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**Minimizing the influence of coronavirus in a built environment**

**MICROBE**

O3/A1. Formulation of the Research Problem

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# **1. Affective Internet of Things**

Affective Internet of Things is applicable in various areas (Fig. 1). For example, wearable emotion sensors are widely used by psychologists and therapists, in clinics, hospitals, etc. IoT is implementing emotional ingredients in the wristbands too. Their sensor technology also allows for gathering data on heart rate, blood pressure and temperature to define an individual’s emotional states. Such emotion sensors are relatively low-cost, easy to use, and have a wide variety of utilization.

Figure 1. Affective IoT application areas.

Smart watches and health wearables create a foundation for technology that helps coordinate daily habits while avoiding potential health issues and other problems. With a modern smart device, the user can track and evaluate their physical condition and how they react to stress-inducing situations, as well as learn to manage stress and anxiety better. The device might instruct them to practice a mind controlling technique or to do breathing exercises to calm down, or turn on relaxing music [1]. There are many advantages to using anthropomorphic approaches when designing things. Anthropomorphic techniques that use human language and symbolism, and devices such as virtual assistants and chatbots, can promote natural interaction, trust, learning and empathy between artificial intelligence (AI) software/models and humans. That’s not to say that a strong anthropomorphic approach is always best. In sensitive situations (such as a robot providing medical advice to a user) overly anthropomorphic approaches could make patients uncomfortable and prevent them from disclosing essential information. Anthropomorphization also offers another opportunity. This is the notion of obtaining digital customer/worker/citizen feedback from the “voice of the thing” (VoT). Humanizing a connected thing creates the opportunity to obtain feedback from it in the same way we would from a human being, complementing existing human feedback. Another key consideration is determining whether a thing has a “voice.” It’s important to distinguish between simple reporting of operational Internet of Things data and what would be considered the VoT. The key distinction is that VoT requires some form of intelligence that drives thing opinion. The VoT doesn’t just report facts. It enriches them, contextualizes, them and provides a rationale for the feedback. While the baseline for thing feedback is simply factual and event-based reporting, the VoT should be associated with something more — encompassing opinions, beliefs, contextual enrichment of narratives and exposition of rationales around balancing short- and long-term goals. That’s the difference between operational reporting and the VoT for the various types of feedback — whether direct, indirect and inferred. Another potential stumbling block is that the anthropomorphization of things will likely span multiple departments including CRM, digital workplace, innovation, IT, marketing and multiple other business units. The ensuing cultural, political and technical hurdles could all complicate progress. As things become more autonomous — and are better able to take actions independent of humans — the ability for things to provide feedback to other things will help accelerate their learning and subsequent performance [2].

New emotion-sensing technologies and software fueled by artificial emotional intelligence can read and analyze not only skin conductance, breathing and heart rate, but also eye movements, facial expressions, changes in voice, etc. And they don’t necessarily require installing expensive hardware, but rather just some recognition software or additional code for computers or smartphones. For example, even slow or uneven cursor movements may reflect distraction or negative emotions of the user. New emotion detection technologies could help employees make better decisions, improve their focus and performance in the workplace, manage stress, and adopt healthier and more productive work styles. Traders are a good example. They tend to overpay for assets and downplay risk in what they call a ‘bidding frenzy’. To address this problem, Philips and ABN AMRO developed the Rationalizer bracelet back in 2009. While the bracelet measured emotions via electrodermal activity, a display was reflecting the user’s heightened emotional states. The display thus signaled the need to pause and rethink financial decisions. Some of the world’s elite coaches, teams, and individual athletes have used headsets produced by San Francisco-based SenseLabs Inc. Their Versus gear connects to an iPhone or iPad via bluetooth and has dry sensors for assessing brain performance. This makes it possible to identify strengths and weaknesses in problem-solving, multitasking, resource management, decision-making, and sleep tendencies. Versus then provides customized exercise protocols to improve mental acuity, concentration, and sleep management. Aggregated data from such devices can help companies understand how internal and external environmental factors impact employees and groups. As a result, they might redesign processes accordingly to help keep personnel better engaged and productive [1].

Emotion AI, also known as affective computing, enables everyday objects to detect, analyze, process and respond to people’s emotional states and moods — from happiness and love to fear and shame. This technology can be used to create more personalized user experiences, such as a smart fridge that interprets how you feel and then suggests food to match those feelings. In the future, more and more smart devices will be able to capture human emotions and moods in relation to certain data and facts, and to analyze situations accordingly. Although emotion AI capabilities exist, they are not yet widespread. A natural place for them to gain traction is in conversation systems — technology used to converse with humans — due to the popularity of virtual personal assistants (VPAs) such as Apple’s Siri, Microsoft’s Cortana and Google Assistant. Today VPAs use natural-language processing and natural-language understanding to process verbal commands and questions. But they lack the contextual information needed to understand and respond to users’ emotional states. Adding emotion-sensing capabilities will enable VPAs to analyze data points from facial expressions, voice intonation and behavioral patterns, significantly enhancing the user experience and creating more comfortable and natural user interactions. Prototypes and commercial products already exist — for example, Beyond Verbal’s voice recognition app and the connected home VPA Hubble [3].

Speech-based emotion analysis in real time opens up more business opportunities. This and other emotion-sensing technologies can enable companies to establish deeper emotional connections with their consumers through virtual assistants. Popular VPA like Siri, Cortana, and Google Assistant use natural-language processing and natural-language understanding to process verbal commands and questions. Adding emotion sensing capabilities will enable them to create more comfortable and natural user interactions. Call centers are another potential customer group. Voice-based emotion sensing can enable automated customer service agents to recognize callers’ emotional states and adapt to them. It will also help management analyze stress levels of human workers. In the future, more and more smart devices will be able to capture emotional reactions to certain data and facts, analyze situations accordingly, and come up with appropriate recommendations. Currently, the healthcare and automotive industries are among the most eager to adopt emotion-sensing features. Car manufacturers are exploring the implementation of in-car emotion detection systems to improve road safety by managing the driver’s drowsiness, irritation, and anxiety. For instance, Panasonic Corporation’s new sensing technology can detect a person's emotions and sense of being hot or cold in a contactless manner. This information can be used for predicting a driver's drowsiness to help keep them awake. The technology measures a driver's blinking features and facial expressions captured by an in-vehicle camera and processes these signals using AI. Further, using the data on heat loss from the driver and in-vehicle illuminance, it predicts transitions in the driver's drowsiness level. Combining this thermal sensation monitoring function, the system helps the driver to stay comfortably awake while driving. When the drowsiness level is high, it issues a sound alarm or a command to rest [1].

