and digital workplace through the captured data.

Similar advances have been proposed for energy-awareness in these spaces and to guide workers in their routine. In this regard, Irizar-Arrieta et al. [24] proposed a digital interface able to inform workers about their performance related to energy consumption. Similarly, the GreenSoul project [25] designed an enhanced object for office environments—an interactive coaster—to persuade workers to be more aware of the energy consumption of the electrical devices surrounding them in their desktop. Also, there are works focused on how to reach larger audiences and several strategies have been implemented to address this goal: from measuring shared lab equipment usage [35] to projecting real-time energy statistics of a factory in the physical environment [27] and convert work equipment into persuasive devices which raise eco-awareness [12].

In contrast to addressed literature, our proposal puts the focus on the requirements to design an open new innovative architecture able to allocate interactive interventions in the workplaces while considering system scalability, users' privacy, and low-cost. Additionally, this approach addresses both, energy consumption and workers health, as a whole rather than individually fighting them with expensive or commercial (e.g., Comfy Enlighted [2]) ad hoc devices. This links the Fog Computing paradigm with the work environment and represents a new way of envisioning the basis for the digital transformation of these spaces. In the following, the proposed architecture will be described together to the different challenges associated with each corresponding layer.

3 SYSTEM MODEL

To address the transformation of a digital workplace into a smart workplace in a generic and widely adoptable way, we proposed the following hierarchical architecture (see Figure 1) inspired by the Fog computing approach.

Fog Computing is defined as a highly virtualized platform that provides processing, storage and networking services between terminals and data centers used by traditional Cloud Computing, typically located, but not exclusively, on the edge of the network [8]. Fog Computing comes to alleviate those fears related to sharing sensitive and private data on the Cloud by conducting computation operations close to where data were generated and, thus, minimizing the amount of information sent to the Cloud. Many studies show that users, enterprises and stakeholders are more keen to share and collaborate if that sensitive data are managed locally at the edge of the network [29].

The smart workplace transformation unavoidably requires using personal data about users' behavior to make better decisions accordingly (see Section 2). For this reason, the proposed architecture aims to define a system model able to transform a workplace into a smart environment using personal data while considering workers' privacy. The architecture is composed of four main layers: (1) Sensing Layer responsible of data collection, (2) Early Stage Computing Layer represented by a Fog network used for local computation, (3) Intensive Computing Layer deployed in a Cloud infrastructure and responsible for data aggregation, which is used to obtain more accurate recommendations, and (4) Worker-Workplace Layer that is used to optimize the interaction between the users and the devices while giving recommendations. This four layers are supervised by a Decision Support System (DSS) that with the aid of the worker, defines through intents the scope of every datum according to some rules such as privacy, presence or availability. This intent-based DSS is based on S3OiA architecture [49]. We explain hereafter the role of functionality of each layer.

3.1 Sensing layer

The Sensing layer is committed to collect as much data as possible from the workplace. It can be best seen as an IoT sub-domain where every digital object does its best to sense as many environmental variables as possible. For instance, a smart phone can easily sense ambient light intensity, background noise or the amount of phone calls interrupting worker's activity. Analogously, a desktop computer can easily infer user activity by counting keystrokes (or clicks in the mouse) in a period of time. It can also detect user presence, sitting posture, eye gaze, eye blinking by using the built-in camera [11]. Additionally, other smart devices such as smart plugs, smart watches, or smart speakers (digital assistants) can be easily reconfigured to report all the data that they seamlessly capture. These data will be later used to be processed and matched to a certain behavior at the upper layers.

3.2 Early Stage Computing Layer

Similarly to a Fog architecture, the Early Stage Computing layer will receive data from the sensing layer and conduct local non-intensive computations. From a data privacy point of view, this layer can be best seen as the frontier in which sensible data shall not go beyond. Hence, as long as the data privacy policies allow it, this layer will send encrypted data to the upper layer for strong recommendations that require much computing power and more robust models.

Devices located at the edge of the network can be typically identified as gateways, computers, or local servers. To further explain the role of the Early Stage Computing Layer, suppose that a smart plug sends the power consumption of a heater. When the gateway detects that the heater has been turned on uninterruptedly for a specified number of hours, it might suggest to turn off the heater, which would result in energy saving. In the next computing layer (i.e., Intensive Computing Layer), the power consumption