Personal assistant robots (PARs) are also prime candidates for developing emotion AI. Many already contain some human characteristics, which can be expanded upon to create PARs that can adapt to different emotional contexts and people. The more interactions a PAR has with a specific person, the more it will develop a personality. Some of this work is currently underway. Vendors such as IBM and startups such as Emoshape are developing techniques to add human-like qualities to robotic systems. Qihan Technology’s Sanbot and SoftBank Robotics’ Pepper train their PARs to distinguish between, and react to, humans’ varying emotional states. If, for example, a PAR detects disappointment in an interaction, it will respond apologetically. The promise of emotional AI is not too far into the future for other frequently used consumer devices and technology, including educational and diagnostic software, video games and the autonomous car. Each is currently under development or in a pilot phase. The video game Nevermind, for example, uses emotion-based biofeedback technology from Affectiva to detect a player’s mood and adjusts game levels and difficulty accordingly. The more frightened the player, the harder the game becomes. Conversely, the more relaxed a player, the more forgiving the game. There are also in-car systems able to adapt to the responsiveness of a car’s brakes based on the driver’s perceived level of anxiety. In both cases, visual sensors and AI-based, emotion-tracking software are used to enable real-time emotion analysis. These systems will detect the driver’s moods and be aware of their emotions, which in return, could improve road safety by managing the driver’s anger, frustration, drowsiness and anxiety [3].

With the help of mood sensor technology, children or elderly family members in need of care will be able to receive timely assistance and support from their families or caregivers. Emotion-sensing wearables will help monitor the state of mind of persons with mental and other health conditions 24/7. When necessary, they will alert doctors and caregivers and inform about upcoming changes in the person’s mood and behaviour. Remote emotions detection is possible as well. One of the devices created at MIT's Computer Science and Artificial Intelligence Laboratory emits radio signals that reflect off a person's front and back body. By measuring heartbeat and breathing, the device can accurately detect emotional reactions. Such remote sensing technologies could be used to diagnose or track conditions such as depression and anxiety, as well as for non-invasive health monitoring and diagnosis of heart conditions. Technology that deduces human emotion based on audio-visual cues may enable businesses to detect consumers’ positive and negative moods to better understand their preferences, analyze customers’ choices to utilize in marketing, and detect users’ annoyances to improve product usability, etc. For instance, a fridge with a built-in emotion sensor may interpret a person’s mood and suggest a more suitable food. Emotion-sensing smart home devices could provide entertainment (music, videos, TV shows or imagery) which matches the user’s current state of mind. Video games might use emotion-based biofeedback technology to adjust game levels and difficulty according to the player’s emotional states. MIT Media Lab spinoff Affectiva has been analyzing people’s facial expressions and non-verbal cues for applications in advertising, marketing, and video games for years. But their vision is to build a multimodal emotion AI platform that senses and measures emotions the way humans do. In September 2017, Affectiva announced the release of cloud-based software that identifies the speaker’s gender and observes changes in speech paralinguistics, tone, volume, speed, and voice quality to distinguish anger, laughter, or arousal.

IBM along with numerous startups are developing techniques to add human-like qualities to robotic systems. The development of emotional AI will lead to creating more effective personal assistant robots. They will be able to distinguish between, and react to, different people and their emotional states. For example, when a robot detects disappointment on the human’s part, it will respond apologetically in a modulated voice. Interacting with a specific person, it will gradually learn emotional awareness. Since emotions remain a fundamental need for humans, emotion-sensing technology should start teaching intelligent objects how to interact with humans as soon as possible [1].

# **2. IoT, Smart Homes, Ambient Intelligence and Affective Computing**

Humans deeply modified their relationships to their housing over the past centuries. Once a shelter where humans could find protection and rest, their living place became the center of the family – the expression of their culture. Nowadays, it is a more self-centered place, where individuals develop their own personal aspirations and can express their social position. Electricity was the first technology to enter the home environment, followed by communication technologies to make a human, ‘a motionless nomad,’ connected with others in any place at any time. A new living place is being invented, the ‘witness’ of our existence, perceiving the inhabitants' rhythms of activities, habits, tastes, and wishes. Among all the services a living place can bring to inhabitants, we find comfort, security, wellness, and health services. The information and communication technologies in homes can now help extend our longevity (Noury 2014).

The world population is ageing rapidly with the percentage of older adults increasing to 24% by 2030 from 10% in 2000. Therefore cost of providing aged care has been growing, especially in countries such as Japan, the USA and Australia. Robotic technology has been identified as being able to help older adults to live independently, and is emerging as an innovative approach to assist older adults directly, for example, robotic wheelchairs and indirectly for instance providing support to stakeholders, including caregivers. A systematic literature review of peer-reviewed literature published in Medline, ScienceDirect, ProQuest, PubMed, Scopus and SpringerLINK, from 1 January 2000 to mid-July 2015 was undertaken. An initial set of 8533 studies was refined to 58 studies. Nine robot types were identified in addressing aged care problems, including companion, manipulator service, telepresence, rehabilitation, health monitoring, reminder, entertainment, domestic, and fall detection/prevention robots. These robot types have been applied to eight key problem areas in aged care, namely social isolation, dependent living, physical or cognitive impairment, mobility problems, poor health monitoring, lack of recreation, memory problems and fall problems. The frequency of research into each robot type was analysed, with the finding some robotic technologies have received more attention (e.g., companion) while other types that can assist older adults with independent living (e.g., cooking and bathing) were not as comprehensively researched [4].

The elderly population is increasing and the response of the society was to provide them with services directed to them to cope with their needs. One of the oldest solutions is the retirement home, providing housing and permanent assistance for the elderly. Furthermore, most of the retirement homes are inhabited by multiple elderly people, thus creating a community of people who are somewhat related in age and medical issues. The ambient assisted living (AAL) area tries to solve some of the elderly issues by producing technological products, some of them dedicated to elderly homes. One of the identified problem is that elderly people are sometimes discontent about the activities that consume most of their day promoted by the retirement home social workers [5]. Costa et al. [5] attempt to improve how these activities are scheduled taking into account the elderlies’ emotional response to these activities. The aim is to maximize the group happiness by promoting the activities the group likes, minding if they are bored due to activities repetition. In this sense, this paper presents an extension of the Cognitive Life Assistant platform incorporating a social emotional model. The proposed system has been modelled as a free time activity manager which is in charge of suggesting activities to the social workers [5].

Wilson et al. [6] describe an integration of robots into smart environments to provide more interactive support of individuals with functional limitations. Robot Activity Support (RAS) system, partners smart environment sensing, object detection and mapping, and robot interaction to detect and assist with activity errors that may occur in everyday settings. Wilson et al. [6] describe the components of the Robot Activity Support system and demonstrate its use in a smart home testbed. To evaluate the usability of RAS, Robot Activity Support also collected and analyzed feedback from participants who received assistance from Robot Activity Support system in a smart home setting as they performed routine activities [6].

A home is not only a technical space according to each individual's role but also a social space where family members interact with each other. However, the number of single-person households has recently shown an exponential increase. At the same time, the smart home technology has been growing in order to provide at-home rest to individuals. In this situation, a home's role as a social space is diluted, and many people cannot receive the social support they need at home [7]. Lee et al. [7] introduce the concept of social connectedness for the interaction between users and smart home devices. It can be divided into two types. One is the Inner Social Connectedness (ISC) that is generated through connections between the user and the devices in their smart home. The other is the Outer Social Connectedness (OSC) that is generated through connections between the user and the smart home devices in other people's houses. Lee et al. [7] also introduce two types of interaction. One is the unmediated interaction, in which users interact with each device and the individual device reveals its presence. The other one is the mediated interaction, in which users interact with a single agent that represents various smart home devices. In order to investigate the impact of both inner/outer social connectedness and mediated/unmediated interaction types, Lee et al. [7] conducted a controlled experiment using a prototype smart home system.

Currently, there is an increasing number of patients that are treated in-home, mainly in countries such as Japan, USA and Europe. As well as this, the number of elderly people has increased significantly in the last 15 years and these people are often treated in-home and at times enter into a critical situation that may require help (e.g. when facing an accident, or becoming depressed). Advances in ubiquitous computing and the Internet of Things (IoT) have provided efficient and cheap equipments that include wireless communication and cameras, such as smartphones or embedded devices like Raspberry Pi. Embedded computing enables the deployment of Health Smart Homes (HSH) that can enhance in-home medical treatment. The use of camera and image processing on IoT is still an application that has not been fully explored in the literature, especially in the context of HSH. Although use of images has been widely exploited to address issues such as safety and surveillance in the house, they have been little employed to assist patients and/or elderly people as part of the home-care systems [8]. In Mano et al. [8] view, these images can help nurses or caregivers to assist patients in need of timely help, and the implementation of this application can be extremely easy and cheap when aided by IoT technologies. This article discusses the use of patient images and emotional detection to assist patients and elderly people within an in-home healthcare context. Mano et al. [8] discuss few studies that take into account the patient’s emotional state, which is crucial for them to be able to recover from a disease.

Smart home technology (SHT) has been identified as a promising means of helping seniors to remain independent and maintain their quality of life (QoL) while containing spiralling care costs for older people. Despite official pilot schemes in many countries to promote SHT in seniors housing, there is limited understanding of the forms that such SHT interventions should take [9]. Wong et al. [9] research builds on the analytical model of intelligent building control systems; the aim is to provide a systematic approach to understanding the key intelligent attributes of smart-home devices. A qualitative participatory evaluation approach involving focus groups was adopted to investigate the needs of seniors and their SHT preferences [9].

Pieroni et al. [10] introduce the concept of Affective Internet of Things (AIoT) where smart objects are empowered with affective capability in terms of abstraction of their emotional state. Moreover each smart object can be associated with a specific `personality'. This approach, already used in the field of social robotics, mainly exploits robots' appearance (i.e. anthropomorphism or zoomorphism). The research aims at extending such a paradigm to everyday-life objects in order to `warm-up' the empathic connections that humans generally establish with `cold' gadgets and devices. A new framework for the Affective IoT has been developed: EMPATI (EMPATI Mimics Personalities on Affective Things on Internet). It provides models and functions to simulate different personality for affective objects living in both virtual and real world. Finally, a set of experiments has been conceived to assess the key aspects of the framework in terms of capability to simulate emotional responses depending on the object interaction with the environment and the affective stimuli [10].

# **3. BIM, Smart and Interactive Buildings**

Building Information Modeling (BIM) is a powerful technology that is used to support decision-making about a building during its life-cycle. The article shows that traditional BIM solutions, due to its static nature, don’t cover all needs of “smart” buildings technology. Dynamic extension of Building Information Model is proposed to cover gaps of traditional BIM in the design and operational stages of “smart” buildings life-cycle.An exploratory model on the usability of a prototyping-process for designing of Smart Building Envelopes [11].

Application of nD BIM Integrated Knowledge-based Building Management System (BIM-IKBMS) for inspecting post-construction energy efficiency [12]. Tracking Users’ Behaviors through Real-time Information in BIMs [13]. An intelligent building supports the needs of its occupants by data analytics. Nowadays, buildings are evolving from being products to become effective service providers for end-users: thus, occupancy topics become crucial. Implementation of Building Management Systems (BMS) into a Building Information Modeling (BIM) environment, connecting real-time information collected by sensors to a BIM database [13].

The IoT application domains empower the vision of a built environment pervaded by sensors and actuators in which homes do not waste energy, where interactive walls display useful information, as well as pictures of art or videos of friends. Even more potentialities could be exploited through data collection, considering that the connected devices have an annual growth more than 10%, and over 500 billion connected devices are expected worldwide by 2025 [14]. Nowadays, several buildings are built from the ground up with nearly one IoT-enabled sensor per square meter monitoring temperature, humidity, the weight in the trash cans, how many people are in a room, and on and on [13].