[1] https://www.comfyapp.com/
[2] https://www.enlightedinc.com/

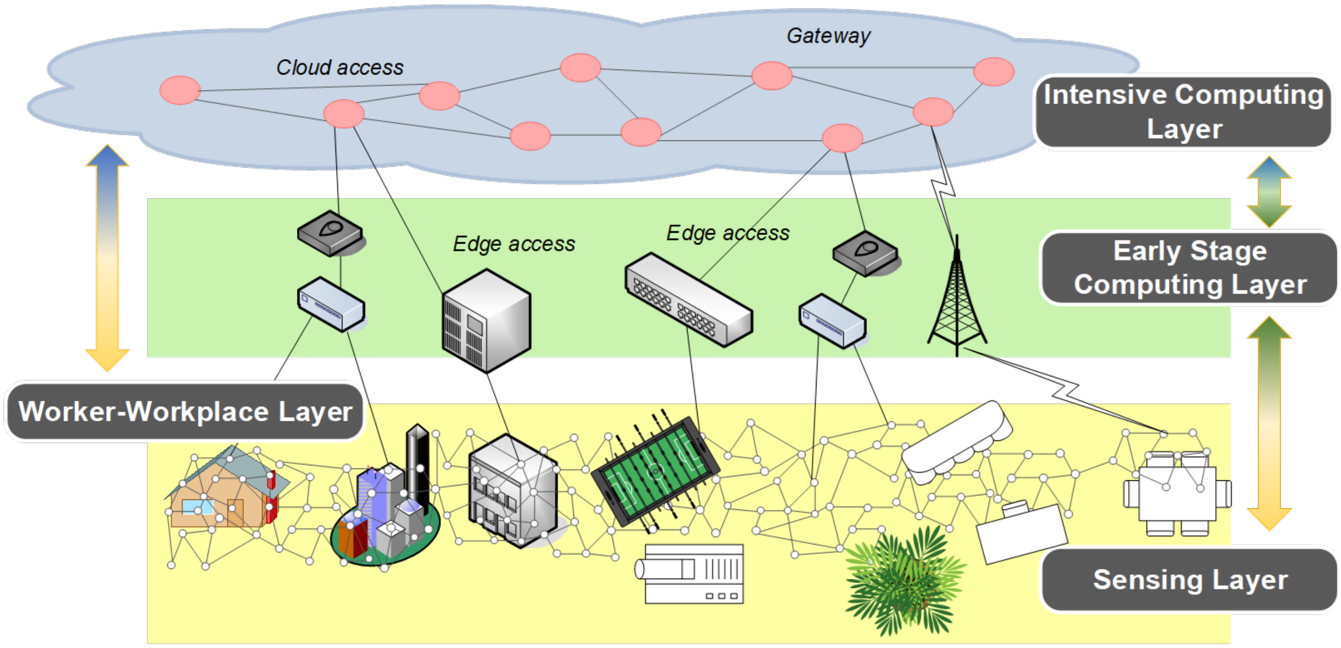

Figure 1: Proposed system architecture

of the heater will be correlated with other variables (e.g., ambient temperature, office hours, office occupancy, etc.) to make the recommendation stronger.

Additionally, it is worth mentioning the situation in which the same physical device—due to its advanced sensing, computing and communication capabilities—belongs to the Sensing and Early Stage Computing Layers at a time. For instance, suppose that a smart phone collects (Sensing Layer) data regarding ambient light intensity. When it detects an excess of ambient light (Early Stage Computing Layer) it might suggest to turn off the office light, which would result in energy saving. However, these data should also be again cross-checked with data from other sources (e.g. the desktop screen is momentarily displaying bright images) in order to make a strong recommendation. This is why the early stage layer will transfer sensed data to the upper layer for intensive computing and global storage.

Finally, it is also worth considering the situation in which a camera is used to track workers' postures and, thus, user privacy is of paramount importance. In this case, we propose to take an alternative approach by encrypting and sending to the following layer the worker's body/face landmarks [11] instead of the whole video stream (as done in [51]). Note that this strategy intrinsically boosts worker's privacy since it is guaranteed that (1) the whole image stream cannot be reconstructed from the landmarks (i.e., no plain images are sent) and (2) no other environmental information of the workplace leave the physical building. Additionally, the overall amount of data transferred to the communications network is greatly reduced.

3.3 Intensive computing and storage layer

At this layer, the power of a Cloud computing infrastructure is exploited by (1) logging and aggregating all the collected data, (2) using a Learning Classifier System able to build a set of user-readable rules (i.e., recommendations), and (3) forwarding these rules to the devices that have sensing but also acting capabilities from the Early Stage Computing Layer (i.e., Worker-Workplace interaction Layer). These recommendations resulting from data analysis, will be mainly transmitted by means of the Worker-Workplace interaction Layer, which will be in charge of finding the best moment/manner to send recommendations to the worker (for instance, worker's presence must be guaranteed before making a recommendation).