It has been estimated that users waste 30% of energy in buildings because of their behavior [15]. Anyway, the occupant variable and the behavior tracking are crucial to define an operational rational use and tailored services on the real needs of users, avoiding wastes of energy [16, 17] in a lean vision of the buildings management [18]. To analyze how the information collected during the operational stage could enlighten end-users about the behavior of both buildings and occupants. Therefore, advantages in tracking the behavior of occupants and in satisfying the needs of users should be derived through the availability of real-time information (e.g., data collected by sensors measuring and reporting outdoor conditions, indoor comfort parameters, system efficiency factors). Later, predictive buildings anticipated the occupancy needs and set themselves to face environmental and behavioral inputs using Information and Communications Technology (ICT) to support managers and operators. Nowadays, cognitive buildings learn from the user behavior and traduce the data coming from the outdoor, the indoor and the social environment using an IoT approach. In this way, the responsiveness is reset in time, making the building autonomous to react in some situation [13].

Within this scenario, user behavior could be tracked in order to define customized operations in which the building measures the number of people inside and adjusts heating and lighting accordingly, turning an empty building off, as a computer goes into standby mode. Moreover, it is possible to localize the heating and cooling systems, providing a detailed, individual climate for each user by means of arrays of responsive infrared heating elements that are guided by sophisticated motion tracking providing thermal “clouds”, following people through spaces and ensuring pervasive comfort whereas improving overall energy efficiency. By adequately processing these data, it is possible to assess building performances, to evaluate user levels of satisfaction, to estimate occupant preferences or to track user behaviors [13].

The research aims to define a workflow to populate BIM models using data gathered through remote sensors, driving parameters in BIM models, changing parameters in digital models to provide input and possibly modifying physical models. In this way, users become aware of their behavior and should interact with buildings, i.e., through online dashboards or apps, improving their behavior and increasing their awareness. Moreover, designers benefit of an improvement of the building process not only collecting and filtering feedback of users in operation, but also checking and verifying instantaneous and historical values of defined parameters. Finally, facility managers are instantly informed about failures or damages and the process can support rapid fault detection [13].

Through ad-hoc apps, it is possible to access sensors data, retrieved from the BMS or directly from the sensors through the Z-wave gateways and to provide feedbacks of the students on comfort level in the classrooms, interacting with the building. In this way, it should be possible to develop strategies such that buildings could adapt their behavior depending on the user needs, communicated via app. The bi-directional interaction through the app embodies the introduction of the human factor into the IoT structure to enable the cognitive building to learn from behaviors providing data in real-time with the capability to process them into adaptive and predictive strategies for improved comfort and servitization. The scenarios are created with data gathered through sensors installed into the building. As an example, in the scenario of the school, when a sensor gives feedback that the air quality in the classroom is getting worse, ventilation will be triggered and the room will improve its air quality. Cognitive buildings are also highly feasible [19] as most modern buildings have already a series of sensors implemented in them when they are finished [20, 21]. The idea is to introduce the user in the loop of information and connect the body of knowledge about the building. Objective data coming from sensors and subjective data coming from students and visitors can be collected directly, i.e., by the user definition of the comfort conditions, and indirectly, i.e. through the sentiment analysis [22]. As an example, data could be gathered through sensors, could be encoded in language (e.g., textbooks, formulas, conversation) or could be captured in sight, sound and motion [23]. By adequately processing these data, it is possible to assess building performances, to evaluate user levels of satisfaction, to estimate occupant preferences or to track user behaviors. Through BIM models, it is possible to transform collected data in usable information to gain deeper insights on how buildings perform throughout their life cycle. In this way, users become aware of their behavior and should interact with buildings, i.e., through online dashboards or apps, improving their behavior and increasing their awareness [13].

Distributed, networked, electronically tagged, interactive devices are increasingly incorporated into the physical environment blurring progressively the boundary between physical and virtual space. This changing relationship between physical and virtual implies not only a change in the operation and use of buildings but also a change in their physical configuration, and therefore, their design and production. Interactive building addresses, therefore both the building defined as physically built environment and the building process implying on the one hand the changing role of architecture with respect to incorporation of interactivity and the resulting multiple and varied use of built environments in reduced timeframes. On the other hand, it is implying the changing role of the architect with respect to the use of networks connecting digital databases and parametric models with customizable design and production tools allowing for linking design to production and use [24].

In order to raise awareness of the role of building information modeling (BIM) in improving energy efficiency and comfort conditions, the work introduces a strategy of combining building simulation tools and optimization methods. Furthermore, it emphasizes the fact that a combination of these strategies with BIM can improve not only the construction process but also enable exploration of alternative approaches. The work discusses the potential application of data integration methodology for an office environment and focuses on the review of the potential performance of integrated systems. It also explains how BIM can help facilitate review of results and methods for improving building performance in terms of energy efficiency and indoor environmental quality [25, 26].

Most BIM (Building Information Modelling) systems serve designers well up until now but will have to evolve toward a more user-centered design, focusing on interactive spaces rather than focusing on digital representation. They are lack of information needed in order to create a virtual environment which can interact with users. Such problems will become more prominent in the case of smart spaces where the environment reacts to users' activity. There are no sufficient tools to design and represent real usage of smart space. A task-based interaction is proposed to apply Smart BIM in a design process. Smart Design systems help end users to experience their daily activity in a virtual environment and understand the space reactions. It can be used as a toolset to improve communications among users and designers in design processes especially in the design of smart environments. Eventually, it is expected that Smart-BIM will lead to match smart technology usability with users' demands. Hence, the prototype gives the opportunity of evaluating users' attitude and expressions toward an interactive and responsive BIM [27].

Intelligent management systems (IMSs) have significant potential for energy savings, but they have not been fully used in buildings and cities. Smart sensor systems based on user behavior will improve indoor environmental quality (IEQ) and user comfort. This work aims to reduce energy consumption and provide comfort conditions by learning user behavior. In order to improve energy efficiency and comfort conditions, smart sensor systems and digital simulation tools play a crucial role in finding optimal solutions to optimization problems [28].

CoSMoS: A BIM and wireless sensor based integrated solution for worker safety in confined spaces [29].

This work explores the application of a real-time monitoring system to achieve optimal indoor environmental quality (IEQ). ICT-related applications have drawn attention from smart buildings as potential means of providing correlations between users and building systems to improve energy efficiency and comfort. In order to investigate whether users can take advantage of natural environmental factors during occupied hours in office buildings, daylight and energy performance simulations were carried out. This work explores users as the primary factors to improve indoor environmental quality (IEQ) and energy efficiency. The results support the use of real-time monitoring systems in office buildings. It seems, however, that there is a need for individual user control of thermal, ventilation, and lighting [28].

This research presents the architecture of a technology platform capable of integrating different types of data from building sensors and providing an interface to manage and operate facility devices, which is supported by advanced optimization algorithms. This interface is potentiated by a BIM-based interface presenting real-time data of the building. The solution, called 3i buildings - Intelligent, Interactive, and Immersive Buildings, is a tool to monitor and manage smart buildings, as well as optimize users experience, energy consumptions and environment quality. This is achieved by a grid of sensors and devices that continuously gather information (structural conditions of the building, occupancy, comfort of occupants, energy consumptions and CO2, COV's and Humidity levels, etc.), which is processed by predictive models able to learn over time. The 3D representation of the models allows managers to take advantage of the virtual environment, by augmenting the facility model and including information about the facility, making it easier and perceptible to users and owners, helping them to make better decisions. These types of systems might help reducing energy consumptions as well as increasing comfort and satisfaction of occupants, maintaining a constant concentration of CO2 and humidity within the facility. The optimized algorithms will allow the system to learn, predicting and reacting to different conditions, giving a more reliable and smooth response to occupants needs [30].

Current urban water research involves intelligent sensing, systems integration, proactive users and data-driven management through advanced analytics. Such research would pave the way for demand-side management, active consumers, and demand-optimized networks, through interoperability and a system of systems approach. The web service integrates state of the art sensing, data analytics and middleware components. We propose an ontology for the domain which describes smart homes, smart metering, telemetry, and geographic information systems, alongside social concepts. This integrates previously isolated systems as well as supply and demand-side interventions, to improve system performance [31].

Building energy management systems (BEMS) are integrated building automation and energy management systems, utilizing IT or ICT, intelligent and interoperable digital communication technologies promoting a holistic approach to controls and providing adaptive operational optimization. The system may have multiple levels from individual sensors and actuators to users’ interface, to facilitate data collection, analysis, diagnose, trend finding, and decision-making. BEMS dynamically control indoor climate in a cost-effective manner and ensures the comfort, safety, and wellbeing of the occupants in buildings [32].

The ability to process large amounts of data and to extract useful insights from data has revolutionised society. This phenomenon—dubbed as Big Data—has applications for a wide assortment of industries, including the construction industry. The construction industry already deals with large volumes of heterogeneous data; which is expected to increase exponentially as technologies such as sensor networks and the Internet of Things are commoditised. In this paper, we present a detailed survey of the literature, investigating the application of Big Data techniques in the construction industry. We reviewed related works published in the databases of American Association of Civil Engineers (ASCE), Institute of Electrical and Electronics Engineers (IEEE), Association of Computing Machinery (ACM), and Elsevier Science Direct Digital Library. While the application of data analytics in the construction industry is not new, the adoption of Big Data technologies in this industry remains at a nascent stage and lags the broad uptake of these technologies in other fields. This paper fills the void and presents a wide-ranging interdisciplinary review of literature of fields such as statistics, data mining and warehousing, machine learning, and Big Data Analytics in the context of the construction industry [33].

Buildings are key players when looking at end-use energy demand. It is for this reason that during the last few years, the Internet of Things (IoT) has been considered as a tool that could bring great opportunities for energy reduction via the accurate monitoring and control of a large variety of energy-related agents in buildings. However, there is a lack of IoT platforms specifically oriented towards the proper processing, management and analysis of such large and diverse data. In this context, we put forward in this paper the IoT Energy Platform (IoTEP) which attempts to provide the first holistic solution for the management of IoT energy data. The platform support for data analytics. As part of this work, we have tested the platform IoTEP with a real use case that includes data and information from three buildings totalizing hundreds of sensors [34].

Due to the complexity and increasing decentralisation of the energy infrastructure, as well as growing penetration of renewable generation and proliferation of energy prosumers, the way in which energy consumption in buildings is managed must change. Buildings need to be considered as active participants in a complex and wider district-level energy landscape. To achieve this, the authors argue the need for a new generation of energy control systems capable of adapting to near real-time environmental conditions while maximising the use of renewables and minimising energy demand within a district environment. They could provide energy management and cost savings for adaptable users, while meeting energy and CO2 reduction targets [35].

# **4. Modern Office Smart Systems**

Some researchers have proposed asking officemates to basically vote on what the temperature should be. Using a phone app or website, building occupants say whether they’re too hot or too cold, and what would make them more comfortable. An algorithm then analyzes the groups’ answer and calculates a temperature estimated to be most acceptable to most people. In previous research, our group placed multiple temperature sensors around an office, and combined their data with information from wristbands that sensed occupants’ skin temperature and heart rates and apps that polled workers about how they felt. We found that adding the data about how people’s bodies were reacting made the algorithm more accurate at calculating the room temperature at which people occupying a given space would feel most comfortable. Our current project, seeks to make things even easier and less intrusive for people, eliminating the wristbands and apps, and only using remote sensing of people’s skin temperature to measure how comfortable they are. We developed a method using regular cameras, thermal imaging and distance sensors to detect occupants’ presence in a space, focus on their faces and measure their skin temperature. From that data, our algorithm calculates whether – and how – to change the temperature in the room regardless of the number of occupants in the space. When we tested it in an office occupied by seven people, they complained less about feeling uncomfortably cold or warm [36].