3.4 Worker-workplace interaction layer

The availability of a large amount of data provides the opportunity to use this information to influence workers and guide their actions towards more healthier and sustainable behaviors. For this reason, this layer oversees optimizing the interaction between the users and the devices by delivering contextualized feedback. This depends on when and how to interact with the workers to effectively influence their behaviour. On the one side, by choosing the right recommendation mechanism (e.g persuasive strategies based on personalized messages [12]). On the other side, by selecting the right moment to provide the recommendations: trough anticipation (about-to-do moments) and reflection on action (just-in-time moments). The first one is based on anticipation, consisting of recognizing pre-action patterns that allow providing immediate interaction to redirect the activity through context-aware signals (lights, sounds or vibrations, among others). The second one consists on providing the worker with all the information related to his behavior and their performance, analyzing in depth patterns and changes over time and showing the possible consequences of this trend. Unlike the previous type of action, in this case we seek to influence future habits through personal inquiry.

3.5 Illustrative Example

To better understand the functionality of the proposed architecture, we give a simple scenario of a worker using a set of standard devices (i.e., desktop computer with in-built camera, smart phone, smart plug, fan, and voice assistant) with sensing capabilities in the workplace environment.

On the one hand, the desktop computer continuously monitors (i.e., Early Stage Computing Layer) the worker position and periodically triggers alerts when no significant movement is detected for long periods of time. Additionally, the face/body landmarks are sent via HTTPS to the Intensive Computing Layer to precisely analyse the worker's gaze, eye blinking and sitting posture. This layer sends back recommendations to the desktop in order to complement their local decisions.

On the other hand, the smart plug is continuously sending the power consumption (via JSON messages) to the same desktop application that locally monitors worker's movements. At this point (Early Stage Computing Layer) the system can infer that if there is no movement and the fan is turned on (i.e., there is power consumption) the worker might have forgotten to turn off the fan and, thus, might decide to trigger a warning via the voice assistant, just in case the worker is still in the office. Additionally, at the Intensive Computing Layer, the power consumption of the smart plug can be correlated with the worker agenda (via Microsoft Outlook Calendar API) to check whether the worker shall be elsewhere and, thus, decide to turn off the fan by means of the smart plug.

Overall, with this example it can be seen how worker comfort and energy efficient can be addressed with the proposed architecture.

4 DRIVERS AND CHALLENGES

We recall that the basic idea behind the system model proposed above is mainly to offer an architecture where: (1) the system is able to propose strategies offering wellness (user perspective) and energy efficiency (resource consumption), (2) the user is strongly involved in the whole system, from sensing data to applying suggested strategies so his preferences and/or privacy are most respected, and (3) sensitive data protection is a major key to consider while transmitting information through different layers of the system model. Hence, each layer is responsible to satisfy the objectives bellow. We explain hereafter how the design of the proposed architecture offers flexibility and privacy for the user. We also discuss how to overcome open challenges related to the same objectives. Figure 2 depicts the drivers (left side) and challenges (right side) for each layer of the proposed architecture.

4.1 Sensing layer

Transforming the digital workplace to pursue wellness and sustainability in these spaces involves quantifying physical metrics of both the employees and their interaction with the work environment.

Work environments are especially challenging scenarios when technology is the primary way to collect data and obtain information about the workers. First, it must preserve their privacy and consider ethical concerns of personal data collection [9]. In particular, users are more reluctant to be monitored in these spaces as it can be associated with their schedules or work performance [4]. Secondly, data needs to be gathered without affecting workers routine and minimizing their attention theft. Thus, it needs to be as non-intrusive as possible, creating an ecosystem surrounding the employee that allows collecting data without any effect on its routine[46].

The proposed architecture considers both factors. Privacy concerns are covered ensuring the security of the data in every layer of the architecture, with special focus on the way sensitive information is processed and sent to the cloud. Therefore, no personal data is available and the privacy of the workers is preserved. The second aspect is avoided by using digital devices deployed in a workplace so that space is not over-instrumented with disruptive elements. In general terms, a successful ICT initiative should have a strong point in ensuring how the user interacts with the technology, promoting its adherence while creating a sense of confidence and trust.

4.2 Early Stage Computing Layer

The Early Stage Computing Layer is similar to the fog Scheme where components in the edge of the network are used to make local computations, preliminary data analysis, and decompose information to make it harder to retrieve in upper layers. This Fog architecture ensures sharing resources and services in the neighborhood of a network while enhancing their secrecy and availability. Indeed, sharing data to the Cloud raises fears when it comes to disclose sensitive and private data. Since user is involved in the whole chain of the proposed system model, he/she might be more keen to share and collaborate if that sensitive data were managed locally at the edge of the network. In this regard, the Early Stage Computing Layer is introduced as an intermediate layer that offers local decisions based on data collected at the Sensing Layer.

However, edge devices are limited in computational and energy resources. Hence, they can only cover common decisions (e.g., turn off office lights when sensing a high ambient light intensity). For this reason, the proposed system model still requires sending data to an upper layer with more computing and storage capabilities.