Smart HVAC technology reduces energy costs, lessens the workload on facilities staff, and provides better comfort conditions for employees. Occupancy sensors. Occupancy sensors are useful for office environments (like most) that don’t have uniform usage all the time. Increasingly mobile workers are leaving desks and conference rooms empty as much as 50 to 60 percent of the time. Meanwhile, you’re heating and cooling space for people who are not there. Occupancy sensors detect the presence of people (typically by detecting motion) currently using individual spaces within an office. That data can be used to adjust temperatures based on real-time utilization, saving you money on energy consumption. While your HVAC system consumes anywhere from 40 to 70 percent of your building’s energy usage, electricity for lighting is also a huge expense. That figure can be 25 percent or more. In addition to controlling a smart HVAC system, occupancy sensors also control lighting to further reduce lighting costs. Thermal sensors. Strategically-placed thermal sensors can detect the differences in conditions in each zone of your space. For example, a crowded conference room can get warm in a hurry, while an open office area with high ceilings can get chilly (since warm air rises and people are closer to the floor). A smart HVAC system uses that data to adjust to changing conditions throughout the day or week. CO2 sensors. CO2 sensors can detect the levels of CO2 gas in a space, which can increase to undesirable levels as occupancy increases. When the threshold is reached, a smart HVAC system can increase levels of fresh air supplied to the space. This technology can have a significant impact on workforce wellbeing [37].

The smart sensors, including mobile phone, wearable device and other sensors, are introduced. They are the key elements to determine human intentions. Wearable devices, such as watches or bracelets, may be adopted for detecting the human sleeping state as the feedback signals of the sleeping function. It can collect human motion information, and feedback to the smart air conditioner for further control. Smart control, based on the information collected by the use of mobile phones and wearable devices, intensifies the interaction with occupants and carries out the intention causing control [38]:

1. Mobile phones with GPS and personal schedules, for detecting the occupants' position and intentions, could foresee the occupants' intention of entering the enclosed space. At this moment, the compressor, which is off in the general situation, could turn on in the full power. Before entering, the circulating fan turns on at the highest speed, and the air deflector swings for 10 min to enhance the air circulation. Therefore, smart control may enable the enclosed space could be cooled down rapidly after the occupant enters.
2. The bracelet with the accelerator could detect the movement of occupants while the sleeping. After the occupant falls into a deep sleep, the air conditioner would lift the indoor temperature flexibly to avoid energy consumption. The smart air conditioner could adjust the compressor output actively according to the occupants' active intention (going home) and passive one (falling into a deep sleep) for the goals of human comfort and energy conservation.

One such system, Comfy, integrates with an office’s heating, ventilation and air conditioning (HVAC) system. It allows employees to make requests from their smartphone or Web browser to have the office space warmed or cooled. The system also makes employee requests visible to everyone else in their heating and cooling “zone”—which subtly encourages compromise and communication between employees who might not see eye-to-eye. With this type of technology, employees get the instant gratification of having their voice heard. Over time, the software analyzes usage habits for each occupant and “learns” workday patterns (for example, when employees arrive and leave for the day). The system then begins to automatically tailor heating and cooling flows accordingly, while optimizing them to be as efficient as possible—resulting in less dramatic fluctuations in office temperature, which can help companies save money. One interesting note that might explain many office squabbles: Women like it hot; men like it Hoth. The median preferred temperature for men is 70F, compared to 72F for women. Among 18- to 25-year-olds and 26- to 35-year-olds, only 32 and 34 percent, respectively, express frequent dissatisfaction (several times a week or more) with their office’s temperature. Compare that to dissatisfaction rates among the 46- to 55-year-old bracket, where 69 percent are frequently dissatisfied.

SOLUTION: Provide different temperature “zones” throughout the office—perhaps in the form of a digital “heat” map—and allow employees to work where they are most comfortable [39].

This system enables users to determine the minimum and maximum conditions for ensuring the best estimated indoor air quality (IAQ) while a building under examination is in the design stage. With the simulator, a user can have detailed information by clicking links for the rooms of the graphical output. Some important information about a classroom is presented at the graphical interface, such as open/closed windows, door status, instant temperature, humidity, current student number, predicted CO2 and O2 ppm values, minimum outdoor air ventilation requirement, and calendar information. To improve the prediction capability, besides their quantity the characteristics of the occupants are also added to the model, such as their physical activity, body weight and height, and time spent in a classroom. For example, CO2 estimations calculated by the model and the number of students in the classroom/corridor that comes from the real course schedule of the department can be seen as a function of time. The statuses of the door/windows (open/closed) are also considered in the model [40].

Sensor and actuator technologies based on ubiquitous computing and wireless sensor networks (WSN) have been employed in attempts to implement responsive environments. The office at Xerox PARC is one of the examples of such responsive environments, where electric outlets, HVAC systems, and lightings were automatically controlled in response to the occupants' preferences [41]. Pan et al. developed an intelligent light control system based on WSN in indoor environments [42]. They showed the proposed system can determine the proper illuminations of devices to achieve the desired optimization goals depending on the illumination requirement according to the user activities and profiles. Much effort has been also devoted to developing smart heating systems using smart thermostat and occupant behaviors. Gao and Whitehouse [43] claimed large potential energy savings would be possible without sacrificing the occupant's comfort only if setback schedules are defined correctly. They introduced a self-programming thermostat that automatically create an optimal setback schedule by sensing the occupancy statistics of a home, but also allow the occupants to select. The experimental results show that the method can reduce heating and cooling demand by up to 15% over the default setback schedule recommended by EnergyStar [44].

However, researchers at Concordia University may have found a solution to this problem: A system that automates the control of indoor environmental conditions and optimizes both individual workers' productivity and energy consumption. The system optimizes indoor environmental conditions including air quality, temperature and lighting based on the preferences of each office worker. The researchers created a mathematical model of the preferences of each office worker to simulate worker preferred indoor temperatures, ventilation rates, natural light and artificial lighting based on sensors places throughout the office [45].

The optimization uses the personal satisfaction curves for all occupants to determine the temperature settings in each office. This optimized “Have-It-Your-Way” (HIYW) system improves occupant’s comfort while reducing energy consumption. Since occupants remain thermally comfortable within a certain temperature tolerance that varies from one individual to another, the results of this approach, which takes advantage of the varying thermal comfort tolerances of the occupants, are quite encouraging. The “Have-It-Your-Way” (HIYW) approach would use all the sensor network connectivity in the building [46].

# **5. Analysis of patents and systems**

Many scientists have also done researches in the field of individual thermal comfort and indoor air quality [47-57]. An overview of patent and systems analysis is provided in Fig. 2. Some of them are briefly described below.

Kim et al. [47] employ machine learning to predict individuals' thermal preference. Kim et al. [47] claim that personal comfort models based on occupants' heating and cooling behavior can effectively predict individuals' thermal preference and can therefore be used in everyday comfort management to improve occupant satisfaction and energy use in buildings.

Liu et al. [49] developed a neural network evaluation model for individual thermal comfort based on the back propagation algorithm. Compared with the experimental data from the human thermal comfort survey, the evaluation results showed a good match with the subject's real thermal sensation, which indicated this model can be used to evaluate individual's thermal comfort, rightly [49].

Wang et al. [50] evaluated a novel approach to personal comfort systems that leverages the time-dependence of human thermal perception. A 6.25 cm2 wearable device, Embr Wave, delivers dynamic waveforms of cooling or warming to the inner wrist. The results indicate that this low-power, wearable device improves whole-body thermal sensation, comfort, and pleasantness [50].

Jung and Jazizadeh [53] have investigated the impact of personal thermal comfort sensitivities – distinct individual reactions to temperature variations– on collective conditioning. They proposed an agent-based control mechanism to simulate the multi-occupancy space, controlled by an HVAC agent to provide air conditioning for multiple human agents using three operational strategies to compare conventional strategies with proposed approach. Researchers’ investigations demonstrated that thermal comfort sensitivity plays a statistically significant role in collective conditioning as it resulted in changes of temperature setpoint in 86% of cases and a higher probability of achieving collective comfort [53].

ComfortSense aimed at [decoupling](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/decoupling) energy demand from indoor comfort [55]. Cottafava et al. [55] approach - which was multidisciplinary and included the contribution of [sociologists](https://www.sciencedirect.com/topics/engineering/sociologist), physicists and computer scientists - was based on [Internet of Things](https://www.sciencedirect.com/topics/engineering/internet-of-things) technologies, on a Living Lab design and testing process and on a Crowdsensing approach. With ComfortSense, users send a feedback about thermal comfort. If the negative feedback is received and, due to other negative feedback previously received, plans to reduce the temperature by 1°*C*, increasing the comfort and reducing the energy consumption. Cottafava et al. [55] also developed three Direct Virtual Sensors (DVS) to predict: (1) the global, (2) the thermo-hygrometric and (3) the air quality comfort. Each DVS was designed to predict future users’ feedback from a few environmental objective measurements as described by the following equation, $y\left(t+1\right)=f\left(\overbar{u\left(t\right)}\right)$, where$ y\left(t+1\right)$ is the output (i.e. the comfort feedback) at time t+1, f is a non-linear function and $\overbar{u\left(t\right)}$ is the array of the average values of the environmental variables (input) at time t. More precisely, each DVS needs the following variables as input: (1) temperature, relative humidity and CO2 (global comfort), (2) temperature and relative humidity (thermo-hygrometric comfort), and (3) temperature, humidity and CO2 (air quality comfort). Thus, for instance, the general comfort DVS equation is described by $y\left(t+1\right)=f\left(u\_{1}\left(t\right),u\_{2}\left(t\right), u\_{3}\left(t\right)\right)$ where ui represents the average value of temperature (u1), relative humidity (u2) and CO2 concentration (u3) at time t [55].



Figure 2. An overview of patent and systems analysis

Lu et al. [57] develop a thermal comfort model with RP 884 of three major climate zones based on k-nearest neighbor (KNN), random forest (RF) and [support vector machine](https://www.sciencedirect.com/topics/engineering/support-vector-machine) (SVM). During the experiment, the researchers also changed the temperature at 1°C by analyzing a thermal comfort model. The results have shown that the best recall of the statistical thermal comfort model is 49.3%, which outperforms that of PMV being 43% based on 7-point thermal sensation scale. In addition, the Q-learning based temperature control can indeed reach the comfortable temperature ranges for occupants with whatever initial temperature set-point [57].

Patent analysis of methods [58, 60, 62-67] and systems [58-60, 62, 63, 65-70] has also been performed. The patented methods are briefly described below.

Huang [58] environment controlling method provide a central processing equipment, obtaine physiological and environmental information by means of said personal physiological measurement equipment and said environment measurement equipment, decide an optimum environmental condition on the basis of said physiological, environmental and health information, transmitte regulation information, and regulate environmental conditions by environment controlling equipment [58].

Nikovski [60] patented a method for personalizing a heating ventilation and air conditioning (HVAC) system for an occupant in an environment, comprising steps: (1) obtaining biometric data of the occupant and measuring continuously environmental data in the environment as current conditions; (2) adapting continuously an estimate of a comfort index of the occupant based on the current conditions; and (3) controlling the HVAC system based on the estimate of the comfort index to personalize the HVAC system, wherein the steps are performed in a processor [60].

Lee et al. [63] patented a method for controlling temperature and humidity by a temperature and humidity control device includes acquiring at least one piece of environmental information and user biometric information, determining, based on the acquired at least one piece of the environmental information and the user biometric information, control information that determines statistical information to be within a certain range, and controlling an HVAC system based on the determined control information [63].

CN107120782A [64] invention provides a heating and ventilating system control method based on multiple-user thermal comfort data. The method comprises the steps that user thermal comfort data are obtained according to current season information fed back by users, the current user movement states and thermal comfort preference; corresponding user thermal comfort preference curves are obtained according to the user thermal comfort data; the thermal comfort probability distribution curves of cold, hot and comfort are obtained according to the user thermal comfort preference curves; a multiple-user thermal comfort probability distribution curve at different indoor environment temperature is obtained according to the thermal comfort probability distribution curves of all users; and the comfort temperature interval of the multiple-user thermal comfort probability distribution curve is used as a selection interval of temperature set values, and the optimal temperature set value of a controlled thermal space is obtained according to the corresponding relation of the air supply volume and the temperature set value. Scientists provided a curve for thermal comfort probability distribution for the user (equation 1) [64]:

$Prob\_{agg}\left(T\_{in}\right)=\frac{\sum\_{j=1}^{n}Prob\_{j}\left(S\_{th}=C,β\right)}{max\sum\_{j=1}^{n}Prob\left(S\_{th}=C,β\right)}$ (1)

where, [eta] represents a number of users of the hot space, C represents each person in the room cool, partial thermal comfort three kinds of comfort model "comfort" category corresponding to the model, indicating that the beta] parameter model of comfort, Sth representation, Tin represents the indoor temperature, Probagg output name, j denotes the number of person in the room [64].