This layer is the most critical point to consider data privacy. Therefore, we propose to (1) Filter/transform personal data, and/or (2) encrypt data before sending it to the upper layer (i.e. Cloud services). Many existing security schemes can be used in this fog-inspired architecture. For instance, SKES-Fog can be implemented in the proposed system model as the architecture could be presented using domains as suggested in [14]. Besides, data filtering or transformation allows to delete unnecessary data during the decision making process (e.g., user's identity). Later, the interaction layer will assign the anonymized data to its corresponding worker to send accurate recommendations (based on the decisions from the Intensive Computing and Early Stage Computing layers).

4.3 Intensive computing and storage layer

The Intensive Computing and Storage Layer takes advantage of the power of Cloud computing infrastructures where: (1) the great amount of collected data is stored as a whole to be all exploited and analysed for accurate decisions, (2) all the sensed data transmitted from the Early Stage Computing Layer are aggregated, (3) workplace recommendations are inferred by using a Learning Classifier System, and (4) rules are forwarded to both Early Stage Computing and Interaction layers, which will merge all data (protected and aggregated) and then use a strategy to communicate recommendations to the workers.

The Intensive Computing and Storage Layer allows to run complex algorithms and use a huge amount of data to make accurate decisions. Some of Learning Classifier Systems could be based on KNN (K-Nearest Neighbors) [16], LSDT for reinforcement learning [30], etc.

However, in view of the sensitivity of the information shared in Fog/Cloud applications, safety and availability are sine qua non conditions for the development and adoption of both Early Stage and Intensive Computing layers. Security schemes proposed in previous sections cover data privacy for Fog and Cloud architectures, and hence, can also be applied for both layers in the proposed system.

4.4 Worker-workplace interaction layer

Besides the technological requirements of the architecture that supports this system, the central pillar of the strategy goes through engaging the users and leading them to appropriate lifestyle changes. In particular, the habits and behaviours that we maintain in the workplace are very entrenched and our tendency is to concentrate on our tasks and leave other factors aside. Thus, any system or architecture designed to promote new habits in these spaces needs to consider the role of the user as a key factor.

The basis of the change-management process are the way the information used as an awareness mechanism and how this information is provided to the workers. In particular, information needs to be delivered effectively and digital feedback is an appropriate way to influence in the receiver [21]. In this proposal, the role of the user is boosted by the Worker-Workplace layer, in charge of optimizing the interaction between the users and the system through contextualized feedback [12] and privacy-based user intentions [49]. The former pursues involving the workers in the process and influencing their behaviour through the application of technological persuasion techniques that increase their engagement and motivation. The latter allows the user to expresses the data a user want to preserve and a set of requirements which have to be accomplished to this endeavour. The user will be always able to supervise the whole procedure in a reliable and understandable manner.

5 CONCLUSION AND DISCUSSION

In this work, we have presented an easily deployable platform to improve energy efficiency and user wellness by transforming the digital workplace. Beyond the addressed technological challenges of the proposal, succeeding in the creation of this kind of smart spaces needs to overcome additional barriers regarding the privacy concerns of the collected data and the lack of adherence of the target audience. Therefore, this work seeks to boost the effectiveness of technology-based interventions by providing an improved interaction framework through personalized and context-aware services. In essence, our approach states that improving how workers interact with the system and ensuring their privacy leads to

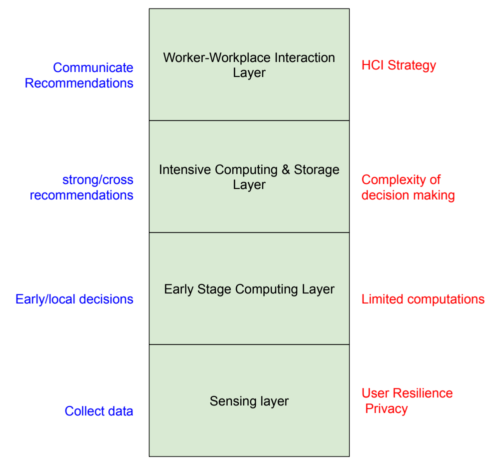

Figure 2: Drivers and Challenges of the proposed architecture

increasing rates of participation and attachment levels that will contribute to bringing health-awareness and energy efficiency to the workplace. There are many directions for future research that have arisen as a result of this proposed architecture. On the one side, find a middleware based on micro-services that can hold and orchestrate the proposal investigating the work that Pore et al. [42] carried on in design issues for Fog and Edge middlewares. On the other side, formally model the different classification or inference tasks within a digital workplace to better understand the way a DSS can decide where (Edge / CLoud) and how to compute (Serial On-the-fly / Parallelization) the incoming sensitive data.

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