CN108413588A [65] method based on thermal imaging and BP neural network, is characterized including following Steps: (1) by the regular typing of user and more new individual essential information, and carry out the Real-time Feedback of hot comfort, institute's typing information is used In the corresponding evaluation index such as calculating BMI and infrared thermal imaging data is instructed to acquire; (2) infrared thermal imaging module carry out thermal imaging data acquisition; (3) carries out the conversion of Infrared Thermogram and temperature field data; (4)is directed to the temperature data points of different user by the extraction of temperature field data according to user's typing information; (5) carries out BP neural network training using user as unit to input layer data; (6) obtains the control strategy of air-conditioning system by data analysis; (7) air-conditioning system automatic controller receive the control signal for coming from message processing module, and to air-conditioning system end End equipment carries out automatically controlling [65].

Laftchiev and Natarajan [66] developed method for controlling an operation of a set of devices for an occupant which use input devices to accept inputs from a plurality of humans, sensors to take sensor measurements, the sensor measurements including measurements of temperature, processor and actuator to cause, in accordance with the control signals, mechanical motion of one or more objects to alter air flow.

Huang [58] environment controlling system integrates and analyzes an individual's physiological and health information as well as environment information on a real-time basis to control environmental conditions and determine a living space beneficial to personal health. A healthy living space suitable for home care and disease management can be established by controlling environmental factors such as temperature, humidity, light, sound, etc. [58].

Karimi et al. [59] developed human-building interaction framework for personalized comfort driven system operations in buildings. This system may provide control information for controlling how an environmental control system controls an environment within a building. The computer data processing system may receive and store reports from multiple users and/or may receive and store reports at different times from a user. Each report may provide information concerning how the user perceives the comfort level of the user's environment at the time the user supplies the information. The computer data processing system may determine and generate the control information for controlling how the environmental control system controls the environment based on the information concerning how each user perceives the comfort level of the user's environment at the time each user provides the information. In addition or instead, the computer data processing system may determine and generate such control information based on the information concerning how a user perceives the comfort level of the user's environment at the different times the user supplies the information [59].

The system proposed by Nikovski [60] consists of a wearable device (configured to obtain biometric data and a comfort level of the occupant and measuring continuously environmental data in the environment as current conditions), a processor (configured to adapt continuously an estimate of a comfort index of the occupant based on the current conditions), and a HVAC system that is controlled according to the estimate of the comfort index [60].

Feldmeier [62] developed control apparatus for a HVAC system which provides personalized comfort control. It can adjust local conditions in different rooms within a building in order to maximize the perceived comfort of individual occupants. The control apparatus locates individuals within a building. For each individual, it senses temperature, humidity and other parameters at the individual's location, calculates a comfort metric indicative of the user's comfort, and can control the flow of chilled or heated air to the individual's location in order to adjust local conditions to maximize the individual's comfort [62].

Lee et al. [63] patented device for controlling room temperature and humidity. It is possible to provide a comfortable environment to a user and save energy while maintaining comfort. The present disclosure relates to a sensor network, Machine Type Communication (MTC), Machine-to-Machine (M2M) communication, and technology for Internet of Things (IoT). The present disclosure may be applied to intelligent services based on the above technologies, such as smart home, smart building, smart city, smart car, connected car, health care, digital education, smart retail, security and safety services [63].

CN108413588A [65] patented personalized air-conditioner control system based on thermal imaging and BP neural network. System includes human-computer interaction module, thermal imaging module, message processing module and passes through BP nerves network technique, which is calculated, optimizes air-condition system control parameter, airconditioning control module for receiving transmission signal and realizing to air-conditioning [65].

Levy and Betz [67] invention involves the personal air conditioning of individual workstations in an open office space layout. The individual workstation's air is supplied by a major air plenum located under a horizontal surface of the workstation. The conditioned air is directed by a smaller self-contained air terminal located under a floor representing a larger major air plenum or chamber. The conditioned air is supplied to the individual workstations at or near the atmospheric pressure. The multiple of smaller air terminals are the movers of the conditioned air by way of driving fans installed therein and activated as the need arises. The conditioned air is moved from the smaller air terminals by flexible air tubes to the air plenum mounted under the desk surface. A person situated at the workstation can control the direction of air emanating from the front of the personalized air outlet plenum toward the person in multiple directions. Further, the person can also control the volume of the personal air by being able to divert some of the air away from the person through a wall in the desk or through a wall of a room partition to an adjoining space. The person at the workstation has the option of dividing the main air stream either to a frontal outlet directed at the person or to an outlet away from the person to enter the general atmosphere of the work space [67].

Levy and Betz [68] object of the invention is to present a system for distributing conditioned air throughout an office layout in a most efficient way. In a building whether large or small, different people have different levels of metabolism and therefore different comfort needs. Personalized air conditioning/displacement ventilation system incorporated in a stand-alone unit, said system is installed on a floor having an air plenum below said floor but above a concrete slab, a supply of conditioned air is located in said plenum and is moving air into a flexible air duct, said stand-alone unit consists of an upstanding chamber being connected to said flexible air duct, said chamber having various controls therein to control a flow of air either to a front of said chamber or to a lateral side of said chamber into the ambient atmosphere surrounding said chamber [68].

CN103062871B [69] invention relates to an air conditioning control system based on the measured skin temperature, including infrared thermometer, the rotating bed, telescopically foldable stand, the orientation controller infrared thermometer, air-conditioning controller Temp, rubber hoses and gaskets, infrared thermometer orientation of the controller are connected with an infrared thermometer, base, air-conditioning controller Temp, infrared thermometer mounted on the base, the bracket fixed to the wall above the bed or table mounted on the desk, rubber a gasket mounted between the base and the bracket, respectively, air-conditioning controller Temp infrared thermometer, infrared thermometer orientation controller, room air conditioner or air conditioning personalized connected [69].

CN105258308A [70] invention discloses a personalized ventilation control system suitable for civil buildings and vehicles. The personalized ventilation control system comprises an air conditioner air supply opening arranged in a peripheral region of a seat. By means of the personalized ventilation control system, the energy utilization efficiency of personalized ventilation can be improved, the heat comfort of the human body is met, energy saving of the air conditioner system is achieved, and meanwhile the requirement for comfort of users is met, and the energy saving function is achieved [70].

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